

## 太陽型星でのスーパーフレア Superflares on Solar-Type Stars

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Stellar flares emit harmful UV and high-energy particles such as protons. Although the atmosphere protects the surface of the planets, certain amount of UV penetrates the atmosphere and high-energy particles reach the ground as secondary radiation. These radiations are thought to affect habitability and evolution of life.

High precision photometry of Kepler spacecraft enables us to detect superflares on G-type dwarfs. By extending Maehara et al. (2012, Nature), we found 1547 superflares on 279 G-type dwarfs detected from light curves of 500 days (Shibayama et al., 2013, ApJS). In the case of the Sun-like stars (with surface temperature 5600 - 6000 K and slowly rotating with a period longer than 10 days), the frequency of superflares with energy of  $10^{34}$  -  $10^{35}$  erg (100 - 1,000 times larger than the largest solar flare) is once in 800 - 5000 years. No hot Jupiters were found in these superflare stars. These superflare stars often show quasi-periodic brightness variation, which might be evidence of the large star spot. Rotational period can be estimated from the brightness variation period. It is interesting that superflares are detected on slowly rotating stars ( $P > 10$  days) like the Sun. Using these data, we studied the statistical properties of superflares. We compare the flare frequency distribution of the superflare and solar flare, and study the similarity of them. We also found that some G-type dwarfs show very high activity and exhibit superflares once in  $\sim 10$  days. In the case of Sun-like stars, the most active stars show one superflare in  $\sim 100$  days.

キーワード: 恒星フレア, 太陽フレア, ハビタビリティ, 進化

Keywords: Stellar flare, Solar flare, Habitability, Evolution

## グリシン前駆体、メチレンイミンの多天体探査 Survey Observations of A Glycine Precursor, Methylenimine (CH<sub>2</sub>NH)

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It is widely thought that prebiotic chemical evolution from small to large and complex molecules would have resulted in the Origin of Life. The interstellar medium (ISM), where more than 170 molecules ranging from simple linear molecules to COMs were detected, show chemically rich environment. Ehrenfreund et al. (2002) argued that exogenous delivery of COMs to the early Earth by comets and/or asteroids could be more than their terrestrial formation by two orders of magnitude; molecules delivered from the Universe might have played an important role in early Earth chemistry. From this point of view, many observations were conducted to search for prebiotic molecules in the ISM, which might turn into the “Seeds of Life” when delivered to planetary surface. Especially, great attention was paid to amino acids, essential building blocks of terrestrial life; many surveys were made unsuccessfully to search for the simplest amino acid, glycine (NH<sub>2</sub>CH<sub>2</sub>COOH), towards Sagittarius B2 and other high-mass star forming regions (e.g., Brown et al. 1979; Snyder et al. 1983; Combes et al. 1996, ...).

In these days, the Atacama Large Millimeter/submillimeter Array (ALMA) is expected to break through such difficulties associated with glycine survey. Garrod (2013) used her chemical reaction network simulation and argued the possibility in detecting glycine with very high spatial resolution (~0.1”) and the collecting power of ALMA. It would be important to know which are potential glycine-rich sources for future surveys. However, the chemical evolution of N-bearing molecules, including glycine, is poorly known. We would need to better understand formation mechanisms of N-bearing COMs including amino acids and to have carefully selected good candidate sources for amino acids before conducting searches for amino acids by ALMA.

Although the chemical evolution of interstellar N-bearing COMs is poorly known, methylamine (CH<sub>3</sub>NH<sub>2</sub>) has been proposed as a precursor to glycine. Theoretical and laboratory studies have demonstrated that glycine is formed on icy grain surface from CH<sub>3</sub>NH<sub>2</sub> and CO<sub>2</sub> under UV irradiation (Holtom et al. 2005). It is suggested that CH<sub>3</sub>NH<sub>2</sub> can be formed from abundant species, CH<sub>4</sub> and NH<sub>3</sub>, on icy dust surface (Kim & Kaiser 2011). Further methyleneimine (CH<sub>2</sub>NH) would be related to CH<sub>3</sub>NH<sub>2</sub>. Another possible route to form these species is hydrogenation to HCN on the dust surface (Dickens et al. 1997; Theule et al. 2011).

However, a source number of such precursor molecules is very limited. In order to increase the number of CH<sub>2</sub>NH sources and to better understand formation paths to CH<sub>2</sub>NH, we conducted survey observations of CH<sub>2</sub>NH, with the NRO 45 m telescope and the SMT telescope towards 11 high-mass and three low-mass star-forming regions. As a result, CH<sub>2</sub>NH was detected in eight sources, including four new sources. The estimated column densities were roughly 10<sup>14</sup>-10<sup>15</sup>, 10<sup>15</sup>-10<sup>16</sup>, and 10<sup>16</sup>-10<sup>17</sup> cm<sup>-2</sup>, respectively, for extended, 10”, and 2” sources. G10.47+0.03 and Orion KL are found to be especially CH<sub>2</sub>NH-rich sources. We used chemical reaction network simulations to investigate formation process of CH<sub>2</sub>NH in the ISM. Under the dark cloud condition, the simulated CH<sub>2</sub>NH abundance in the gas phase is more than 10 times lower than our observations even if we conservatively estimate the CH<sub>2</sub>NH abundance with an extended source. On the other hand, if we include hydrogenation reaction to HCN in our model, the CH<sub>2</sub>NH abundance increased about by two orders of magnitude, enabling us to reconcile the observed abundance of CH<sub>2</sub>NH. We also showed that this reaction is dominant in the early, low temperature phase of cloud evolution.

キーワード: 生命起源, 化学進化, 星間空間, グリシン

Keywords: Origin of Life, Chemical Evolution, Interstellar Medium, Glycine

星間での有機物生成・変成と地球への伝搬：地上実験と宇宙実験による検証  
Formation, alteration and delivery of interstellar organics: Verification with experiments  
on ground and in space

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星間での宇宙線による複雑有機物の生成, 太陽系での変成, 惑星間塵による地球への伝搬を含む生命起源のシナリオを構築した。その検証のための加速器実験, および宇宙実験(たんぽぽ計画)について説明する。

キーワード: 生命の起源, 星間有機物, 宇宙線, 惑星間塵, たんぽぽ計画, 粒子線照射

Keywords: origins of life, interstellar organic compounds, cosmic rays, interplanetary dust particles, Tanpopo Mission, particles irradiation

## Polymerization of methionine: Ignition of sulfur metabolism? Polymerization of methionine: Ignition of sulfur metabolism?

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Methionine, sulfur-bearing amino acid, is one of protein-forming 20 amino acids. On the other hand, peptide formation using methionine is known to be difficult, because of large thermal stability of methionine. Incorporation of methionine into peptide has importance to form metal-sulfur-cluster in protein or other biologically important molecules, such as taurine. In order to overcome difficulties to make methionine-bearing peptide, new series of experiments were performed in the present study. Experiments were performed at 175 C and 150 MPa, using various mixtures. Methionine-trimers, which were not formed by previous investigators, were produced in the present study. Surprisingly a part of methionine was converted into glycine and then glycine-methionine peptide was newly formed. Those results demonstrated that high T and P conditions were suitable for not only methionine-peptide formation but also making multi-component peptide. Sulfur isotope compositions were determined on run products of the present study. Run products were enriched or depleted in <sup>32</sup>S compared to starting materials. Hydrogen sulfides were preferentially released from methionine for the <sup>32</sup>S-depleted samples. The <sup>32</sup>S-enriched samples are explained by loss of sulfate from methionine, although oxidants of methionine-sulfur are still unclear. Modern living organisms metabolically produce sulfide and sulfate from methionine and cysteine. Such metabolic path is similar to the abiological production of sulfide and sulfate in the present study. This may imply that course of sulfur metabolism was most likely established early in the prebiotic age when methionine was incorporated in prebiotic protein.

キーワード: prebiotic, methionine, peptide, sulfur  
Keywords: prebiotic, methionine, peptide, sulfur

## 生命を生み出す地球外海洋を作る Formation of extraterrestrial oceans: Cradles of life

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科学研究費に提案中のプロジェクト「太陽系の海と生命たち」(代表:山岸明彦氏)の1グループとして、太陽系形成の新しい描像に沿った衛星起源・進化の理論研究、氷高圧物性実験、岩石水相互作用研究により、巨大惑星の氷衛星の起源と形成過程、地下海形成過程および普遍性の解明を目指している。

雪線(スノーライン)の外側で集積した木星型惑星周囲には氷に富む衛星系が存在する。軌道共鳴状態に入ると潮汐摩擦で、地下海が生成・維持される。太陽から遠ざかると表面温度は下がるが、NH<sub>3</sub>, CH<sub>4</sub>, COなど融点を下げる成分は増える。水岩石相互作用により生成される塩類は、生命材料となるとともに氷の融点を下げる。いわゆるハビタブルゾーン(液体の水が安定に存在する領域)は、氷天体地下圏を想定すると、大きく広がることになる。

多様なパラメーターに基づく地下海存在条件を明らかにするため、(1)氷衛星の材料・起源・進化の理論研究、(2)高圧下の氷物性と融解条件の解明、(3)岩石水相互作用と塩類の供給の解明、(4)氷衛星地下海の検出精度の向上の研究を行うことを計画している。とくに、JUICE ミッションのガニメデ観測を想定して、本研究から地下海検出のために必要な測地・重力精度を明らかにする。塩類を含む海の進化、塩類の分光測定、地下海のエネルギー環境、有機物については別班と協力して、生命を育む地下環境を明らかにする。

太陽系外惑星では、主星の近くまで移動した Hot Jupiter と呼ばれる天体が多く発見されている。衛星系が形成された後に、巨大惑星の軌道が内側に移動すると、氷衛星が水衛星となり、最後には散逸して岩石衛星になると考えられる。近年、太陽系の木星、土星は形成後に軌道が現在よりもかなり内側(1-2AU)まで移動したシナリオが考えられている。木星の衛星カリストのCO<sub>2</sub>の存在や未分化内部構造は、木星の軌道進化を制約づけるか、木星の衛星系の形成時期がかなり後であることを示唆することになる。

キーワード: 氷衛星, 生命存在条件, 地下海, ハビタブルゾーン, 木星型惑星, 惑星系の起源

Keywords: icy satellites, habitability, interior ocean, habitable zone, gas giant planets, origin of planetary systems

## 国際宇宙ステーション曝露部での微粒子捕集、微生物有機物曝露実験：たんぽぽ Tanpopo: Astrobiology Exposure and Micrometeoroid Capture Experiments - Experiments at the Exposure Facility of ISS-JEM

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Tanpopo, a dandelion in Japanese, 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 at the Exposure Facility of Japan Experimental Module (JEM: KIBO) of the International Space Station (ISS). The Tanpopo mission consists of six subthemes: Capture of microbes in space (Subtheme 1), exposure of microbes in space (Subtheme 2), analysis of organic compounds in interplanetary dust (Subtheme 3), exposure of organic compounds in space (Subtheme 4), measurement of space debris at the ISS orbit (Subtheme 5), and evaluation of ultra low-density aerogel developed for the Tanpopo mission (Subtheme 6). 'Exposure Panel' for exposure of microbes and organic materials and 'Capture Panels' for capturing micro particles with aerogel will be launched. The panels will be placed on the Exposed Experiment Handrail Attachment Mechanism (ExHAM) in the ISS. The ExHAM with the panels will be placed on the Exposure Facility of KIBO (JEM) with the Japanese robotic arms through the airlock of KIBO. The panels will be exposed for more than one year and will be retrieved and returned to the ground for the analyses.

キーワード: パンスペルミア仮説, 微生物, 有機物, エアロゲル, 宇宙曝露実験

Keywords: Panspermia hypothesis, Microbes, Organic compounds, Aerogel, Space exposure experiments

## Rock Magnetic Constraints on the origin of putative biological magnetite in the Martian ALH84001 Carbonates

### Rock Magnetic Constraints on the origin of putative biological magnetite in the Martian ALH84001 Carbonates

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McKay et al. (1996) discussed 4 lines of evidence that were consistent with the possible presence of ancient life on Mars. Although none of these have been falsified, the one that has triggered the most intense debate concerns the claim that some of the fine-grained magnetite crystals embedded in small carbonate deposits might have been formed by the magnetotactic bacteria. These magnetite particles, when examined by high-resolution transmission electron microscopy, are indistinguishable from particles only produced by magnetotactic bacteria on Earth (Thomas-Keprta et al., 2001). Unfortunately, the magnetic and microscopic analyses done to date do not allow us to provide a direct statistical test of the probability that these particles are of biological origin, vs. the hypothesis they form from high-temperature decomposition of siderite (FeCO<sub>3</sub>).

In the past decade, developments in superconducting magnetometry and electron microscopy now provide new experimental approaches that can be applied to this problem. First, the new Ultra-High Resolution Scanning Magnetic Microscopes (UHRSMs) can detect magnetic moments 3 to 4 orders of magnitude below the sensitivity of the best superconducting rock magnetometers, and robust dipole-fitting routines allow the 3-D vector magnetic moment of tiny particles to be resolved quantitatively. We have shown recently that individual fragments of the famous ALH84001 carbonate blebs can be imaged clearly using this technique, opening the possibility of experimental tests that should distinguish low-temperature (biological) from high-temperature (thermal decomposition) magnetite. Magnetite produced by thermal decomposition of carbonate during shock heating should carry a relatively strong Thermo-Remanent Magnetization (TRM), whereas biological magnetite trapped during carbonate growth should have a much weaker detrital magnetization (DRM). Fuller et al. (1988) reported a simple technique that compares the relative intensities of the Natural Remanent Magnetizations (NRMs) to Isothermal and Anhyseretic magnetizations (IRMs and ARMs) that can easily distinguish TRMs from DRMs; this new sensitivity now be applied to these particles. Second, because the magnetotactic bacteria use genetic control to manufacture their magnetite crystals, particles within the same cell are of very similar size and shape. When these cells die and leave their magnetite crystals in the sedimentary record as magnetofossils, they produce clumps of similarly-sized crystals because they stick together magnetically with very strong force (Kobayashi et al., 2006). Sediment transport and removal processes cannot disaggregate them, but they do get scrambled together during extraction and high-resolution TEM studies. We therefore need to do very high-resolution studies that can demonstrate the position of these crystals within the carbonate matrix of the ALH 84001 carbonate precipitates. We propose to use the new focused ion-beam (FIB) milling techniques available at the Earth-Life Science Institute of TiTech to make 3-dimensional reconstructions, at a 5 to 10 nanometer scale, of rectangular chunks of the ALH84001 carbonate. At this resolution, the putative magnetosomes will be represented by up to 500 voxel elements, each with definitive elemental composition. We should be able to determine whether clusters of particles within these carbonates are of similar size and shape, as expected from collapsed magnetosome chains. It will then be very simple to do statistical tests to determine whether these clumps are non-random assemblages sampled from the background crystal size distribution. The debate about life on Mars may rise again!

Fuller et al.,1988, *Geophys. Res. Lett.*, v. 15, p. 518-521.

Kobayashi, et al.,2006,: *Earth and Planetary Science Letters*, v. 245, no. 3-4, p. 538-550.

McKay et al.,1996, *Science*, v. 273, no. 5277, p. 924-930.

Thomas-Keprta, et al.,2001, *Proc. Natl. Acad. Sci. USA*, v. 98, no. 5, p. 2164-2169.

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Keywords: Martian Magnetofossils, Rock Magnetism, Panspermia, Carbonate

**Cu-Zn ores in 2.7 Ga komatiite-basalt assemblages in Abitibi Greenstone Belt, Canada, and their associations to microbes**  
**Cu-Zn ores in 2.7 Ga komatiite-basalt assemblages in Abitibi Greenstone Belt, Canada, and their associations to microbes**

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Archean greenstone belts are hosting many massive sulfide ores. In particular, komatiite-basalt sequences are hosting Ni-Cu ores, which are mostly considered as a magmatic in origin. Some Ni-Cu ores are associated with serpentinization near seafloor. Such serpentinization may have been important for early life as hydrogen donors with alkaline fluids. Cu-Zn-Pb ores are also reported from the same komatiite-basalt sequences, although the origin of these ores are still uncertain. One representative 2.7 Ga komatiite-basalt sequence appears in the Munro area of the Abitibi Greenstone Belt. In order to understand the origin of Cu-Zn-Pb ores, mineralogical and geochemical studies are performed on ores at Munro area. Sulfide ores are essentially developed in black shale zones, and some ores are disseminated in altered volcanic rocks. Chalcopyrite, sphalerite, pyrrhotite are major minerals associated with minor galena, electrum, pentlandite, etc. Sulfur isotope compositions of those sulfides are ranging are not magmatic values. Some ores are rich in Se and As. Host volcanic rocks are extensively hydrated (followed by metamorphism) forming tremolite, chlorite and talc. Those features are similar to the modern submarine hydrothermal deposits, rather than magmatic ore deposits. Therefore, Cu-Zn-Pb ores in komatiite-basalt sequences were formed by black smoker type submarine hydrothermal activities. Carbon isotope analyses of organic matter in ore-associated sediments suggest that methanogens were active when komatiite became serpentinite, followed by submarine hydrothermal activities.

キーワード: Komatiite, ore, submarine, Abitibi, microbe

Keywords: Komatiite, ore, submarine, Abitibi, microbe



## 地球および地球外深海熱水環境における生命生態系 Microbial community development in deep-sea hydrothermal vents in the Earth, and the Enceladus

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Over the past 35 years, researchers have explored seafloor deep-sea hydrothermal vent environments around the globe and studied a number of microbial ecosystems. Bioinformatics and interdisciplinary geochemistry-microbiology approaches have provided new ideas on the diversity and community composition of microbial life living in deep-sea vents. In particular, recent investigations have revealed that the community structure and productivity of chemolithotrophic microbial communities in the deep-sea hydrothermal environments are controlled primarily by variations in the geochemical composition of hydrothermal fluids. This was originally predicted by a thermodynamic calculation of energy yield potential of various chemolithotrophic metabolisms in a simulated hydrothermal mixing zone. The prediction has been finally justified by the relatively quantitative geomicrobiological characterizations in various deep-sea hydrothermal vent environments all over the world. Thus, there should be a possible principle that the thermodynamic estimation of chemolithotrophic energy yield potentials could predict the realistic chemolithotrophic living community in any of the deep-sea hydrothermal vent environments in this planet. In 2005, a spacecraft Cassini discovered a water vapour jet plume from the sole pole area of the Saturnian moon Enceladus. The chemical composition analyses of Cassini's mass spectrometer strongly suggested that the Enceladus could host certain extent of extraterrestrial ocean beneath the surface ice sheet and possible ocean-rock hydrothermal systems. An experimental study simulating the reaction between chondritic material and alkaline seawater reveals that the formation of silica nanoparticles requires hydrothermal reaction at high temperatures. Based on these findings, we attempt to built a model of possible hydrothermal fluid-rock reactions and bioavailable energy composition in the mixing zones between the hydrothermal fluid and the seawater in the Enceladus subsurface ocean. The physical and chemical condition of the extraterrestrial ocean environments points that the abundant bioavailable energy is obtained maximally from redox reactions based on CO<sub>2</sub> and H<sub>2</sub> but not from with other electron accepters such as sulfate and nitrate. In the low-temperature zones, the available energy of the Enceladus methanogenesis and acetogenesis is higher than those in any Earth's environment where the methanogens sustain the whole microbial ecosystem. Our model strongly suggests that the abundant living ecosystem sustained by hydrogenotrophic methanogenesis and acetogenesis using planetary inorganic energy sources should be present in the Enceladus hydrothermal vent systems and the ocean.

## 光合成における光吸収とエネルギー伝達：バイオマーカーの拡張に向けて Light absorption and energy transfer in photosynthesis: Toward extending our current biosignatures

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In the recent success in detecting for extrasolar planets, several habitable planets, which can sustain liquid water, have already been discovered. From reflection spectra on exoplanets, what and how to detect signs of life, biosignatures, have been controversial (Kiang et al. 2007). One of proposed biosignatures is vegetation red edge (VRE), which is observed from reflectance spectra on the Earth. VRE is identified as a sharp contrast in about 700 - 750 nm due to the absorption in visible region by photosynthetic pigments like chlorophylls and the reflection in NIR region. However, VRE is an effective as biosignature only if exovegetation shows the same spectral feature to that on the Earth (Seager et al. 2005). Therefore, the criterion as biosignature needs to be extended when the primary stars are totally different. Because in future missions searching for a second earth, the M type stars (cooler than Sun) will be the main targets, as the first step, we focused on the fundamental properties of purple bacteria which absorbs longer wavelength radiation (1025 nm).

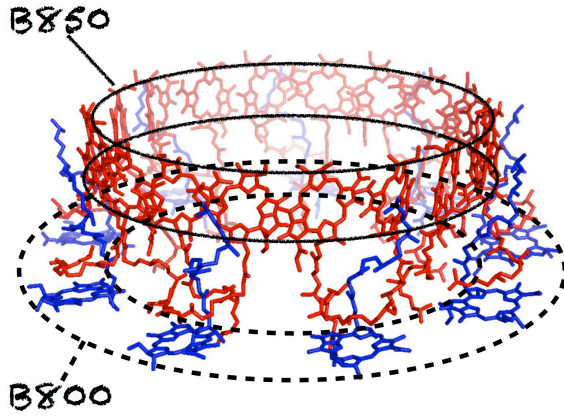
We investigated light absorptions and excitation energy transfers (EETs) based on quantum dynamics simulations for light harvesting complexes (LHCs), which contain array of photosynthetic pigments. After light reaches in LHCs, effective EET is accomplished by corporative electronic excitation of the pigments. We used theoretical models for LHCs in purple bacteria (LH2s). LH2 is made of 2 rings: inner ring (B850) and the outer (B800), as shown in Figure. In our model, a dipole-dipole approximation was used for the electronic excitations. The low-lying electronic excited states of a LH2 were computed by using transition dipole moment of first excited state of each pigment calculated at time-dependent density functional theory. Corresponding to the light absorption process, the oscillator strength in the system could be computed. The oscillator strength of one LH2 was in a good agreement with the experimental value. Subsequently, quantum dynamics simulations were performed by Liouville equation to examine the EET process. In this model, the densities relaxed according to energy gradient. This treatment corresponded with the EET process. The relaxation parameters were determined based on the energy transfer time from B800 to B850 (0.8 ps). The calculated transfer time between two LH2s was determined to 2.72 - 3.67 ps in good agreement with the experiment values (2.0 - 10.0 ps). In order to deal with more realistic system, we calculated at a macro structural model. The calculated systems were composed of 7 LH2s and 19 LH2s, where LH2s were aligned in triangle lattice. As the system size increases, the oscillator strength shifted longer and the transfer velocity became faster. In photosynthesis, collected energies are efficiently transferred to lower energy sites where redox reactions take place, very efficiently by EET. When two pigments in central LH2 in the system were exchanged to pigments absorbed longer wavelength radiation (850 nm to 890 nm), the transfer velocities became faster. Moreover, in order to examine for what environments the absorption spectra of purple bacteria were optimized, the absorption efficiency was calculated from blackbody spectra expected in typical extrasolar planets. As a result, the absorption efficiency was maximum at the emission spectrum of a black body at around 200 K. Furthermore, the Light absorptions and EETs in purple bacteria, cyanobacteria and plants will be examined by using our methodology.

Keywords: biosignatures, extrasolar planets, photosynthesis, quantum chemical calculation, light harvesting, purple bacteria

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## 火星初期のハビタブル・トリニティ環境と今後の生命探査計画の候補地 Ancient Habitable-Trinity Mars and Future Targeting of potential Signs of Life

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Mars, the most Earth-like planet in our solar system, once had Habitable-Trinity conditions: an interfacing ocean, atmosphere, and nutrient-enriched primordial crustal materials with energy circulation driven by the Sun. Mars is thus considered the best target to search for life beyond Earth, as there are no other planetary bodies in our solar system that record Habitable-Trinity conditions. Following the termination of Habitable Trinity conditions nearly 4.0 Ga, when a strong dynamo shut down prior to the post-heavy-bombardment Hellas and Argyre impact events, the atmosphere was thinning, and plate tectonism was ongoing though waning, life would have found it increasingly difficult to survive at or near the surface, and thus would have migrated to the subterranean to persist. Vent structures, such as those located in the western part of Elysium Planitia where oceans once occupied the Martian surface and long-term magma-water interactions (billions of years) may be still ongoing, as evidenced through pristine lavas, faults that cut youthful surfaces, and geologically-recent flood events, are thus considered to be optimal targets to search for signs of life on Mars. The vent structures were formed by the transfer of subterranean materials to the surface likely due to magma-water interactions. The geologically youthful vent structures could be readily investigated in situ through current mission design.

キーワード: ハビタブル・トリニティ, 生命の存在可能性

Keywords: Habitable Trinity, potential signs of life

## Origin of life component of the Earth Origin of life component of the Earth

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The Earth is highly depleted in volatile in general. Water is one of them and only 0.023wt% among mass of the solid Earth. If the parental chondrite is carbonaceous with 2.3wt% water, the Earth must have been covered by 380km thick ocean, where too much amount of water was present, hence no life was born because of no supply of nutrients (Maruyama et al., 2013). Origin of water is critical to control the birth of life on rocky planet. Snowline is a concept of the boundary whether solid ice or vapor (gas) is stable at 2.7AU. If the Earth was formed at 1.0AU, the Earth must have been dry, no atmosphere and no ocean.

By this reason, there are several ideas to make the Earth with thinly covering ocean. One of such ideas is that Earth was born as a dry planet with Moon at 4.5-4.6Ga, followed by late bombardments to transport water components to the Earth at 4.4Ga (Maruyama et al., 2013).

Here we propose that late bombardment delivered not only water component but also carbon and nitrogen together at 4.4Ga. The organic lines are present within a narrow region around 2.1AU which is much closer to the Earth than the snowline. Asteroids derived from chondritic materials were transported to the Earth at 4.4Ga, and their organic matters turned to be primordial atmosphere from which primordial ocean was born. C and N with respect to O and H are enriched to make reduced atmospheric composition which could be favorable to synthesize complex organic compounds at the interface between atmosphere and ocean.

## 宇宙ダスト上のアミノ酸生成過程についての理論的研究 Theoretical investigation of amino acid formations on interstellar dusts

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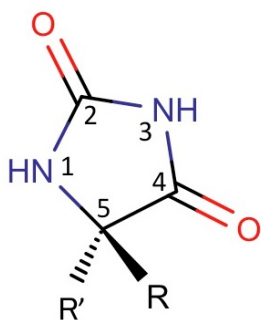
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Molecular evolution in the interstellar space remains unsolved. Formations of molecules in space have been extensively studied by experiments and space observations. Formations of complex organic molecules are expected in the interstellar space. In fact, some amino acids were found in meteorites and amino acids were detected after UV irradiation of interstellar ice analogs.

In the amino acid formation in space, many precursors and molecular evolution pathways are expected. Among these possible pathways, it is very important to know the energy profiles and molecular structures in the major formation pathways. In this study, possible amino acid formation pathways are investigated by using accurate quantum chemistry methods at the density functional theory levels.

Two formation pathways of glycine and alanine were examined: (1) hydrolysis of aminoacetonitrile and (2) hydrolysis of hydantoin derivatives. In the aqueous solution model, Polarizable Continuum Model was used.

Calculated formation energy of glycine is the most stable in the formation pathway in vacuum and no excessively stable intermediates existed. In aqueous solution, hydantoin pathway was slightly unstabilized. In conclusion, glycine production is considered to be occurred easily if the components exist. Similar trend is expected for the alanine production.



## ISS/JEM 曝露部利用実験たんぽぽ：宇宙塵捕集計画と地上実験 Cosmic dusts capture on the International Space Station: Progress of the ground-based experiment

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**Introduction:** Organic matter in interplanetary dust particles (IDPs) records the primitive chemical history in the early Solar System as well as it is thought to have delivered the building blocks of life to the early Earth (Chyba and Sagan, 1992). The Japanese Astrobiology working group, Tanpopo, is planning to collect the IDPs using a low-density silica aerogel (0.01 g/cm<sup>3</sup>) (Tabata et al. 2011) on the International Space Station (Yamagishi et al. 2009). The mission has a great advantage that collection of the pristine IDPs without atmospheric entry heating and terrestrial contamination will be expected. One thing that has to be considered is a possible modification of the chemical composition of organic matter in IDPs upon their high velocity impact to the aerogel. This issue has been also concerned in the Stardust cometary dust sample return mission. Although the laboratory simulations have been conducted to study the alteration of minerals (Okudaira et al. 2004; Noguchi et al. 2007), the alteration of organics under a realistic condition has not been well understood. As a ground-based experiment, we have conducted a laboratory experiment of aerogel capture of Murchison meteorite powder at 4 km/s using a two-stage light gas gun, in order to evaluate the extent of modification of organic matter in the meteorite.

**Experimental:** The Murchison meteorite powder (~500 ug) of a particle diameter of 30-100 um in a polycarbonate sabot was shot at ~4 km/s using a two-stage light gas gun at JAXA/ISAS. The penetrations of the meteorite powder formed ~70 tracks of ~10 mm length in aerogel. Six terminal particles were extracted from the aerogel tracks using a tungsten needle and were pressed between two Al foils. The particles on the Al foils were analyzed by micro-Fourier transmission infrared (FTIR) spectroscopy at the beamline 43IR, Spring-8 and Osaka Univ., and micro-Raman spectroscopy at Osaka Univ. For a comparison, pre-shot Murchison meteorite powder was analyzed by these micro-spectrometers.

**Results and discussion:** The IR imaging detected the regions of absorptions of aliphatic carbons, CH<sub>3</sub> at 2960cm<sup>-1</sup> and CH<sub>2</sub> at 2920cm<sup>-1</sup> within the two Murchison terminal particles captured by aerogel. Thus, organic matter is survived through the high velocity impact at 4 km/s. The spectral intensities of aliphatic carbons in the terminal particles are slightly lower than those in the pre-shot Murchison meteorite. CH<sub>2</sub>/CH<sub>3</sub> ratios obtained from the IR spectra of the terminal particles were 0.3 ? 3, while those of the pre-shot sample were 1.3 ? 2. The difference in the ratios may be reflected by modification of aliphatic chains of organic macromolecules in the meteorite, e.g., demethylation, methylation, or cracking, due to the high velocity impact heating. From the two terminal particles, D- and G- bands, which are derived from carbonaceous matter, were detected by micro-Raman analyses. Peak widths and positions of the two bands showed similar values to those for pre-shot Murchison meteorite. Thus, modification of aromatic structures after the aerogel capture is unlikely. Although relative amounts of organics were low in the four other terminal particles, this may be reflected by original heterogeneity of the meteorite.

キーワード: ISS/JEM 曝露部, 宇宙塵, 有機物, アストロバイオロジー, 生命の起源, エアロゲル

Keywords: International Space Station, Cosmic dusts, Organic matter, Astrobiology, Origin of life, Aerogel

## 軽ガス銃を用いた小惑星衝突模擬実験によるアミノ酸合成の可能性 Possibility of production of amino acids by impact reaction using a light-gas gun as a simulation of asteroid impacts

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We are interested in the production process of amino acids in space. Especially, asteroids coming to Titan satellite have made impact reaction on the surface including nitrogen gas, water ice and methane. On the Titan surface, various material, produced by the impact reactions, have been stored under low temperature and dark condition. To do the simulation experiment, a JAXA 2-stage light-gas gun has been used. A projectile with 6.5km/s of speed hits a water + iron target in 1 atm of nitrogen gas, causing an impact reaction. Figure 1 shows a crater on the target. Figure 2 shows produced black soot which deposited onto the aluminum sheet. The samples produced are carefully collected and analyzed by HPLC, FTIR, TOF-MS. As a result of HPLC, peaks suggesting the existence of glycine and alanine in the samples produced were confirmed.

Keywords: impact reaction, gas gun, Titan, asteroid, amino acid, HPLC



Fig.1 A crater on the target.



Fig.2 Produced black soot deposited onto the aluminum sheet.



## 火花放電および陽子線照射による弱還元型模擬原始大気からのアミノ酸生成 Amino acid formation from simulated mildly-reducing primitive atmospheres by spark discharges and proton irradiation

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原始地球上での有機物の生成を考える上で、原始大気の組成、特にその酸化還元状態が重要である。Miller は、メタン、アンモニアを多く含む模擬原始大気中で火花放電を行い、アミノ酸の生成を確認した。しかし、今日では原始地球大気は、中性ないし弱還元型と考えられている。どの程度まで還元的であったならば、原始地球大気中でのアミノ酸生成が可能かを調べるため、種々の混合比の二酸化炭素、メタン、窒素、水蒸気の混合気体に火花放電、もしくは陽子線照射を行い、生成物中のアミノ酸の定量を行った。

火花放電の場合は、弱還元型（二酸化炭素：メタン=7:3）の場合でもアミノ酸生成が困難となったが、陽子線照射の場合はさらに還元性の弱い二酸化炭素：メタン=9.5:0.5 の場合でもアミノ酸が生成した。このことは、原始大気組成により、アミノ酸生成に必要なエネルギー源が異なることを示す。

キーワード: 弱還元型原始大気, 火花放電, 陽子線照射, 生命の起源, アミノ酸

Keywords: mildly-reducing primitive atmospheres, spark discharge, proton irradiation, origins of life, amino acids

## 模擬海底熱水系におけるアミノ酸の安定性と反応 Stability and reactions of amino acids in simulated submarine hydrothermal systems

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1970年代末の海底熱水噴出孔の発見は、生命起源研究に大きなインパクトを与えた。それまで、ミラーの実験などにより原始大気中での有機物生成の重要性が考えられていたが、惑星科学の進歩とともに、原始大気が強還元型でないと考えられるようになり、そのような環境下でのアミノ酸などの有機物の生成が限定的とみなされるようになったためである。海底熱水噴出孔では非還元的な地球を考えた場合でも局所的な強還元的な場を保持していると考えられ、有機物の生成・進化に有利と考えられた。さらに、マグマの熱による海水の加熱とそれが冷海水中に噴出することによる急冷、熱水中に溶解出した高濃度の金属イオンやシリカの触媒作用なども化学進化に有利に働くことが期待できる。

海底熱水噴出孔での有機物進化の研究のため、室内模擬実験が多数行われてきた。初期の実験では、閉鎖系のオートクレーブが用い、種々の試料をガスで加圧後に加熱し、その生成物を調べるが多かった。しかし、オートクレーブでは、海底熱水噴出孔の大きな特色である、加熱された海水の急冷 (quenching) の効果を検証することができない。そこで、海底熱水系のよりよい模擬のため、種々のフローリアクターが考案された。

本研究では、海底熱水噴出孔での化学進化、特にアミノ酸の重合に関して、オートクレーブおよびフローリアクターを用い、それらの特性の比較とそれらの中でのアミノ酸重合物の生成の可能性の検証を行った。

キーワード: 海底熱水系, アミノ酸, 生命の起源, フローリアクター

Keywords: submarine hydrothermal systems, amino acids, origins of life, flow reactor

## メイラード・タイプ反応で生じる微小球状有機物の形態観察 Scanning electron microscopic observation of organic microspherules formed by Maillard-type reaction

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It has been suggested that organic microspherules played a role as a physical container to maintain catalytic molecules and their reaction intermediates at concentrations high enough to sustain catalysis in prebiotic chemistry on the early Earth (Weber, 2005). Experimental studies on the formation of organic microspherules from a variety of organic compounds, such as amino acids (Fox and Harada, 1958), gelatin and gum arabic (Oparin, 1976), organic extracts from meteorite (Deamer, 1985; Deamer and Pashley, 1989), interstellar organic analogue (Dworkin et al. 2001), fatty acids and polycyclic aromatic hydrocarbons (Groen et al. 2012), formaldehyde and ammonia (Cody et al. 2009; Kebukawa et al. 2013) have been reported. However, the formation process and stability of these organic microspherules have been unexplored. In this study, sizes, shapes, and distributions of organic microspherules formed during the progress of Maillard-type reaction of formaldehyde and ammonia were investigated.

### Experimental:

Paraformaldehyde (120mg), glycolaldehyde (120mg), ammonium hydroxide (54ul), calcium hydroxide (30mg) in 2ml of water in a glass tube was heated at 50-90 degrees C for 71-720 hours. For comparison, the samples without ammonium hydroxide were heated under the same conditions. After heating, the sample solutions were centrifuged. The precipitated material were rinsed with 2N HCl to dissolve calcium, and dried at 50 degrees C to obtain organic solids. The organic solid samples were pressed on a indium plate, gold-coated, and observed by a scanning electron microscopy (SEM).

### Results and discussion:

After several minutes in heating, all the sample solutions turned yellow and eventually turned brown to black. Organic solids were produced at 90 degrees C but 50 degrees C. The yields of organic solids from sample solutions with ammonia were 10 times higher than those without ammonia. The yields gradually increased during heating. While distorted-shaped aggregates are produced from the samples heated for 71-120 hours, micron-sized organic microspherules (0.4-4.0 um) were observed from those heated for 240-720 hours. The samples with ammonia show perfectly round shapes of microspherules. Some microspherules are large and oval in the sample heated for 480 hours. The sizes of the microspherules increased with heating time. Organic solids produced by the same reaction as this study's at 90 degrees C for 72 hours consist of approximately equal abundances of aromatic and aliphatic carbons (Kebukawa et al. 2013). This molecular composition could result in amphiphilicity that is related to formation of the stable microspherules observed in this study. Formaldehyde and ammonia are thought to have been commonly present on the early Earth, and thus the organic microspherules formed by these molecules which proceed polymerization efficiently under mild conditions, could have played a role as a precursor of prebiotic cell membrane.

Keywords: organic microspherules, Maillard reaction, prebiotic cell membrane

## DNA 蛍光色素を用いたエアロゲルに衝突した微生物の検出 Fluorescence imaging of microbe-containing micro-particles that had been shot from a two-stage light-gas gun into an ult

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We previously proposed an experiment (the Tanpopo mission) to capture microbes and organic compounds on the Japan Experimental Module of the International Space Station. An ultra low-density silica aerogel will be exposed to space for one year. After retrieving the aerogel, particle tracks and particles found in it will be visualized by fluorescence microscopy after staining it with a DNA-specific fluorescence dye. In preparation for this study, we simulated particle trapping in the aerogel so that methods could be developed to visualize the particles and their tracks. During the Tanpopo mission, particles that have an orbital velocity of about 8 km/s are expected to collide with the aerogel. To simulate these collisions, we shot *Deinococcus radiodurans*-containing Lucentite particles into an aerogel from a two-stage light-gas gun (acceleration 4.2 km/s). The shapes of the captured particles and their tracks and entrance holes were recorded with a microscope/camera system for further analysis. The size distribution of the captured particles was smaller than the original distribution, suggesting that the particles had fragmented. We were able to distinguish between microbial DNA and inorganic compounds after staining the aerogel with the DNA-specific fluorescence dye SYBR green I as the fluorescence of the stained DNA and the autofluorescence of the inorganic particles decay at different rates. The developed methods are suitable to determine if microbes exist at the International Space Station altitude.

Keywords: Aerogel, Space experiment, Hypervelocity impact experiment, DNA-specific fluorescence dye.

Keywords: Aerogel, Space experiment, Hypervelocity impact experiment, DNA-specific fluorescence dye

## 酵素活性を利用した極限環境生命探査法の検討ーホスファターゼとカタラーゼー Studies on life detection methods by using enzymatic activities: Phosphatase and Catalase

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南極, 砂漠, 火星などの極限環境における生命探査法として, ホスファターゼ活性やカタラーゼ活性を用いた酵素活性測定法を検討した。

キーワード: 極限環境, 火星, 生命探査, 酵素活性, ホスファターゼ, カタラーゼ

Keywords: extreme environments, Mars, life detection, enzymatic activities, phosphatase, catalase

## Molecular approach to the characterisation of Sri Lanka red rain cells Molecular approach to the characterisation of Sri Lanka red rain cells

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The recent mysterious phenomenon that has attracted much attention is that of the red rain which fell in Polonnaruwa, Sri Lanka, on 13 November 2012. The microbial content in red rain shows generic similarities to that of the Indian red rain which fell in 2001. The morphological property of those microbes has been well documented [1,2]. Various microscopic analyses of our Sri Lankan red rain sample indicate that the defining red rain cells (RRC) exist in the presence of other microorganisms including diatoms. In our past paper, the ultrastructure of RRC shows that it is possibly a spore-form and so allowing them to thrive in the extreme upper biosphere conditions [3]. We also show the presence of uranium in the abnormally thick cell wall of RRCs.

In this report, we present the molecular approach to the characterisation of microbial communities in red rain and reveal the genus of RRCs. A beads-beating protocol is carried out for the efficient extraction of DNA and denaturing gradient gel electrophoresis (DGGE) for the analysis of microbial communities.

### References

- [1] Louis and Kumar (2006) New red rain phenomenon of Kerala and its possible extraterrestrial origin, *Astrophysics and Space Science*, **302**, 175-187.
- [2] Samaranyake et al. (2013) Microorganisms in the coloured rain of Sri Lanka, *Journal of Cosmology*, **21**, 9805-9810.
- [3] Miyake et al. (2013) Discovery of Uranium in Outer Coat of Sri Lankan Red Rain Cells, *Journal of Cosmology*, **22**, 1-8

キーワード: 赤い雨, 極限環境微生物, ポロンナルワ  
Keywords: Red rain, Extremophile, Polonnaruwa

## 縞状鉄鉱床の形成で最古の有機炭素を生成した機構 The mechanism that had formed the oldest organic carbon with the banded ironstone formations

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M. T. Rosing は約 38 億年前の縞状鉄鉱床が形成された時期に生成された西グリーンランドの堆積岩の中に最古の有機炭素を検出したと報告した [1]。その報告によれば、その堆積岩に含まれた 2~5  $\mu$  のグラファイトの微粒子の炭素同位体比 ( $^{12}\text{C}/^{13}\text{C}$ ) の値が無機炭素のそれより大きい。ところが、連鎖反応を行う分子のシステムにより実現している光合成によって最古の有機炭素が生成されたとすることはできない。本報告において、著者は縞状鉄鉱床の形成によって生成された浮遊物に  $^{12}\text{C}$  が少し多く取り込まれた仕組みを提案する。

炭酸水に鉄の微粉末を加えると、写真 1 に示すような現象が観察できる。水底の鉄の微粒子の表面に気泡ができて、その気泡が鉄の微粒子を水底から水面に浮上させる。炭素の電気陰性度は水素より大きいので、鉄の酸化によって、炭酸水の  $\text{CO}_2$  から酸素が取り除かれる。自由になった炭素原子は電気陰性度のために鉄と分子間力で結びつき、浮遊物ができる [2]。浮遊物の鉄の原子は酸素と結合して酸化鉄となり、自由になった炭素原子が浮遊物の分子間結合を増強し、外界のエネルギーを得て有機物質が生成される。

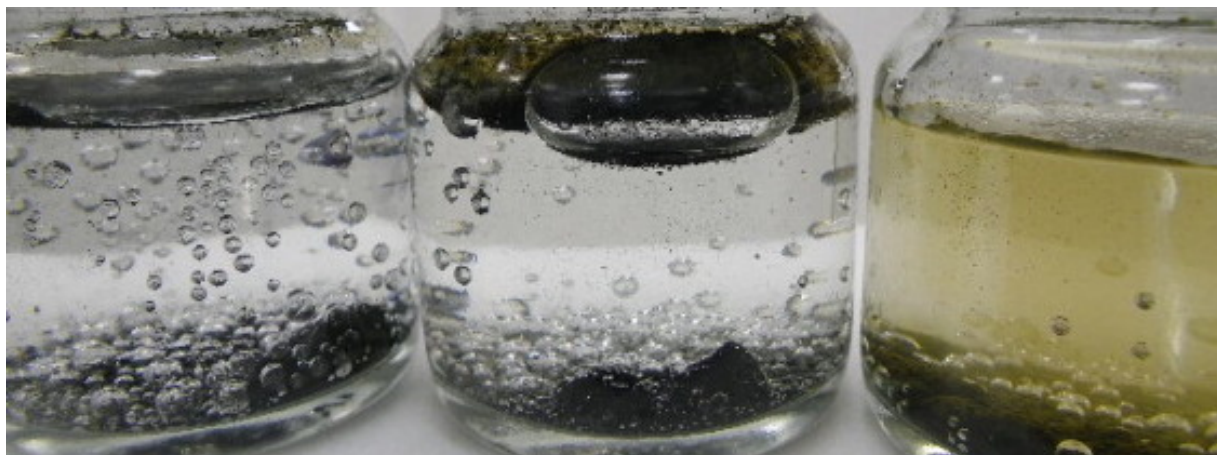
約 38 億年前の地球の表面は酸化物や硫化物や炭酸塩などで覆われており、大気には多くの二酸化炭素ガスがあったが、海ができ、その海水温度もある程度の温度以下になり、大気中の二酸化炭素が海水に溶けるようになっていた。そのような状況において火山の噴火が頻繁に発生して多量の鉄の微粒子が放出されて、縞状鉄鉱床が形成された。他方、大気中の二酸化炭素の分子が頻繁に水面に衝突した。それが、分子間結合で構成された浮遊物に含まれた。浮遊物は水面で累積される。そこに、紫外線等によるエネルギーが外部から供給されて、浮遊物の中で有機分子の組織も形成された。やがて、それらが海底に沈殿して堆積した。こうして、大気中の二酸化炭素に由来する  $^{12}\text{C}$  炭素同位体が西グリーンランドの堆積岩に取り込まれた。

### [参考文献]

- [1] Rosing M. T. (1999).  $^{13}\text{C}$ -Depleted Carbon Microparticles in >3700-Ma Sea-Floor Sedimentary Rocks from West Greenland, *Science* Vol.283 No.5402 pp.674-676.  
[2] Karasawa S. (2010). Inorganic production of membranes together with iron carbide via oxidization of iron in the water that includes carbon dioxide plentifully, *AbSciCon 2010*, #5168.

[写真 1] 炭酸水に鉄の微粉末を加えると気泡が発生し浮遊物できて集積される様子 (左:作りおいた古いメッシュ#300 の鉄の微粉末、中央:作って新しいメッシュ#300 の鉄の微粉末、右:やや粒が大きいメッシュ#200 の鉄の粉末)

キーワード: 38 億年前, 縞状鉄鉱床, 有機炭素, 二酸化炭素, 炭素同位体比  
Keywords: 3.8 billion years ago, Banded iron formation, Organic carbon, Carbon dioxide, Carbon isotope ratio



小笠原産ハマサンゴの B/Ca および  $\delta^{11}\text{B}$  測定から明らかになる 19 世紀末以降の北西太平洋の海洋酸性化と石灰化への影響  
Ocean Acidification and its effect on calcification since the late 19th century revealed by  $\delta^{11}\text{B}$  of Ogasawara coral

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サンゴ骨格のホウ素同位体 ( $\delta^{11}\text{B}$ ) は海水の pH 計になることが知られている。海水 pH は大気中の二酸化炭素分圧 ( $\text{pCO}_2$ ) と密接に関係していることから、地質時代の  $\text{pCO}_2$  の推定への期待も高まっている。しかしながら、サンゴの石灰化作用が  $\delta^{11}\text{B}$ -pH 関係に影響する可能性も指摘されており、その不確実性があまり深く評価されていない。これまでに  $\delta^{11}\text{B}$ -pH 関係を評価したものはそのほとんどが pH を制御した飼育実験によるものであり、野外で採取された試料に対する評価は今のところグレートバリアリーフやグアム島などに限られている。そこで本研究では、北西太平洋に位置する小笠原諸島父島で採取された長尺の塊状ハマサンゴ骨格に対する過去 125 年間 (AD1873-1998) の  $\delta^{11}\text{B}$  および B/Ca の測定結果を報告する。 $\delta^{11}\text{B}$  は産業革命以降の海洋酸性化の明瞭な傾向を捉えており、さらにその傾向から明らかになるサンゴの石灰化作用との関わりについて議論する。また測定が比較的簡便であることから近年注目を集めている、石灰化生物の炭酸塩骨格中のホウ素の含有量 (B/Ca) が pH 計として使えるかどうかについても同様に議論を行う。

キーワード: ホウ素, 小笠原, サンゴ, 石灰化, 海洋酸性化

Keywords: boron, Ogasawara, coral, calcification, Ocean Acidification



## 海洋酸性化が温帯性サンゴの成長に与える影響について Ocean acidification influences on coral growth of temperate species

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Carbon dioxide concentration in the atmosphere has steadily increased since the industrial revolution due to burning of fossil fuel and will cause the global warming and ocean acidification. It will raise the ocean temperature around Japan and reduce the seawater pH and then it may bring serious threat to corals dwelling around Honsyu Island, Japan. Last year, our research group did temperature-controlled culture experiments of temperate coral species from the Pacific side of Honsyu Island of Japan under the present level of the partial pressure of CO<sub>2</sub> (pCO<sub>2</sub>). But, synergetic effect of the global warming and ocean acidification on these corals has not been tested yet in detail. In this study, we focus on the how the different pCO<sub>2</sub> levels (past, present, and future) can influence skeletal growth of temperate *Acropora* coral species under the different temperature setting using a precise control system. This system was used to generate six different pCO<sub>2</sub> levels: (i) pre-industrial, ~300 μatm, (ii) present-day pCO<sub>2</sub>, ~400 μatm, and at four near-future conditions, (iii) ~550 μatm, (iv) ~750 μatm, (v) ~1000 μatm and (vi) ~1200 μatm at three temperature conditions (17, 25, and 27 deg C). Our early results suggested a negative influence of higher pCO<sub>2</sub> levels on skeletal growth of temperate *Acropora* corals, but not so sensitive compared to tropical and subtropical *Acropora* corals.

キーワード: 海洋酸性化, 温帯サンゴ, 石灰化, 地球温暖化

Keywords: Ocean acidification, temperate coral, calcification, global warming

## 地球温暖化に伴う水温上昇が日本近海の藻場分布に及ぼす影響予測 Projecting impacts of rising water temperature on the distribution of seaweeds around Japan

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高解像度気候予測モデル MIROC4h によって得られた 1950 年から 2035 年までの海面水温の結果と、フタエモクおよびカジメに関する簡易生物指標を組み合わせることによって、日本近海の熱帯・亜熱帯性藻場と温帯性藻場が将来の地球温暖化にともなう水温上昇による影響評価を行った。1950 年から 2000 年の再現実験の結果は、水温上昇により熱帯・亜熱帯性藻場は北上したこと、温帯性藻場の南限は北上したものの、北限の北上は見られなかったことを示した。RCP4.5 シナリオに基づく将来予測結果は、高知県沿岸域では 2010 年代にカジメからフタエモクへの遷移が起こる可能性を示している。このような、温帯種から熱帯・亜熱帯種への藻場種の遷移は日本近海の沿岸域の生物生産性や食物連鎖網、ひいては生態系サービスの変化をもたらす可能性が示唆される。

キーワード: 藻場, 地球温暖化, 気候予測モデル, カジメ, フタエモク

Keywords: seaweed bed, global warming, climate model, Ecklonia cava, Sargassum duplicatum

## 変動環境下でのサンゴ集団内の遺伝的変異—物質循環との関連— Standing genetic variation of coral populations under changing environments

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How genetic diversities affect ecosystem functions is one of key questions to understand the maintenance of genetic diversities and their roles in ecosystem. To evaluate the functional genetic diversities of corals which are main composers of coral reefs, I genotyped 20 colonies (collected in front of Sesoko Station) of *Acropora digitifera* which is one of dominant coral species around the Ryukyu Archipelago where is the northern peripheral area of coral reefs, and performed common garden experiment using five clonal fragments from each colony (to reduce accidental response in each genotype) to estimate variations of growth and photosynthetic efficiencies among colonies, namely, genotypes. Genotyping was performed with microsatellite markers for coral host and ITS2 direct sequencing for symbiotic algae, indicating that all host colonies were genetically distinct and belonging to major populations around the Ryukyu Archipelago and mainly maintaining clade C symbionts which are dominant around this region. In common garden experiment, all colonies showed different growth patterns whilst the photosynthetic efficiencies showed similar optimal peaks among colonies. The experimental approach above suggests that there are standing genetic variations in host itself of *A. digitifera*, which might guarantee the adaptive potential of coral population for future global warming in northern peripheral reef area. These genetic variations might also contribute to the change of material cycles in future coral reefs.

## 沿岸生態系における炭素フロー：ブルーカーボン研究 Carbon flows in estuarine and shallow waters: blue carbon study

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これまで海洋による CO<sub>2</sub> 吸収は、外洋で発揮されていて、陸域からの負荷を受ける沿岸海域では有機物が分解する場、すなわち CO<sub>2</sub> の放出源と考えられてきた。とりわけ、都市河川が流入し人間活動の影響を受けた内湾は、大量の CO<sub>2</sub> 放出を伴う富栄養化の進んだ環境価値の低い場所であるとの認識が強かった。ところが近年、沿岸生態系では、熱帯林に匹敵もしくはそれを上回る高い炭素貯留速度の事例が示されるようになってきた。したがって、沿岸海域はまさに炭素の missing sink となっている可能性がある。国連環境計画 (UNEP) は、海洋で固定される炭素を「ブルーカーボン」と新たに称し、特に沿岸海域の堆積物中に貯留される炭素ストックの重要性をアピールした。

そこで、「沿岸海域が大気中 CO<sub>2</sub> の吸収源」であるという、新たな仮説を検証することは重要であると考えられるものの、陸・河川・外洋の影響を受ける複雑な場という沿岸海域の特性により、実証には手法・労力・解析上の困難が伴う。したがって、「未知の炭素フロー」の検証作業はすすんでいない。本研究プロジェクトでは、河川-浅海域-沿岸海域、さらに大気-海水-海底堆積物を含めた広範なかつ長期的な炭素輸送像全体を沿岸生態系ブルーカーボンの研究対象とし、大気・海水・堆積物における全相 (気体・液体・固体) の全炭素 (無機態・有機態) の動態 (ストック・フロー) を抜け落ちなく実測し、未知の炭素フローを浮き彫りにすることを目標としている。

キーワード: 気候変動, 炭素隔離, 炭素貯留, ブルーカーボン, 海草場, 内湾

Keywords: climate change, carbon sequestration, carbon storage, blue carbon, seagrass meadows, estuarine waters

## 石垣島浅海域の大気-海水間 CO<sub>2</sub> フラックスに関する現地調査とパス解析 Field investigation and the path analysis of air-sea CO<sub>2</sub> flux in shallow waters of Ishigaki Island

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近年、海洋に存在する炭素の総称「ブルーカーボン」は、気候変動対策の重要なオプションとして注目されており、地球全体の光合成活動によって固定される炭素の約 55 % に相当する。特に、藻場などの植生が生育している浅海域は、炭素隔離・固定機能の場として重要であると考えられている。しかしながら、亜熱帯の浅海域におけるブルーカーボンの機能について、調査・解析技術が確立されていないため未解明な部分が多い。

このため、本研究では現地調査とパス解析を用いて、大気-海水間 CO<sub>2</sub> フラックスに直接的または間接的に影響を及ぼす環境要因を検討し、因果関係の相対的な影響度を推定した。現地調査では、2013 年 7 月に石垣島の浅海域（吹通川河口、白保海岸、名蔵海岸および川平海岸）を対象とし、大気-海水間 CO<sub>2</sub> フラックスとその環境要因（風速、水温、塩分、溶存無機炭素濃度 (DIC)、全アルカリ度 (TA) 等) の測定を行った。また、パス解析では、因果関係の強さについて様々な推定・検証を行い、大気-海水間 CO<sub>2</sub> フラックスに影響を及ぼすと考えられる重要な環境要因を明らかにした。

キーワード: ブルーカーボン, 沿岸植生, 大気-海水間 CO<sub>2</sub> フラックス, パス解析  
Keywords: blue carbon, coastal vegetation, air-sea CO<sub>2</sub> flux, path analysis

## 石垣島名蔵湾における大型藻類の $\delta^{15}\text{N}$ の空間分布とその成立要因について Spatial distribution and its characteristics of stable nitrogen isotopic composition of macroalgae in Nagura Bay

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亜熱帯サンゴ礁域に対する陸域由来の窒素負荷の影響を空間的に把握し、その空間分布の成立要因を検討するため、沖縄県八重山諸島の石垣島西部に位置する名蔵湾とその流入河川流域を対象として、ウミウチワ類（大型藻類）とリュウキュウスガモ（海草類）の  $\delta^{15}\text{N}$  と  $\delta^{13}\text{C}$  の空間分布特性の調査・分析、陸水の水質分析、および流域の土地利用解析を行った。

2013 年 6 月に名蔵湾沿岸海域で優占して生育するウミウチワ類とリュウキュウスガモを計 7 測線上で 50 m おきに採取し、各々計 55 試料を得た。併せて、河川水、湧水、海水の水質調査と採水、及び主要な流入河川及び排水路で流量観測を行った。実験室にて、植物試料については  $\delta^{15}\text{N}$  と  $\delta^{13}\text{C}$ , C/N 比を分析し、水試料については無機溶存イオン濃度を分析した。加えて、国土数値情報データを基に GIS を用いて流域の土地利用状況について解析した。そして、水質結果と併せて流入河川流域の窒素負荷源の検討を行った。

結果として、ウミウチワ類とリュウキュウスガモの  $\delta^{15}\text{N}$  値は、全測線で沿岸から離れるにつれて最大 +6 ‰ から +2 ‰ へと低下する傾向を示した。しかし、主要河川の名蔵川河口に近い測線では、海岸線から約 1 km の範囲において  $\delta^{15}\text{N}$  値が他測線よりも高く維持され、その低下勾配も小さかった。その要因として、先行研究より名蔵川河口北方部は南風によって生じる流れが滞留する場所であることが示されており、本調査以前の 3 ヶ月間の最多風向も南風であった。したがって、名蔵川河口北方部周辺で名蔵川から供給される栄養塩が停滞し、海水の希釈効果が小さくなり、対象種の  $\delta^{15}\text{N}$  値が相対的に高くなったと推測された。

一方、流入河川の  $\text{NO}_3\text{-N}$  濃度と土地利用形態別面積割合の相関を調べた結果、果樹園・耕作地、及び放牧地・草地の面積割合と河川水の硝酸態窒素濃度の間に正の相関がみられ、それらが主要な陸域窒素負荷源である可能性が示唆された。また、 $\text{NO}_3\text{-N}$  濃度と流量を基に  $\text{NO}_3\text{-N}$  フラックスを算出したところ、名蔵川河口で 81.9 mg/s、その上流部で 59.4 mg/s となり、名蔵川河口のマングローブ域、もしくはそこへ流入する別の流域を起源とする窒素が負荷されている可能性が示唆された。

キーワード: ウミウチワ類, リュウキュウスガモ, 窒素安定同位体比, 陸域由来窒素, 名蔵湾, 干潟・マングローブ域

Keywords: Padina spp., Thalassia hemprichii, Stable nitrogen isotopic composition, land-derived nitrogen, Nagura Bay, mangrove swamps and tidal flat

## 二枚貝の炭素・窒素安定同位体比による養殖域からの懸濁物拡散の評価 Propagation of suspended matter from aquacultures as traced by stable C and N isotope ratios of bivalves

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Recently there is growing concern about the impact of densely-deployed aquacultures on coastal marine ecosystems in the Philippines. As suspension-feeding bivalves are expected to reflect local food sources, their effectiveness as an environmental indicator were examined by analyzing stable carbon and nitrogen isotope ratios of bivalves living in aquaculture and neighboring seagrass areas. As a whole, the  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  of bivalves collected in the seagrass areas ranged from -13.1 to -11.0 and from +4.0 to +6.6, respectively, but in seagrass area where water mass from aquaculture area passed through typically lower values (-18.9 ~ -16.1 and +2.7 ~ +5.2, respectively) were observed, and they were the lowest in the aquaculture area (-24.4 ~ -19.8 and +3.4 ~ +4.3, respectively). It suggests that bivalves mainly fed on sinking particles, and presumably also seagrass-derived particles in seagrass areas. Higher C/N ratio was observed at sites where impact of aquaculture was larger. Although the interspecies differences and food selectivity etc. may affect the variability of the bivalve  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  to some extent, these results demonstrated that stable isotope ratios of bivalves could be used as an effective indicator to evaluate propagation areas and actual effects of suspended matter resulting from anthropogenic source on ecosystems.

キーワード: 懸濁物食二枚貝, 海草, 養殖, 炭素・窒素安定同位体比

Keywords: suspension-feeding bivalve, seagrass, aquaculture, stable carbon and nitrogen isotope ratios

## 熱帯・亜熱帯海草藻場堆積物における有機炭素の保存機構——非吸着態有機炭素の重要性とその起源 Organic carbon preservation in tropical seagrass-bed sediments: importance of sorptive vs. non-sorptive mechanisms

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陸棚域を含む沿岸海洋堆積物は、グローバルな炭素循環の中で有機炭素の主要なシンクとなっており、近年は特に二酸化炭素の吸収源として地球温暖化と海洋酸性化に拮抗する機能という観点から注目が集まっている。サンゴ礁・海草藻場・海藻群落等の浅海域大型一次生産者群落は、占有面積では必ずしも大きくないが、地球上で最も高い総一次生産ポテンシャルを有する生態系の一つであり、沿岸海洋堆積物への有機炭素の主要な供給源となっている可能性がある。特に海草藻場はそれ自身に堆積物の集積作用があることから、藻場自体が長期的な炭素固定・隔離容量を持つと期待されている。本研究では、熱帯(タイ)・亜熱帯(石垣島)・温帯(瀬戸内海)の海草藻場において、最長200 cmの堆積物コアをサンプリングし、堆積物中の有機炭素の蓄積状況について調査した。

海草藻場堆積物に含まれる有機炭素は、塩分補正後の乾燥重量に対して概ね500 - 1300  $\mu\text{mol C g}^{-1}$ の範囲に入ったが、マングローブからの流出物の影響を受ける熱帯海草藻場では時として4000  $\mu\text{mol C g}^{-1}$ に達することがあった。一方、海草の生育しない砂泥質干潟堆積物や、生育面積の小さな海草藻場堆積物では、500  $\mu\text{mol C g}^{-1}$ 未満の場合がしばしば見られた。炭素安定同位体比( $\delta^{13}\text{C}$ )は-28 ‰から-12 ‰の範囲であった。このことは、堆積物中の有機炭素の供給源として、海草自体(およそ-10 ‰)、植物プランクトン(およそ-22 ‰)、陸上植物(マングローブを含む、およそ-28 ‰)の3つに依存している事実を反映している。

沿岸海洋堆積物では一般に、有機炭素は堆積物粒子の表面に吸着することによって安定化すると考えられており、堆積物が熟成するにつれ、蓄積されている有機炭素(OC)の量と堆積物比表面積(SSA)との比率が一定の範囲( $\text{OC/SSA} = 0.6 - 0.9 \text{ mg C m}^{-2}$ )に収斂することが知られている(Mayer 1994; Keil et al. 1994)。今回調査した海草藻場堆積物の場合、温帯域のアマモ場の試料ではOCとSSAとの間に強い相関が見られ、OC/SSA比は平均0.72  $\text{mg C m}^{-2}$ と、従来から知られている傾向と一致していた。これに対してアマモの生育しない裸地干潟や沖合の堆積物ではOC/SSA比がこれより低い場合が多かった。一方、亜熱帯・熱帯の海草藻場堆積物では、OCとSSAとの間に一定した関係が認められず、OC/SSA比は温帯アマモ場堆積物に比べて概して高かった。

熱帯・亜熱帯海草藻場においてOC/SSA比と有機炭素の $\delta^{13}\text{C}$ との関係を調べたところ、変動性が二つの傾向に分類されることがわかった。第一の傾向は、主として熱帯海草藻場で見られ、OC/SSA比が大きくなるに従い $\delta^{13}\text{C}$ が-28 ‰から-26 ‰の範囲に収斂した。この範囲の $\delta^{13}\text{C}$ を示す有機炭素は、藻場の立地条件から、後背地のマングローブからの流出物に由来するものと考えられる。第二の傾向は、OC/SSA比が大きくなるとともに $\delta^{13}\text{C}$ が一貫して上昇する場合で、亜熱帯の海草藻場堆積物に典型的に見られた。OC/SSA比が3.5  $\text{mg C m}^{-2}$ まで上昇した時点で $\delta^{13}\text{C}$ は-12 ‰に達し、次第に飽和する傾向が見られた。これは、 $\delta^{13}\text{C}$ が-10 ‰前後である海草の組織に由来するデトリタス粒子が堆積物中に徐々に蓄積する結果として現れるパターンと解釈することができる。

以上の結果は、海草藻場は実際に有機炭素を堆積物中に蓄積する高い機能を持つことを明らかにしている。しかし、海草藻場堆積物における有機炭素の蓄積・保存機構として、温帯のアマモ場堆積物の場合は、鉱物粒子表面への吸着による安定化が主要なメカニズムと考えられるのに対して、亜熱帯・熱帯の海草藻場では海草やマングローブに由来するデトリタス粒子の集積が重要な意義を持つという、顕著な相違があることが示唆された。このような有機炭素保存形態の違いが現れるメカニズムとその生態学的な意義について、今後さらに研究を進める必要がある。

キーワード: 炭素循環, 有機物, 沿岸海洋, アマモ場, 堆積物, 比表面積

Keywords: carbon cycle, organic matter, coastal ocean, seagrass beds, sediment, specific surface area



## 石垣島吹通川河口域における無機炭素循環 Inorganic carbon cycle at the Fukido estuary in Ishigaki Island

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海洋生態系によって固定される炭素「ブルーカーボン」は、地球上の生物によるCO<sub>2</sub>固定量の55%に相当する、重要な炭素ストックである。沿岸域では、ブルーカーボンの一部が堆積することで長期間大気から隔離されるため、今後の気候変動対策の有効なオプションの一つとして近年注目されている。熱帯-亜熱帯域においては、海草場やマングローブなどの沿岸域生態系が広範囲に分布しているため、ブルーカーボンによる大気中CO<sub>2</sub>の固定ポテンシャルが高いと予想される。反面、陸域から流入した有機物や枯死した植生の分解が卓越することで、ブルーカーボンが固定されることなく、大気中へ再放出されている可能性も想定される。

熱帯-亜熱帯域のブルーカーボンが大気中CO<sub>2</sub>に与える影響の評価のためには、大気とのガス交換も含めた炭素循環の正確な測定が不可欠である。特に、熱帯-亜熱帯域では時間的な変動が他の気候帯と比べて大きいため、ある程度長期間の連続的な観測が必要となる。本発表では、亜熱帯域である石垣島の吹通川河口域における海草場を対象として、大気-海水間CO<sub>2</sub>フラックスを渦相関法で連続測定し、海草バイオマス等と比較して、無機炭素フローの解析を行った。

渦相関法による大気-海水間CO<sub>2</sub>フラックスは大気中CO<sub>2</sub>の吸収を示していた ( $-1.00 \pm 0.11 \mu \text{mol/m}^2/\text{s}$ ;  $\pm$ は95%信頼限界)。この値は、期間中の他の手法(バルク法・フローティングチャンバー法)による測定値と整合的な値であった。また、測定期間中の台風の接近前後で傾向の変化が確認された。同期間中の海草場のNPPは独立栄養的であり、対象水域においてブルーカーボンの生成と大気中CO<sub>2</sub>の吸収がリンクしていたことが確認された。当日の発表では、今回の測定で得られた結果とそのほかの気候帯の測定結果と比較し、亜熱帯域の沿岸域のブルーカーボン固定ポテンシャルについての考察結果を発表する。

キーワード: 炭素循環, ブルーカーボン, 大気-海水間CO<sub>2</sub>フラックス, 海草場, 渦相関法

Keywords: Carbon cycle, Blue Carbon, Air-sea CO<sub>2</sub> flux, Seagrass, Eddy covariance method

## 琉球列島宮古島産の硬骨海綿の骨格記録 Skeletal records in sclerosponges from Miyako-jima, Ryukyu Islands

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Sclerosponges, living in dark environments of tropical to subtropical shallow oceans, precipitate calcium carbonate skeleton with growth bands. They grow slowly at an approximate rate of <1 mm/year unlike corals (about 1 cm/year) but can be so long-lived for several decades to hundred years like corals (e.g., Benavides and Druffel, 1986). Skeletal oxygen isotopic ratios ( $\delta^{18}\text{O}$ ) reflect variations in sea surface temperature and seawater  $\delta^{18}\text{O}$  with the latter being closely related to salinity reflecting the precipitation-evaporation balance at the sea surface and changes in water mass transport (e.g., Wu and Grottoli, 2009). In contrast to zooxanthellate corals, which commonly show positive correlations between skeletal  $\delta^{18}\text{O}$  and carbon isotopic ratios ( $\delta^{13}\text{C}$ ), there do not exist vital effects in the secretion of sclerosponge skeleton (Druffel and Benavides, 1986). Previous studies showed significant decrease trends in the  $\delta^{13}\text{C}$  records toward the present, which is probably a result of  $^{12}\text{CO}_2$  added into the atmosphere/ocean from fossil fuel burning (e.g., Bohm et al. 1996). Therefore, sclerosponges are shown to provide annually resolved time series of proxy records of ocean environments since the Industrial Revolution. However, longer (>100 year) proxy records from sclerosponges were derived only from the Atlantic Ocean.

Here we present  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  records from high-Mg calcite skeleton of two sclerosponges (*Acanthochaetetes wellsi*) collected at a water depth of about 10 m from Miyako-jima, Ryukyu Islands in the North Pacific. The samples were slabbed to a thickness of 5 mm parallel to the skeletal growth and subsamples for stable isotope measurements were taken every 1 mm. External precision of replicate measurements of interlaboratory calcite material throughout the stable isotope analysis using a continuous flow isotope ratio mass spectrometer system (Delta V Advantage and Gasbench II: Thermofisher Scientific Inc.) of Ryukyu University was  $\pm 0.05$  per mil for  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$ . Soft X-ray images showed highly developed skeletal growth bands with >100 high/low density layers. The secular changes in  $\delta^{13}\text{C}$  of the two sclerosponges were quite similar to previously reported  $\delta^{13}\text{C}$  records from Atlantic and Pacific corals and sclerosponges. The long-term  $\delta^{18}\text{O}$  trends of the two samples are characterized by slight depletions throughout their living periods, indicative of an overall trend toward warmer ocean environment around Miyako-jima. Our sclerosponge-based estimates of sea surface temperature and salinity may document thermal and hydrologic variations in the Ryukyu Islands, furthering a good understanding of northwestern tropical-subtropical Pacific climate change for the last several centuries in conjunction with coral-based long proxy records.

キーワード: 硬骨海綿, 骨格, 酸素同位体比, 炭素同位体比, 古環境, 琉球列島

Keywords: sclerosponge, skeleton, oxygen isotope composition, carbon isotope composition, paleoenvironment, Ryukyu Islands

## 沖縄本島の遺跡から出土したシャコガイ殻化石によるサンゴ礁環境解析 Paleoenvironmental analysis using Tridacnidae shells from archaeological sites in Okinawa-jima, subtropical southwestern

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Symbiont-bearing Tridacnidae giant clams living in shallow waters of the Indo-Pacific tropical and subtropical regions can be used as an archive for documenting high-resolution record of thermal and hydrologic variations in coral reef environments for the past. Their shells, composed of dense aragonitic increments, are less sensitive to diagenetic alteration than porous skeleton of corals. They have annually and daily banded shells structure, providing chronological controls (e.g., Bonham 1965). The oxygen isotope composition ( $\delta^{18}\text{O}$ ) of shells, which are precipitated isotopically equilibrium with seawater, can reflect the temperature and seawater  $\delta^{18}\text{O}$  (e.g., Aharon & Chappell 1986). Several studies on paleoenvironmental reconstructions around the Ryukyu Islands were performed using geochemistry in fossil corals from Okinawa-jima (Mitsuguchi et al. 1998), Yonaguni-jima (Suzuki et al. 2001), Kikai-jima (Morimoto et al. 2007), and Kume-jima (Seki et al. 2012). However, only a  $\delta^{18}\text{O}$  record has been published from 6.2 ka giant clams from Kume-jima (Watanabe et al. 2004).

Here we present seasonally resolved  $\delta^{18}\text{O}$  time series of fossil Tridacnidae shells recovered from two archaeological sites (the Kogachibaru Shell Mound and the Second Aragusuku-Shichabaru Ruin) in Okinawa-jima, southwestern Japan to reconstruct subtropical coral reef environments of the past. The samples, mainly composed of aragonite shells with limited amounts of calcite cements, were selected for geochemical analyses. The radiocarbon dating results indicated that they lived during the early and middle Shell Mound periods in Okinawa-jima, corresponding to the middle-to-late Holocene, which is in good agreement with ages inferred from excavation (Okinawa Prefectural Board of Education 1987; Okinawa Prefectural Archaeological Center 2006). The shell  $\delta^{18}\text{O}$  values roughly showed seasonal variations, coincident with the occurrence of annual growth bands. The averages of annual, summer, and winter  $\delta^{18}\text{O}$  values of fossil shells were significantly lower than aragonite theoretically precipitated in present-day coral reef water of Okinawa-jima. These results demonstrate that the seawater temperature was higher and/or salinity was lower at the sites than today. It is likely that the giant clams lived in relatively small and/or closed coral-reef lagoons with less water circulation where seawater is highly susceptible to insolation-induced temperature increase and input of fresh water; the effect could be enhanced by the fisheries lifestyle that stonewalling would be constructed at shallow waters through the use of tidal variation during the Shell Mound period in Okinawa-jima.

Although it is extremely difficult to find well-preserved fossil Tridacnidae shells from carbonate sediments that are not fragmented, archaeological ruins and shell mounds can yield many fossils. Results of our study suggest that the use of fossil shells from archaeological sites can enable the reconstruction of temporal and spatial variations in coral reef environments and of the history of lifestyles and culture during prehistoric and protohistoric ages.

キーワード: サンゴ礁, シャコガイ, 殻, 化石, 酸素同位体組成, 遺跡

Keywords: coral reef, Tridacnidae, shells, fossil, oxygen isotopic composition, archaeological site

## 将来の台風に対するサンゴ礁防波堤機能の評価 Evaluation of natural break water of coral reefs affected by typhoons in the near future

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Tropical cyclones are one of the most extreme natural catastrophic events over the world and devastate coastal areas affected by floods and coastal erosions. Ryukyu Islands in the northwest Pacific is especially prone to many typhoons every year (Emanuel et al. 2008 Bull Amer Meteor Soc). However, the region is moderately protected from storm surge and wave during typhoons because coral reefs play a role in natural break water. For the last several decades, coral cover and species diversity on coral reef have shown dramatic declines in the region, influenced by global and local stresses (e.g., Hongo and Yamano 2013 PLoS ONE). According to the numerical modeling of global warming at the end of 21 st century, moreover, the mean intensity of tropical cyclones will probably increase significantly in the near future (Meehl et al. 2007 IPCC 4th Report). It is thus of some interest to understand the impact of tropical cyclones on the coastal areas in the region and the evaluation of coral reefs as natural break water.

To calculate a hydraulic force on a natural break water, we measured 9 transects using the echo sounder system (HFD-1000; Hongo et al. 2013 The Quat Res) on from the coast to the reef crest at Ishigaki Island in Ryukyu Islands during November 2013. To evaluate a contribution to reef formation by corals, moreover, we observed species abundance (cover) of tabular corals at the island. We shows that a change of role in natural break water of coral reefs in the island from present to end of 21 st century. Furthermore, we suggest necessary information of corals (e.g., cover and species) for maintenance of natural break water in the near future. The information are like to be one of basic criterion for determination of species in terms of direct transplantation of juvenile or adult corals, if the coral reefs will decline in the near future.

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キーワード: 台風, サンゴ礁, 石垣島, 琉球列島, 天然の防波堤

Keywords: typhoon, coral reef, Ishigaki Island, Ryukyu Islands, natural break water

## 植物根圏は温室効果ガス代謝のホットスポット Plant rhizosphere is a hotspot for greenhouse gas emissions

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根圏微生物研究の創始者である Hiltner は 1904 年にマメ科植物根の周辺土壌では細菌数が増加することを明らかにし、それは根粒から放出される窒素化合物の影響であると考察した。演者らは、ダイズ根粒は  $N_2O$  を吸収する能力が高いにも関わらず、圃場環境ではマメ科作物根圏から  $N_2O$  が発生するという矛盾に関心を持ち、分子生態学的手法により  $N_2O$  発生機構の解明を行ってきた。 $N_2O$  は強力な温室効果ガスであり、オゾン層破壊ガスでもあるからである。その結果、老化根粒では根粒タンパク質を物質的な起点とする一連の食物連鎖と窒素形態変化(根粒タンパク質→アンモニア→亜硝酸→ $N_2O$ )の中で  $N_2O$  が発生すると考えられた。また、 $N_2O$  から  $N_2$  への還元は *nosZ*+根粒菌が担っており、根粒根圏から発生した  $N_2O$  を吸収し  $N_2$  に還元するため、*nosZ*+根粒菌により根圏全体の  $N_2O$  発生が削減できることを室内実験および圃場レベルで明らかにした。 $N_2O$  から  $N_2$  への還元能力を強化した突然変異株 *nosZ*++根粒菌は、 $N_2O$  還元活性が高く、比較ゲノム解析からその原因となる遺伝子が同定された。

肥料削減は持続的農業の一つの目標である。窒素条件を変化させた水田に栽培したイネ植物体に生息している細菌群集構造の解析を行った。その結果、低窒素環境でイネ根に *Burkholderia*, *Bradyrhizobium*, *Methylosinus* 属の特定の細菌群の相対存在比が上昇した。機能遺伝子として、メタン酸化や植物ホルモン関連遺伝子の相対存在比が低窒素環境で上昇し、これらの現象は、定量 PCR および  $^{13}C$  標識メタン添加実験からも支持された。また、低窒素区のイネ根では、N, S, Fe および芳香族化合物の細菌代謝関連遺伝子が増加した。これらの結果は、低窒素環境が水稻根の共生細菌群集を形作る鍵因子であり、水田生態系の生物地球化学的過程に影響することを示唆している。植物は微生物共生を通じて窒素やリン等の栄養を獲得するため、栄養が貧弱な土壌でも生育できる。近年、イネ科植物にもマメ科植物の共生遺伝子 *CCaMK* が微生物共生に必須であることが示唆されている。微生物群集構造解析の結果、圃場生育した *CCaMK* 変異イネ根で *Rhizobiales* 目を含むいくつかの共生細菌が減少した。*Rhizobiales* 目細菌には窒素固定細菌やメタン酸化細菌が多く存在する。そこで、水田におけるメタンフラックスを調べた。日本晴と *CCaMK* 変異体 (NE1115) は、低窒素区においてメタンフラックスが有意に約 2 倍上昇した。一方、慣行区では両者に差が観察されなかった。種々の解析の結果、イネ *CCaMK* 遺伝子が低窒素環境でメタン酸化窒素固定微生物を受容している結果が得られた。 $^{15}N$  自然存在比の結果は、日本晴地上部における  $\delta^{15}N$  が NE1115 より有意に低く、空気中の軽い窒素で希釈されたため窒素固定が上昇したことが強く示唆された。以上の結果より、イネ *CCaMK* 遺伝子が低窒素環境でメタン酸化窒素固定微生物を受容していると考えられた。窒素施肥レベルなどの環境変動下の群集構造解析から、鍵微生物と推定される微生物の分離と特性解析を行った。

キーワード: メタン, 一酸化二窒素, 根圏, 根粒菌, 細菌, 安定同位体

Keywords: methane, nitrous oxide, rhizosphere, Bradyrhizobia, bacteria, stable isotope

## 微生物生態情報の把握は森林の窒素循環メカニズムの理解を深めるのか Does microbial ecology expand our understandings of nitrogen cycle in forests?

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Forests cover approximately 70% of Japan's total land area, representing a largest reservoir of diversity of organisms including plants, animals, fungi, protists and prokaryotes on land. These organisms are closely associated each other in material cycles if not directly. Thus, we need to know how materials are cycling between the organisms in order to address a fundamental question in ecosystem ecology: why do forests have the richest biodiversity on land? However, it is not easy to understand the material cycles in a forest because the forest has the various environmental heterogeneity which greatly affect the cycle. For example, nitrogen dynamics can be different in soils around hills and valleys in forests. Such spatial heterogeneity of the dynamics in the soils has been explained mainly from phenomenological perspectives using abiotic information such as soil moisture, soil temperature or litter quality. However, these perspectives have not fully explained the dynamics. Here, we suggest that such heterogeneity need to be explained in the context of ecology of microbial communities which mediate the nitrogen dynamics. More specifically, we suggest that understanding the nitrogen dynamics based on the physiology, population dynamics and diversity of the microbial communities can provide the mechanistic insights into the nitrogen cycle in forests.

We analyzed the spatial heterogeneity of nitrogen dynamics and associated microbial communities in natural and planted forest soils in Asia. Specifically, we focused on nitrification in which ammonium are oxidized to nitrate and found the close association between gross nitrification rates and population size of nitrifiers in the soils. Additionally, nitrification rates cannot be fully explained by using environmental properties including substrate supply, soil moisture, soil temperature and litter quality, but can be explained by using the population size of nitrifiers. This shows that the better understandings of the microbial ecology allows us to more accurately predict the spatial heterogeneity of material cycles. In this presentation, we would like to discuss how information on microbial ecology expands our understandings of nitrogen cycle in forests.

キーワード: 微生物生態, 窒素循環, 森林

Keywords: microbial ecology, nitrogen cycle, forest

## ヒ素の環境挙動に影響を及ぼす微生物群集機能の解析 Diversity of microbial arsenic transformation pathways associated with arsenic cycling in the environment

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Arsenic (As) is a naturally occurring toxic element that is widely distributed in nature. Although the concentrations of As in natural systems are generally low ( $\sim 15 \mu\text{g g}^{-1}$  in soil and  $\sim 10 \mu\text{g L}^{-1}$  in surface waters), the elevated levels of As have been released via natural sources (i.e. volcanic activity) and anthropogenic activities due to its increasing industrial use. As can exist in four oxidation states (-III, 0, III and V), while they are mainly found as trivalent [arsenite; As(III)] and pentavalent [arsenate; As(V)] in natural systems. Depending on its oxidation state, As exhibit different mechanisms of toxicity to microorganisms and other biota. As(III) is highly reactive with thiol containing proteins and is considered more toxic than As(V). Despite its toxicity, microorganisms have developed mechanisms to tolerate As and/or utilize the element for respiratory metabolism. Although various microorganisms have been identified to catalyze As transformation including both oxidation and reduction, we have just began to unveil the full diversity of different microbial processes associated with the redox cycling of As in the environment.

To gain insight into microbial roles in the geochemical dynamics of As, the combined geochemical, physiological and molecular biological analyses were applied to examine As-impacted environments and microcosms. Microbial populations were analyzed using 16S rDNA-based molecular approach combined with metagenomic sequencing. The presence of indigenous microbial populations capable of As transformation was examined by using both molecular approach targeting As functional genes and cultivation approach. The genes coding for arsenite oxidase (*aioA*), which catalyzes the oxidation of As(III) coupled to O<sub>2</sub> reduction, have been recovered from geochemically distinct geothermal habitats (pH 2.6-8) as well as the soils from mine tailing. Successful cultivation of various As(III)-oxidizing bacteria confirmed the microbial attribute in As oxidation *in situ*. In contrast, from the As impacted lake sediments and soils, diverse sequences of anaerobic arsenite oxidase (*arx*) and arsenate respiratory reductase (*arr*) genes were detected, while no *aio* genes were recovered. The anaerobic arsenite oxidase, Arx, is known to catalyze arsenite-oxidation coupled to nitrate reduction or photosynthesis. Consistent with the molecular approach, the anaerobic arsenite-oxidizing nitrate reducer and arsenate-reducing bacteria were isolated from the lake sediments.

Our results showed that As redox metabolisms are widespread within phylogenetically and physiologically diverse bacteria, including both chemolithotrophic and organotrophic aerobes and anaerobes. This study revealed the diversity of As transformation pathways associated with geographically and geochemically distinct environments and presented the mechanisms behind microbial processes controlling the redox cycling of As.

キーワード: ヒ素, 微生物, ヒ素酸化酵素, ヒ素還元酵素

Keywords: arsenite oxidase, arsenate reductase, microbial arsenic transformation, soil microbiology

## 深海底に存在する酸化鉄皮膜地帯での微生物調査 Biosignature found in iron oxide mineralogy of iron-oxidizing microbe origin?

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Recently, many iron mats have been discovered at deep-sea hydrothermal fields in all over the world. It has been thought that microbes, especially iron-oxidizing microbes, are the key players for forming the iron mats. However, there was no direct evidence to this, due to cultivation difficulty of iron oxidizers. Recently, '*Mariprofundus ferrooxidans*' that belong to the Zeta-proteobacteria was successfully isolated. From this isolation, it has been proved that this microbe can oxidize ferrous iron as the electron donor, and can widely be observed in various deep-sea low-temperature hydrothermal fields. Therefore we have investigated how these microbes contributed to the formation of the iron mat using mineralogical and culture independent approaches.

We tried to clarify mineralogical properties of natural or lab-prepared iron oxides of iron-oxidizing microbes by using XAFS, SEM and EDX. Natural samples were collected at 3 sampling sites: iron mats from deep-sea hydrothermal fields in the Mariana Volcanic Arc, Mariana Trough and the Okinawa Trough. Lab-prepared iron-oxide synthesis was carried out using chemoautotrophic bacterium *Mariprofundus ferrooxydans* PV-1 (ATCC BA-1020) and was cultured by diffusion cell's method (Kikuchi et al., 2011, 2014). SEM observation showed similar morphology to all samples, which have distinctive plait-like structure, and at where iron oxides precipitate around distinctive materials. Although each natural iron-oxide sample was precipitated at different environments and with different dominant microbial species within the natural samples, XAFS showed identical spectrum. Regardless of medium employed in the cultivation, lab-prepared iron oxides also showed similar spectrum to natural samples. XANES fitting suggested that iron mats consist of ferrihydrite and iron-organic complex being the same as the lab-prepared iron oxides. These results strongly supported the iron-oxidizing chemolithoautotrophs had significant ecological roles in producing the iron mat. These mineralogical analyses may help to find biosignature in the deep-sea environments.

キーワード: 鉄酸化細菌, バイオシグニチャー, 鉱物学的特徴, 深海, 熱水活動域

Keywords: iron-oxidizing bacteria, Biosignature, Mineralogical property, deep-sea, hydrothermal fields



## 日本海溝横断調査から見えた海溝生命圏の成り立ち The trench biosphere observed from the transect water sampling for the Japan Trench

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我々は、これまでにマリアナ海溝チャレンジャー海淵内の水塊中微生物相が海溝上に拡がる深層水海中の微生物相と著しく異なること、即ち、チャレンジャー海淵には、“海溝生命圏”と呼ぶべき独自の微生物生態系が存在することを明らかにした (Nunoura et al. in preparation)。この水深 10,000m を超えるチャレンジャー海淵は、表層での一次生産に乏しい熱帯の貧栄養水塊下に存在し、また、他の海溝から孤立する特徴を有す。それに対し、日本海溝は、最大水深は 8,000m 程度と比較的浅く、海洋表層での生物生産の大きな豊かな海域に存在し、また、北西太平洋の他の海溝とも連なる地形である。即ち、日本海溝は海溝生命圏の普遍性を検証し、更に海溝生命圏を支える要素を検討するに優れた条件を有していると言える。今回、我々は、東日本大地震後に行われた三度の緊急調査 (MR11-03、YK11-E03、YK11-E04) にて海溝を横断する計 8 地点から採水し、海洋表層から海底までの水柱について微生物生態解析を行なって、海溝生命圏の普遍性、その成り立ちについて検討した。なお、一連の緊急調査においては、斜面崩壊由来の懸濁物に影響された深海水塊微生物相の変動が既に報告されている (Kawagucci et al. 2012)。

キーワード: 日本海溝, 硝化

Keywords: Japan Trench, nitrification

半閉鎖水塊における熱水プルームイオウ酸化独立栄養微生物 SUP05 の炭素、窒素循環への寄与  
SUP05 contribution for Carbon and Nitrogen cycles in semi-closed water mass

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In the deep sea hydrothermal plume, significantly elevated microbial biomass has been reported depending on chemolithoautotrophic activities by hydrothermal reduced chemicals. The potential energetic is sulfur, methane and hydrogen oxidation, and microbial production is up to date. The most important microbes in the plume is SUP05 phylotype (genus Thioglobes), which is known to have sulfur and H<sub>2</sub> oxidation pathway, RubisCO carbon assimilation pathway, and denitrification pathways. In this study, we compared the bicarbonate and inorganic nitrogen species with SUP05 cell densities in the hydrothermal plume of the TOTO caldera hydrothermal field with half-closed water mass system in the Southern Mariana Trough. The cell densities of SUP05 is strong negative correlation with bicarbonate and nitrate, however, the correlation slope indicated the nitrogen assimilation but not the nitrogen respiration (denitrification). Only the nitrogen assimilation occurred in the plume is also supported by the lack of denitrification genes in the plume sample with the metagenomic analysis.

キーワード: イオウ酸化微生物, 熱水プルーム, 窒素同化, ゲノム  
Keywords: Chemolithoautotroph, SUP05, TOTO, metagenomics

「何が、どこに、どれくらいいて、何をしているか」から「それはどのような意味があるか」へ  
From who, where, how many and what to 'Earth science'

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ライトとホビーが放射性ラベルしたグルコースの取り込み速度の測定手法を提案して50年、水圏を対象とした微生物生態学が何を明らかにしてきたのかをごくごくかいつまんで眺め、地球科学としては何が課題かを考えたい。

キーワード: グルコースの取り込み vs. チミジンの取り込み, 生産 vs. 呼吸, ミリ秒 vs. 年  
Keywords: 14C-glucose uptake vs. 3H-Thymidine uptake, Production vs. Respiration, sec vs. year

## 西南日本の付加体深部帯水層における微生物ポテンシャルと物質循環 Microbial potential and carbon cycle in deep aquifer of the accretionary prism of South-west Japan

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西南日本の太平洋沿岸は「付加体」と呼ばれる厚い堆積層からなる。この堆積層の深部地下圏には嫌気的な地下水が貯留された帯水層が広く分布しており、その深部地下水には大量のメタンが溶存していることが知られている。静岡県中西部に存在する地下 150 m から 1,500 m 掘削された大深度掘削井では、深部地下水とともにメタンを主成分とする付随ガスも検出することができる。静岡県島田市の大深度掘削井において行われた過去の研究では、付加体深部帯水層において微生物群集によるメタン生成が行われていることが明らかにされている。しかし、付加体における広域での微生物学的、地球科学的研究は未だ行われていない。そこで本研究では、静岡県中西部に存在する 14 か所の大深度掘削井から深部地下水と付随ガスを採取し、各種環境データ測定、地球化学分析、微生物の嫌気培養、遺伝子解析を試みた。そして、付加体の深部地下圏における微生物ポテンシャルと物質循環に関する知見を得た。

深部地下水の水温は 24.2 °C から 49.3 °C、pH は弱塩基性であった。酸化還元電位は全ての大深度掘削井で -325 mV から -114 mV の値を示した。電気伝導率は 92 mS m<sup>-1</sup> から 2,110 mS m<sup>-1</sup> と地下水サンプルによって幅広い値を示した。地下水中の NO<sub>3</sub><sup>-</sup> や SO<sub>4</sub><sup>2-</sup>、S<sup>2-</sup> 濃度は検出限界以下であり、溶存有機炭素 (DOC) 濃度は 0.3 mg l<sup>-1</sup> 以下から 50 mg l<sup>-1</sup> と多様であった。付随ガスの分析から、多くのサイトの付随ガスにメタンが 90% 以上含まれていることが明らかとなった。一方、幾つかのサイトではメタン (50-80%) 以外にも窒素ガスが 20% から 50% ほど含まれていた。付随ガスのメタンと地下水の溶存無機炭素 (DIC) の炭素安定同位体比分析により、多くのサイトでの付随ガスに微生物起源のメタンが含まれていることが示唆された。

深部地下水に有機基質を添加した嫌気培養実験の結果、2-3 日以内に水素発生型発酵細菌による水素ガスと二酸化炭素の生成が確認された。さらに、水素発生型発酵細菌と水素資化性メタン生成菌の共生コンソーシアによるメタン生成も培養開始から 3-5 日以内で確認された。

バクテリアの 16S rRNA 遺伝子を対象とした遺伝子解析より、水素発生型発酵細菌が優占していることが明らかとなった。また、付随ガスに 20% から 50% の窒素ガスを含んでいたサイトからは脱窒菌の存在も示された。アーキアの 16S rRNA 遺伝子を対象とした遺伝子解析では、深部地下水中に水素資化性メタン生成菌が優占していることが示された。

一連の研究結果より、広範囲の付加体地下圏において、水素発生型発酵細菌と水素資化性メタン生成菌の共生によって堆積層に含まれる有機物からメタンが生成される炭素循環が存在することが明らかとなった。また、幾つかのサイトではメタン生成に加えて、有機物またはメタンを電子供与体とし、NO<sub>3</sub><sup>-</sup> または NO<sub>2</sub><sup>-</sup> を電子受容体とする脱窒が行われている可能性も示唆された。

キーワード: 付加体, 深部帯水層, メタン生成, 発酵, 微生物共生, 地下環境

Keywords: accretionary prism, deep aquifer, methanogenesis, fermentation, syntrophic biodegradation, subsurface environment

## 地球微生物学が解き明かすメタン循環 The global methane cycle revealed through geomicrobiological analysis

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Methane is one of the major end products of anaerobic microbial metabolism. Based on stable carbon and hydrogen isotopic compositions of methane, geochemical studies have systematically classified the origin of methane; 1) biological pathways consisting of carbon dioxide reduction coupled to molecular hydrogen oxidation and methyl-type fermentation, and 2) abiological pathways such as thermal degradation of organic matter and Fischer-Tropsch type reaction. In contrast, regarding methane consumption, recent advances in seafloor biosphere research have unveiled the complexity of processes involved in the transformation, migration and fate of methane. Particularly, it has been recognized that marine sediments with high methane flux harbor novel lineages of microorganisms, the physiological traits of which are largely unknown due to their resistance to cultivation. Recent advances in seafloor biosphere research indicate that microbes play much more important roles in methane production and consumption than previously assumed. Though these biogeochemical processes are not fully understood, future combined approach of geochemistry and geomicrobiology will shed light on the global methane cycle on Earth.

キーワード: 海底下生命圏, メタン, メタン生成, 嫌氣的メタン酸化  
Keywords: seafloor biosphere, methane, methanogen, methanotroph

## 蛇紋岩流体中の水素-メタン-水の同位体システムティクス Isotope systematics among H<sub>2</sub>, CH<sub>4</sub> and H<sub>2</sub>O in fluid associated with serpentinization

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Serpentine-hosted hydrothermal systems have attracted considerable attention as sites of abiotic organic synthesis and as habitats for the earliest microbial communities, because hydrothermal fluids derived from ultramafic rocks are characterized by high concentrations of H<sub>2</sub> and CH<sub>4</sub>. During water-rock reactions, Fe (II) in olivine of ultramafic rock is oxidized to Fe (III), which accompanies the reduction of water to yield H<sub>2</sub>. Methane and hydrocarbons are often observed in serpentine-hosted hydrothermal systems and are thought to be produced from H<sub>2</sub> and CO<sub>2</sub> via Fischer-Tropsch-type (FTT) reactions. On the other hand, H<sub>2</sub> and CH<sub>4</sub> can be consumed and produced by microorganisms such as methanogens and methanotrophs around the hydrothermal systems. When we collect and analyze samples, those chemical compositions could have been altered due to microbial activities. Therefore, it is very difficult to clarify processes related to H<sub>2</sub> and CH<sub>4</sub> around the serpentine-hosted hydrothermal systems.

Isotopic compositions are useful tool to discriminate origins and reaction pathways of chemical components. As representative controlling factors of isotopic compositions are temperature equilibrium, isotopic compositions of substrate, and isotopic fractionation, the dynamics of isotopic compositions are complicated in natural environments. Therefore, polyphasic aspects, such as hydrological, geological and microbiological interpretations, are needed. However, even complete hydrogen isotopic analysis of H<sub>2</sub>, CH<sub>4</sub> and H<sub>2</sub>O from serpentine-hosted systems and basic laboratory experiments has been reported in only a few studies. As the isotope systematics among H<sub>2</sub>, CH<sub>4</sub> and H<sub>2</sub>O in fluid associated with serpentinization remain unexplored, I will present the review of some previous studies and results of explorations of hydrothermal systems at Mid Cayman Ridge during YK13-05 cruise.

キーワード: 蛇紋岩流体, 安定同位体, 水素, メタン  
Keywords: serpentinization, stable isotope, hydrogen, methane

## 下北八戸沖の夾炭層を含む海底下深部堆積物中の酢酸酸化活性 Acetate-oxidation activities in the deep seafloor biosphere associated with coalbeds off the Shimokita Peninsula

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2012年に統合国際深海掘削計画第337次航海 (IODP、Expedition 337)により下北八戸沖で、海底下約2kmに埋没した未成熟の石炭層に関連する炭化水素循環システムと微生物学的・地球化学的プロセスを明らかにすることを目的として地球深部掘削船「ちきゅう」によりC0020サイトでライザー掘削が行われた。未成熟の石炭(褐炭)はその熟成の過程で、有機酸や炭化水素などの有機物を溶け出させ、それらが微生物の代謝活動を支えていると考えられている。

本研究では掘削された堆積物コア試料(海底下2466m)に、<sup>14</sup>Cトレーサー (sodium [<sup>14</sup>C]-bicarbonate、[2-<sup>14</sup>C]-acetate)を添加し、酢酸開裂型メタン生成活性と酢酸酸化活性を測定した。酢酸開裂型メタン生成活性は、海底下約2kmの褐炭層より浅部で $0.2\text{?}4\text{ pmol cm}^{-3}\text{ d}^{-1}$ であり、最も高い活性は海底下1990mの褐炭層試料で検出された。褐炭層以深では、 $0.1\text{?}0.2\text{ pmol cm}^{-3}\text{ d}^{-1}$ 程度とより低い活性を示した。酢酸のメチル基に<sup>14</sup>Cでラベルした[2-<sup>14</sup>C]-acetateを添加した試料中の<sup>14</sup>C-CO<sub>2</sub>の生成量から見積もられた酢酸酸化活性は、1800 mbsfで最も高く( $150\text{ pmol cm}^{-3}\text{ d}^{-1}$ )、深度の増加と共に低くなり、夾炭層以深では検出限界以下となった。1800 mbsf付近では海緑石が多産することから、この深度での高い酢酸酸化活性には、海緑石に含まれる酸化態の鉄(Fe(III))が電子受容体として寄与している可能性が示唆される。

グルコースを電子供与体としたときの微生物硫酸還元過程で起こる硫黄同位体分別の温度依存性  
Temperature effect of sulfur isotope fractionation by sulfate reducers when used glucose as electron donor

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Sulfate reducing microbe (SRM) is responsible for over 50 % of organic carbon remineralization in marine sediments and thus plays a prominent role in sulfur cycle. Based on a large number of culture experiments of SRM, sulfur isotope fractionation by SRM changes depending on environmental factors including temperature, sulfate concentration and availability of electron donor. The isotope fractionation is recorded in sedimentary sulfates and sulfides. Hence, the sulfur isotopic fractionation is useful to reconstruct ancient environmental condition. However, the mechanism controlling the degree of the sulfur isotopic fractionation is still unclear. Particularly, we have to consider the physiology. Previous culture experiments of SRM indicated that the temperature effect varies with species of SRM. However, there is little temperature control experiments using various electron donor with same strain. We carried out temperature control experiments at 25 °C, 30 °C and 37 °C, by sulfate reducing bacteria DSM 642 using glucose as electron donor. Our results revealed growth rate of DSM 642 is fastest at 30 °C, when using glucose as electron donor. Growth rate is the fastest at 37 °C when using lactate as an electron donor. Sulfate reduction rate is thought to primary factor controlling isotope fractionation. In addition, growth rate and sulfate reduction rate have basically positive correlation. Accordingly, the shift of sulfur isotope fractionation by temperature must be changed when used glucose as electron donor. This result indicates that we should pay attention not only sulfate reduction pathway but also oxidation pathway of electron donor. We report temperature dependency of sulfur isotope fractionation by DSM 642 using glucose as electron donor at the first time, to elucidate the mechanism controlling the degree of the sulfur isotopic fractionation during microbial sulfate reduction.

キーワード: 硫黄同位体, 硫酸還元菌

Keywords: sulfur isotope, sulfate reducing bacteria



## 熱アルカリ細胞溶菌法による海底下微生物群集構造解析 A hot-alkaline DNA extraction method for deep seafloor communities

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環境試料を用いた分子生態学的解析では、対象とする微生物群集全体から試料となる核酸が抽出されることを前提としている。地球上に存在する微生物の半数以上が生息するとされている海底下の堆積物を対象に市販キットによる核酸抽出を行い、SYBR Green I によって残渣中の微生物濃度を計測したところ、抽出操作によって溶菌する微生物の割合は場合によっては 20% 以下であることが明らかになった。本研究では、環境中に生息する微生物群全体の姿を捉えることを目指し、微生物破碎効率の高率化と核酸抽出手法としての確立を目的とした。地球深部探査船「ちきゅう」などによって採取された海底下堆積物について、アルカリ溶液や市販のキットを含む複数の条件で DNA を抽出したところ、アルカリ溶液を用いた時に 95% を超える溶菌率が得られた。しかし、アルカリ処理による DNA への影響を調べたところ、一本鎖化だけでなく DNA 自体の断片化も引き起こすことが明らかとなった。DNA の断片化を抑えつつ、溶菌率を向上させる条件の検討の後に、それぞれの DNA 抽出物に含まれるバクテリア、アーキアの存在比の測定を行ったところ、溶菌率の違いによって構成種にも違いが見られた。このことから、抽出によるバイアスが実際に微生物群集構造解析の結果に影響を与えていることが示唆された。

キーワード: 海底下生命圏, DNA 抽出, アーキア

Keywords: Subseafloor microbial community, DNA extraction, bias, archaea

## アンチモンによる土壌性細菌群集及びヒ素酸化能への影響 Effect of antimony on arsenite oxidation by soil microbial community

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Antimony (Sb) and arsenic (As) are naturally occurring toxic elements in the earth's crust, and both elements exist commonly in sympatric environment. The chemical properties and the mode of toxicity of those elements depend on their oxidation states. Although both oxidation states are toxic, trivalent is more toxic than pentavalent chemical form. The microbiological oxidation of As(III) can impact on the geochemical cycling of arsenic in the contaminated environment, and more than 30 phylogenetically diverse As(III)-oxidizing bacterial strains have been isolated. Although natural microbes are exposed to multiple contaminants in situ, the effect of co-contamination on microbial As(III)-oxidation activity is not well understood. To gain insight into the microbial roles in the biogeochemical cycles of As, we evaluated the effect of co-contamination of Sb and As on the microbial community and their As-oxidizing activity by using solid-phase culturing which was inoculated with antimony mine tailing soil (Ichinokawa, Ehime, Japan). As(III) oxidation rates increased exponentially and reached steady state at day-8 in which 0.15 mM As(III) was oxidized to As(V) in 22.9 hrs. The addition of antimonite tartrate (Sb[III]-tar, 0.15 mM) at day-9 inhibited arsenite oxidation, which was then reduced to 40% by day-15. Successional changes in bacterial community compositions were observed after Sb(III)-tar addition by 16S rDNA- and arsenite oxidase gene (aioA)-targeted analyses. Total of 69 As(III)-oxidizing strains were isolated from the solid samples obtained before and after the Sb(III)-tar addition, and the Sb(III)-tar tolerance of representative isolates were determined. Various As(III)-oxidizing strains exhibited different levels of Sb(III)-tar tolerance in growth response and As(III)-oxidation rates. These results indicated that the co-contamination of As and Sb affect the community composition and activity of As(III)-oxidizing microbial population reflecting the differences in cellular responses among strains to Sb toxicity.

キーワード: 重金属複合汚染, ヒ素, アンチモン, 固相カラム連続培養, 土壌細菌群集

Keywords: Heavy metal pollution, Arsenic, Antimony, Solid phase advective culturing, Soil bacterial community

## 関東平野南部における地下堆積物中の細菌群集構造 Bacterial community structure in different subsurface sediments of the southern Kanto Plain

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二酸化炭素放出の削減および省エネルギーの必要性から、近年、特に都市部建物において地圏熱利用ヒートポンプシステム (GSHP) の普及が進んでいる。GSHP は冷暖房用恒温熱源として、年間を通して温度がほぼ一定な地下の熱を利用するものである。このような技術の普及に加え、都市部の地下利用やヒートアイランド現象等の影響によって今後地下 (地表から深さ約 100 m まで) の温度環境が変化することが予測される。地下の温度変化が地下地盤や地下水の水質、地下に生息する微生物に影響を与えることは容易に推測されるが、実際に地下の温度変化によって何が起こるかについては、ほとんどわかっていない。地下の温度変化によって地下の微生物群集がどのように変化するかを明らかにするためには、まず熱の影響を受ける前の群集構造を理解する必要があると考え、本研究では、関東平野南部の異なる 3 地点において、様々な深度のボーリングコア中に存在するバクテリアの群集構造を明らかにすることを目的とした。

日本大学文理学部 (世田谷区)、埼玉大学 (さいたま市)、東京農工大学府中キャンパス (府中市) の各キャンパス内で掘削したボーリングコアについて、10-12 の異なる深度から DNA を抽出し、16S rRNA 遺伝子を対象とした次世代シーケンス解析を行った。その結果、深さ 0-30 m では優占する細菌がサイトによって異なっており、日本大学では Actinobacteria 門、Firmicutes 門が半数以上を占めたのに対し、埼玉大学では Chloroflexi 門、 $\gamma$ -、 $\delta$ -proteobacteria 綱、東京農工大学では  $\alpha$ -、 $\beta$ -、 $\gamma$ -proteobacteria 綱が多く検出された。特に埼玉大学では Chloroflexi 門の中でも Dehalococcoidetes 綱および Anaerolineae 綱と分類される OTU 多く検出され、海成層に特に多く分布していた。一方、30 m 以深では全てのサイトで  $\beta$ -、 $\gamma$ -proteobacteria 綱が優占していた。一部のグループの細菌については、その相対量と深度や間隙水の pH、電気伝導度、堆積物中の粒子径分布との間に相関が見られた。したがって、サイトや深さごとの群集構造の違いは、各サイトの堆積年代、堆積環境と現在の地下環境の違いに起因すると考えられる。本研究で得られた結果をもとに、今後、実際に地下温度変化が起きた場合、細菌の群集構造がどのように変化するかを明らかにしたいと考えている。

キーワード: 地下微生物, 地中熱ヒートポンプ, 次世代シーケンス解析, 細菌群集構造

Keywords: subsurface microorganisms, ground source heat pump, next generation DNA sequencing, bacterial community structures

## TOWARDS THE NEXT GENERATION OF CARBONATE-BASED PROXIES TOWARDS THE NEXT GENERATION OF CARBONATE-BASED PROXIES

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Reconstructions of past climate and environments are largely based on stable isotopes and trace element concentrations measured on fossil foraminiferal calcite. Element and isotope composition of foraminiferal calcite roughly reflects seawater composition and physical conditions, which in turn, is related to paleoceanographic parameters. Additional biological controls on test composition biases such correlations and needs to be corrected for when aiming at precise and accurate reconstructions. The various physiological processes involved in foraminiferal biomineralization have, however, different impacts on different elements and isotopes. For instance transmembrane transport of Ca-ions has a large impact on Mg fractionation (and hence the Mg-temperature proxy), whereas it has very little effect on Na/Ca ratios (a novel proxy for salinity). Many foraminifera-based proxies are thus impacted by more than one physiological process, which can only be corrected for by 1) quantification of the impacts of these processes (ion pumping, photosynthesis, pH regulation, etc) on calcitic element and isotope composition and 2) combine high-resolution multi-element and isotope analysis to simultaneously correct for these impacts. Since trace metals and isotopes are affected by multiple parameters, combining analyses not only makes reconstructions more robust, but also fundamentally more accurate.

## 二枚貝類原鰓亜綱における貝殻微細構造の進化 The evolution of shell microstructure of protobranch bivalves

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Molluscs are the second largest taxa and most of them have the shell of calcium carbonate. Molluscan shells are composed of the complex structural units that are called shell microstructures. Molluscs demonstrate a great variety of microstructures which are similar in phylogenetically close taxa. Thus, investigations of shell microstructures can provide clues for systematic and phylogenetic analyses of molluscs, including fossil taxa. Additionally, these trends suggest the possibility that the shell microstructure had a crucial role in the evolution of Mollusca.

The Protobranchia is an ancestral group of the Bivalvia and comprise four superfamilies (Nuculoidea, Nuculanoidea, Manzanelloidea, and Solemyoidea). However, the systematics of protobranch bivalves has been also problematic, because their simple external shell morphology can provide an insufficient number of informative characters. Therefore, Comprehensive investigation of the shell microstructure and molecular phylogenetic study of protobranch bivalves are required for understanding molluscan evolutionary history. The purpose of this study is to reveal the relationship between the shell micro-structure of protobranch bivalves and molecular phylogeny, and to discuss the evolution of the shell microstructures and their significance as novel morphological characters.

As the result of molecular phylogenetic analysis, it is revealed that the species of protobranch bivalves formed a distinct clade with long branches expect for one exception. One species of Sareptidae were included in Nuculanoidean clade while Sareptidae is placed within Nuculoidea in earlier systematics. SEM observation revealed that each of four superfamilies has a distinct trend in the composition of shell microstructures. And the results of the molecular phylogenetic analysis and the observation of the shell microstructure were consistent with each other. This condition indicates the shell microstructures of the Resent protobranch bivalves show a phylogenetic constraint. Nevertheless, previous study shows this trend is imperfect in fossil taxa. Some fossil nuculoids have nacreous structures and some fossil nuculids possess homogeneous structures. The foliated aragonite that resembles nacreous structure is known as the most primitive shell microstructure. Ancestral nacreous structure was first originated in the Paleozoic protobranch bivalves prior to any other structures that are found in protobranchs of younger ages. Thus, the absence of the nacreous structure may represent the secondary condition in protobranchs. However, the loss of nacreous might be unreasonable, because nacreous structure is considered to be the strongest shell microstructure. In further studies, the evolution of the shell microstructure of protobranchs should be discussed in terms of the habitats and the production costs of the shells as well as protective functions of shells.

Keywords: shell microstructure, mollusca, bivalve, protobranch

Tube mechanical properties and structural design of *Hydroides elegans* under multiple stressors  
Tube mechanical properties and structural design of *Hydroides elegans* under multiple stressors

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Most marine calcifiers construct robust calcareous skeletons or shells through biomineralization to protect themselves from predatory attacks. Due to increased anthropogenic emission of CO<sub>2</sub> in recent years, reduced global ocean pH and decreased carbonate concentration in seawater are expected to impede the CaCO<sub>3</sub> accretion in shell formation and produce a mechanically brittle shell structure. In addition, the effect of elevated pCO<sub>2</sub> level can act synergistically with temperature and salinity changes in seawater, further affecting the calcification process adversely. To investigate the combined effects of multiple environmental stressors on calcifying marine organisms, we studied the effects of pH (8.1 and 7.8), salinity (34 and 27 ‰), and temperature (23 °C and 29 °C) on the mechanical properties of the tubes built by the tubeworm, *Hydroides elegans*. By employing Micro-CT scanning and micro-force testing, information on tube topography and mechanical properties were analyzed using finite element analysis (FEA). Markedly, despite the structural deterioration observed in reducing pH and salinity, the level of elevated temperature counteracts these effects and even strengthen the overall mechanical properties. This may suggest that warming conditions in the early subtropical summer seawater may rescue the tapeworms from decreasing pH and salinity in the near future.

キーワード: calcifiers, biomineralization, stressors, Hydroides, tubeworm  
Keywords: calcifiers, biomineralization, stressors, Hydroides, tubeworm

## The mechanical consequence of ocean acidification - the application of finite element analysis

## The mechanical consequence of ocean acidification - the application of finite element analysis

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We studied the effects of low pH (near-future average pH 7.8) seawater on the structure and mechanical properties of the calcifying serpulid tubeworm, *Hydroides elegans*, compared to normal pH (current average pH 8.1).

We found that tubes produced at pH 7.8 altered tube ultrastructure, volume and density, and decreased the mean tube hardness and elasticity to a large extent by ~80% and ~70%, respectively. Specifically, mechanical properties of the outer and inner surfaces of the tube were curbed by pH 7.8, and the tube breaking force required to damage the tube was reduced by 64%.

Nano-indentation to spatially map the micromechanical properties of tubes built by the biofouling serpulid tubeworm, *Hydroides elegans*. The mechanical information was analyzed by computational model, finite element analysis (FEA). In order to study the details of strength properties of the shell, finite element analysis (FEA) was used to simulate the consequence of predatory attack in nature for both shells produced in the control and treatment seawater. The finite element analysis provided a reasonable answer to this phenomenon: altered mechanical properties shifted the stress development and distribution within the tubes and therefore resulting in mechanical weaker part of that were suffering from higher stress concentration.

キーワード: Hydroides, ultrastructure, tubeworm, calcifyer, mechanical properties

Keywords: Hydroides, ultrastructure, tubeworm, calcifyer, mechanical properties

## 異なる pH 環境下における有孔虫の石灰化可視化観察 Visualization approach on foraminiferal calcification under various pH

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Foraminifera, marine unicellular organism, have been thought as one of the major carbonate producer in ocean. Their calcareous tests are commonly utilized as paleo-environmental indicators in various studies of earth science because their tests have been archived as numerous fossil in sediment for long time and various environmental information are brought by population, morphology and geochemical fingerprints. The calcareous test itself is interested by many foraminifer scientists. The knowledge about the cytological process on carbonate precipitation has been described for couples of decade using by multi approaches. Foraminiferal regulations of calcium and carbonate ion uptake into calcareous tests from ambient seawater under different pH conditions are of great interest. Our previous studies showed the potential to understanding the biomineralization of foraminifera by the application of fluorescent indicators. Recently, we apply the method to show the spatial distributions of cytological calcium and pH in living cell at several pH conditions (7.5-8.1). Observed results show that foraminifera controls pH variation and concentration of calcium at even different environmental pH. These observations results will help to consider how the geochemical compositions arranging on the foraminiferal test, sensitivity of pH proxy of boron and others.



## 共焦点顕微鏡による共生大型有孔虫 *Amphisorus kudakajimensis* の細胞内形態と石灰化プロセスのライブ・イメージング Live confocal imaging of cytoplasmic structure and calcification processes in *Amphisorus kudakajimensis*

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有孔虫の殻形成メカニズムについては、これまで多くの研究報告がなされてきたが、細胞学的なアプローチの研究が不足している。有孔虫のバイオミネラリゼーションを理解するためには、ライブ・イメージング技術を応用させ、殻形成に必要なカルシウムイオンや石灰化に関わるタンパク質の挙動を明らかにすることで、バイオミネラリゼーションの全貌を明らかにする必要がある。本研究では共生大型有孔虫 *Amphisorus kudakajimensis* を用いたライブ・イメージングを行い、有孔虫の細胞に様々な細胞透過型の蛍光プローブの導入に成功した。これにより基本的な細胞内形態の可視化とともに、細胞内カルシウムイメージング法と薬理学的手法を併用することで、有孔虫の細胞内におけるカルシウムイオンの挙動を把握することができた。また、細胞膜不透過型の pH 指示薬 (HPTS) を用いることで、殻形成が行われる場である有機基質基盤 (Organic template) のアルカリ化 (pH 9.0) と、糸状細胞の特定領域における酸性化 (pH 6.0) を可視化することができた。

キーワード: 石灰化, カルシウムイメージング, ライブセル・イメージング, 共焦点顕微鏡  
Keywords: calcification, calcium imaging, Live-cell imaging, confocal microscopy

Internal pH distribution and post-metamorphic biomineralization in the tubeworm, *Hydroides elegans*  
Internal pH distribution and post-metamorphic biomineralization in the tubeworm, *Hydroides elegans*

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The serpulid tubeworms produce a diverse tube structure through controlled calcification. Cellular environment associated with actively calcifying serpulid tubeworms at metamorphosis were studied using pH and calcium sensitive indicators. With a notable degree of compartmentation, the thoracic region between the collars showed a high pH value above 8.5 and elevated calcium ion levels. As suggested by SEM-EDX results, such region also demonstrated a higher Ca signal. To analyze the presence of crystalline CaCO<sub>3</sub>, the unpolished sample was characterized using SEM-EBSD at 20kV, this low voltage and non-destructive approach showed the direct formation of aragonite. Applying in situ lift-out technique at the calcified region, TEM specimen was prepared for structural analysis using selected area diffraction pattern. This study documents the cellular environment during the first calcification event in the serpulid tubeworm at the transition of metamorphosis and the subsequent aragonite formation.

キーワード: imaging, serpulid tubeworms, visualization, calcifyer, biomineralization

Keywords: imaging, serpulid tubeworms, visualization, calcifyer, biomineralization

## オウムガイ可溶性貝殻タンパク質のゲノム解析：軟体動物における生体鉱物の進化史解明へ

### Genomic Exploration of the Nautilus' Shell Matrix Hydrophilic Proteins: An Insight To Their Evolution in Mollusks

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The presence of a calcium-carbonate-based shell is a defining feature of most members of Mollusca. Thus, research on the genomic aspects of biomineralization of this group is interesting, since the resulting knowledge can be useful for understanding their evolutionary success. Interestingly, most members of cephalopods have secondarily lost their external mineralized shells. The nautiloids, however, is one of the two extant cephalopod groups still maintaining their true shells. Phylogenetically, the nautiloids had diverged from the ancestors of non-shelled, extant cephalopods (Neocoleoidea) in the mid-Paleozoic (Silurian/Devonian boundary,  $\pm 416$ MYA), older than the split between ammonoids and neocoleoids. This makes studies on nautiloid shell biomineral-proteins important and interesting, since insights from the nautiloids might shed light on how shell internalization and de-mineralization events evolved in cephalopods, while at the same time, might help to elucidate the evolution and identification of core components of mollusk shell biomineralization proteins, through comparisons with other molluscan biomineral-related protein data. In this talk, we are reporting our result of the genomic explorations to identify biomineralization-related proteins in the nautiloid *Nautilus pompilius*. To do so in our research, we first determined the total transcriptome sequences from the mantle tissue using pyrosequencing, while simultaneously did a total proteome analysis of the shell's hydrophilic proteins by orbital-trap mass-spectrometry. We then conducted a transcriptome-proteome comparative analysis in order to identify the hydrophilic components of shell biomineral-related proteins in the Nautilus, where we identified 51 distinct shell specific EST/proteins sequences. In the talk, we are also going to discuss how the findings provide an insight to the study of the evolution of mollusk shell biomineralization.

キーワード: 貝殻タンパク質, オウムガイ, トランスクリプトーム, プロテオーム, バイオミネラリゼーション  
Keywords: Shell matrix protein, Nautilus, Transcriptome, Proteome, Biomineralization

## 地球化学とゲノム生物学を繋げるためのコユビミドリイシサンゴを使った研究 Using *Acropora digitifera* to bridge the gap between genome biology and geochemistry

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Coral's calcification mechanism has been receiving great attention in the fields of both geochemistry and biology. In geochemistry, high-resolution proxies using coral skeletal elements have been developed to reconstruct climate history (Gagan et al, 2012). In parallel, coral genomes have been sequenced progressively. However, trials that connect these two different fields of studies focusing on coral calcification have not been conducted yet. In this study, we focused on *Acropora digitifera* as the target species because enough genomic information is available (Shinzato, 2011) and its potential as geochemical proxies (Inoue, 2011). First, using ZoophyteBase, which has been recently developed as coral's proteome database (Dunlap et al, 2013), we investigated the genes that are potentially related to metabolism using inorganic minerals in seawater and analyzed their gene components and the correlations with seawater chemistry. Second, using next-generation sequencing, we are currently comparing *Acropora digitifera*'s gene expression between fast and slow calcification lineages of this species. In addition, coral skeletal elements of these materials have been analyzed by ICP-AES. In this presentation, we report the progress of these analyses focusing on calcification related genes and skeletal elements.

References: [1] Dunlap et al, 2013. BMC Genomics. DOI: 10.1029/2011PA002215 [2] Gagan, et al, 2012. Paleoceanography. DOI: 10.1029/2011PA002215 [3] Inoue et al, 2011. Geophysical Research Letters. DOI: 10.1029/2011GL047786 [4] Shinzato et al, 2011. Nature. DOI:10.1038/nature10249

Keywords: *Acropora digitifera*, Calcification, Gene, Skeletal elements

## 腕足動物における殻体タンパク質の網羅的同定 Comprehensive identification of shell matrix proteins in brachiopods

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Brachiopods are marine invertebrates that appeared in the Cambrian, and they have two shells like bivalves composed of calcium carbonate or calcium phosphate. Shells contain organic matrix, which have important roles in the biomineralization processes. Recently, many shell matrix proteins in molluscs have been identified, and their roles in shell formation have been discussed. On the other hand, shell matrix proteins in brachiopods have not been identified, except for partial amino acid sequences of a chromoprotein, named ICP-1. In this study, we performed comprehensive identification of shell matrix proteins of the brachiopod *Laqueus rubellus* using proteomics combined with transcriptomics. As a result, we identified a total of 18 shell matrix proteins. BlastP search showed that these proteins have no homologues in skeletal proteins identified from other phylum, suggesting that brachiopod and mollusc shells are different in origin.

## 殻タンパクのアミノ酸の窒素同位体比の有用性 Utility of nitrogen isotopic composition of amino acids in shell protein

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Stable isotopic composition of sedimentary organic nitrogen has been employed as a proxy to understand biogeochemical nitrogen cycles in marine and lacustrine environments. However, modification of the isotopic signals during early diagenesis (including heterotrophic assimilation/disassimilation, recycling, and reproduction) in water column and sediments always leads to much uncertainty on the interpretation of bulk isotope data. Recently, we found that a proteinogenic amino acid, phenylalanine, shows little change in the nitrogen isotopic composition during heterotrophic degradation even in long-length grazing food webs, whereas the other proteinogenic amino acid, glutamic acid, shows significant <sup>15</sup>N-enrichment at each step of food webs. Moreover, the isotopic signals of these amino acids in shell protein are always identical to those of biomass protein (e.g., muscle tissue) when the shell was produced. These results imply that the nitrogen isotopic composition of phenylalanine and glutamic acids from shell protein (e.g., in microfossils of foraminifera) captures (1) primary isotopic signals of organic nitrogen in the environment where the shell was produced and (2) trophic position of the shell-owner in ecosystems when the shell was produced.

In the presentation, we will show comparative data sets on the isotopic composition of amino acids between muscle and shell protein from various organisms, and discuss its applicability as a proxy to estimate the primary isotopic signals in environments and the trophic position of organisms of interest.

キーワード: アミノ酸, 窒素同位体, 食物連鎖

Keywords: amino acid, nitrogen isotope, food web

## カリブ海のサンゴ骨格に記録される北大西洋の窒素固定量の変動 Variation of North Atlantic nitrogen fixation in Caribbean coral skeletons

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Oceanic nitrogen fixation is important as new nitrogen in oligotrophic oceans and balances with denitrification in global nitrogen cycle controlling primary production. North Atlantic ocean is known to have higher nitrogen fixation rates, although the controlling factors have been debated by modern observations and sediment cores in geological time scales. Reef corals have been widely used as paleo-environmental proxy in oligotrophic oceans. Recent studies suggested that nitrogen isotopes of organic matter preserved in coral skeletons  $\delta^{15}\text{N}_{\text{coral}}$  have the potential to record coral nitrogen sources on decadal to millennia scale. In this study, we report recent 90-year records of nitrogen isotopes in *Diploria* sp. coral cores from Cayman Islands.  $\delta^{15}\text{N}_{\text{coral}}$  values were  $+1.9 \pm 2.6$  ( $\sigma$ ) ‰ (n=139), which suggested that the variation of  $\delta^{15}\text{N}_{\text{coral}}$  was controlled by nitrogen fixation ( $\sim 0$  ‰) in ambient seawater. The trend line of  $\delta^{15}\text{N}_{\text{coral}}$  increased  $\sim 4$  ‰ from 1920s to 2010s. This result suggests that nitrogen fixation rate in Caribbean Sea decreased during the past 90 years. Detrended  $\delta^{15}\text{N}_{\text{coral}}$  showed a negative correlation between Atlantic Multi-decadal Oscillation (AMO) index ( $R=-0.71$ ,  $P \ll 0.001$ ), which suggested that nitrogen fixation rate increased in higher SST condition leading an index for hurricane activity on multi-decadal scales. In this presentation, we discuss the relationship between nitrogen fixation and hurricane activity in global warming state.

Keywords: Coral skeletons, nitrogen isotopes, nitrogen fixation, Caribbean Sea, North Atlantic Ocean

## クロロフィル蛍光法を用いた浮遊性有孔虫の光共生生態の探究：生態指標確立に向けて

### Fluorometric analysis of photosymbiosis: Toward quantitative validation of ecological proxy of planktic foraminifers

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Endosymbiosis of planktic foraminifers with photosynthetic algae (photosymbiosis) is established especially among species which dominate in warm, low-nutrient surface water. Here, photosymbiosis probably plays an important role for host foraminifers, and can be considered as an adaptive ecology to live in such oligotrophic oceans. Therefore, back in geologic time, photosymbiosis could have been involved with species adaptive radiation as well. In such viewpoint, stable isotopic change of foraminiferal test through ontogeny, attributed to change of symbiont photosynthetic effect, has been used as an indicator to detect fossil photosymbiosis. However, how host-symbiont association change through ontogeny, if any, is practically unknown and has never been quantified. Here, we offer new insights for photosymbiosis based on photosynthetic characteristics of symbionts, obtained by in vivo fluorometric analysis (Fast Repetition Rate Fluorometry, FRRF).

We cultured two symbiont-bearing species, *Globigerinoides sacculifer* and *Globigerinella siphonifera*, and conducted FRRF measurement on individual host-algal consortium during the culture period. FRRF can identify photosymbiosis of individual foraminifer instantly in a non-destructive manner, and gives us various photosynthetic characteristics of symbionts, i.e., maximum fluorescence yield ( $F_m$ , index of chlorophyll content), photochemical efficiency ( $F_v/F_m$ , index of potential photosynthetic activity), and effective absorption cross-section of photosystem II ( $\sigma_{PSII}$ , capability of the absorbed energy to promote a photochemical reaction).

Sequential FRRF analyses on single individuals revealed that  $F_m$  increases with growth, and then decrease drastically at the end of their life, which means that the algal biomass per individual foraminifer increases through ontogeny, but the symbionts are rapidly digested at the end.  $F_v/F_m$  and  $\sigma_{PSII}$  values were constant through ontogeny, though  $F_v/F_m$  drops in correspondence with the decrease of  $F_m$ . Compared between the two species, average values of both  $F_v/F_m$  and  $\sigma_{PSII}$  showed statistically significant differences.  $F_v/F_m$  was significantly higher in *Gs. sacculifer*, which means that symbionts are more actively photosynthesizing in *Gs. sacculifer*. Because  $F_v/F_m$  is mainly depends on nutrient availability, it is a direct evidence of nutrient (metabolite) flow from host to symbionts. On the other hand,  $\sigma_{PSII}$  was higher in *Gn. siphonifera*, indicating that this species can utilize low light energy more efficiently, i.e., more " low-light-adapted " than *Gs. sacculifer*. Actually, it is consistent with inferred habitat preference of *Gn. siphonifera*, which is relatively deeper than *Gs. sacculifer*.

These FRRF results provide us information of foraminiferal photosymbiosis both quantitatively and qualitatively. When the information is combined with test geochemistry mentioned above, it will presumably enable us to quantify the photosynthetic activity from foraminiferal tests. Then, it can be applied to fossil specimens as a validated ecological proxy of photosymbiosis.

キーワード: 浮遊性有孔虫, 光共生生態, 高速フラッシュ励起蛍光法

Keywords: planktic foraminifers, photosymbiosis, Fast Repetition Rate Fluorometry



## コユビミドリイシ初期ポリプ骨格の酸素・炭素同位体比 Skeletal isotope compositions of *Acropora* coral primary polyps experimentally cultured at different temperatures

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We investigated temperature and growth-rate dependency of skeletal oxygen and carbon isotopes in primary polyps of *Acropora digitifera* (Scleractinia: Acroporidae) by culturing them at 20, 23, 27, or 31 °C. We cultured primary polyps of *A. digitifera* at Sesoko Station, University of the Ryukyus, Motobu, Okinawa Prefecture, Japan for 10 days. From the results of the polyp weight and polyp area, calcification was most rapid at 27 and 31 °C. The  $\delta^{18}\text{O}$  — temperature relationship ( $-0.18\text{‰}/\text{°C}$ ) is consistent with reported ranges for *Porites*, indicating that juvenile *Acropora* polyps can be used for paleotemperature reconstruction. We found a gap between curves for the experimental polyps and the equilibrium curves for inorganic aragonite of about 3.0 ‰ for  $\delta^{18}\text{O}$  and 8.0 ‰ for  $\delta^{13}\text{C}$ , with the primary polyp values being lower than the equilibrium values of inorganic aragonite. The kinetic isotope effect was evident in the polyps cultured at low temperature but disappeared at high temperatures, despite relatively low light levels. The estimated upper calcification flux limit for a kinetic isotope effect ( $\sim 0.4 - 0.7\text{ g CaCO}_3/\text{cm}^2\cdot\text{y}$ ) was similar to that of *Porites* colonies with a linear extension rate of  $<5\text{ mm/y}$ , suggesting that the calcification flux may be used as a measure of kinetic isotope effect dominance in different genera at different growth stages.

キーワード: coral, temperature, stable isotopes, polyp, kinetic effect  
Keywords: coral, temperature, stable isotopes, polyp, kinetic effect

## 薩摩硫黄島のサンゴ：火山性熱水活動の新たな指標と生物適応 Corals at marine volcano of Satsuma iwo-jima: Implication for a new proxy of hydrothermal events and biological adaptati

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Coral cores from massive corals could record marine environmental and ecological changes in their annual bands with monthly temporal resolution in the present and/or the past. We discovered large massive *Porites* corals living at active volcanic island of Satsuma Io-Jima, located 50 km south from Kyushu area, southern part of Japan. Satsuma Io-Jima provides a unique opportunity to observe marine organism living under extreme environments of volcanic gases emission and different types of hydrothermal activities from sea flower. We collected eleven coral cores from four different conditions around the island to test if corals could record volcanic and hydrothermal activities and how corals could survive in extreme environments such as very low pH condition with CO<sub>2</sub> emission. Coral annual bands recorded in x-ray images revealed that these corals have been survived at least during last a few hundreds years. Coral extension rate for the site near hydrothermal vent was significantly small (1-2mm/year) relative to that for general condition of *Porites* corals (ca. 10-20 mm/year), suggesting that coral growth was influenced by hydrothermal activity. We will demonstrate our preliminary results of geochemical approaches of  $\delta^{18}\text{O}$ ,  $\delta^{13}\text{C}$ , Sr/Ca, Mg/Ca, Ba/Ca, and F/Ca in coral skeletons and in surrounding seawater and discuss the possibility for reconstructing the past hydrothermal events and relationship between marine ecosystem and extreme environments at volcanic activity as the analogues for coral adaptation to future ocean acidification.

キーワード: サンゴ骨格, 熱水活動, サンゴ生物適応, 海洋酸性化

Keywords: Coral geochemistry, hydrothermal activity, coral adaptation, ocean acidification

有孔虫プロキシーと堆積物生態系動態  
Sediment ecosystems dynamics on proxies development of foraminifera

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堆積物生態系動態が有孔虫の環境プロキシー形成に与える影響を議論する

キーワード: 堆積物生態系, 動態, 深海有孔虫, 環境プロキシー  
Keywords: Sediment ecosystems, dynamics, deep-sea foraminifera, environmental proxies

Benthic Foraminifera from the deep-water Niger delta (Gulf of Guinea): Assessing activity of hydrate pockmark  
Benthic Foraminifera from the deep-water Niger delta (Gulf of Guinea): Assessing activity of hydrate pockmark

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We present an ecological study of foraminifera from 4 deep-sea stations sampled in a pockmark field from the deep-water Niger delta (Gulf of Guinea, Equatorial Atlantic Ocean). All stations are located very close to each other (less than 1.2 km distance). Both sites GMMC-01 and GMMC-02 settle in an active pockmark where methane seepages were recorded by ROV observations. A third station (GMMC-03) is located in a topographic depression which is interpreted as a collapsed pockmark where no gas seepage takes place. The site GMMC-04 is a reference station, without past or present seepages. The main objective of this study is to define whether fossilizing benthic foraminifera are reliable and relevant proxies to detect gas emission in relation to hydrocarbon resources. We focus on living (stained) and dead individuals from present environments, and combine our observations with an outstanding analysis of stable isotopes ( $\delta^{13}\text{C}$ ,  $\delta^{18}\text{O}$ ) in tests of living and dead foraminifera. Our observations show that degraded organic matter with low bio-availability is present at all stations with a preferential burial of organic compounds in topographic depression (GMMC-03 station). Mudclast breccias cemented by authigenic carbonates (mainly aragonite) are recorded at both station of active pockmark (GMMC-01 and -02). There, prokaryotic consortia involved in both sulphur and methane cycles underline that both sulphide production and methane oxidation take place in the sediment close to sediment-water interface. Compared to the reference site GMMC-04, living foraminifera recorded at active and inactive pockmark show only minor changes in terms of diversity, standing stocks and faunal composition. However, the  $\delta^{13}\text{C}$  signal of some living and dead (but well-preserved) foraminiferal species (*Ceratobulimina contraria*, *Melonis barleeanus*, *Uvigerina peregrina*) is moderately depleted in active pockmark compared to both other stations. This depletion may be related to (1) a discrete geochemical imprint of anaerobic methane oxidation in upper sediments and (2) a potential effect of prokaryotic  $^{13}\text{C}$ -depleted biomass as a potential food source for benthic foraminifera. Overgrowth of authigenic carbonate on badly preserved foraminifera generates an important shift to lower  $\delta^{13}\text{C}$  values. Whereas living faunas reflect "snapshot" environmental conditions at the sampling period (November 2011) when seepages were likely discrete, dead faunas (modern thanatoconosis) carry a reliable message integrating temporal variability of gas emission. They reveal major faunal differences that are quite reliable to detect gas hydrate seepages in different pockmark stages with some key-species (i.e., *Bulimina marginata*, *Bolivina albatrossi*) underlining periods of enhanced methane emission and pockmark collapsing.

**Potentials and challenges on the use of environmental DNA to reconstruct deep-sea ecosystem and environmental changes.**  
**Potentials and challenges on the use of environmental DNA to reconstruct deep-sea ecosystem and environmental changes.**

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Deep sea is one of the most difficult to access environment, and consequently one of the most poorly known. However, deep-sea sediments and the organisms inhabiting this environment play a crucial role in the oceans geochemical cycles. Benthic communities are often well adapted to their local environment and therefore can reflect accurately the present conditions but also can provide insights into the past history of environmental changes. Unfortunately, except for a few specific taxa, most knowledge on deep-sea biodiversity is still missing. Deep-sea fauna is very patchy and rarity of most taxa adds to the sampling difficulty using traditional methods. Environmental DNA (eDNA) presents the advantage not to rely only on living organisms present in the sample. The presence of a species in an environment can also be detected using trace DNA left by the organism in the sediments (fragment of dead organisms, fecal pellets, etc). Recent development of DNA sequencing technologies led to promising results in the large-scale exploration of biodiversity from deep-sea environments based on eDNA using environmental DNA.

Here we will examine the use of environmental DNA as a proxy to reconstruct deep-sea communities and estimate environmental conditions in the deep-sea ecosystem. We will present data obtained from deep-sea (500-9000 m) around Japan as well as from worldwide deep-sea oceans to explore the potential use of eDNA as a proxy at various geographical and historical scales and levels of resolution. The data obtained from Iheya North vent field in the Okinawa Trough allowed us to compare the signal of eDNA along extreme environmental gradients at a very restricted geographical scale, while worldwide deep-sea eDNA survey provided us with information of on the global deep-sea environment history and colonisation. Potential of eDNA obtained from sediments to obtain information on water column processes such as plankton blooms will also be discussed.

キーワード: Deep Sea, Environmental DNA, Biodiversity, Sediment, Hydrothermal vent  
Keywords: Deep Sea, Environmental DNA, Biodiversity, Sediment, Hydrothermal vent

## 相模湾・初島沖海底における酸素分布の長時間時系列観測 Long term monitoring of oxygen distributions at sea floor, Sagami bay, Japan.

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堆積物-水境界における酸素濃度は、物理、化学的、そして生物活動によって常に変動している。とりわけ底生生物によって引き起こされるバイオターベーションやバイオイリゲーションは、海底へ拡散によって浸透するよりも多くの酸素を供給するため、堆積物表層部を酸化環境に維持に重要な役割を担っている。では、実際の深海底において、酸素と生物はどのような関わりがあるのか？ この疑問に答えるためには、酸素センサやカメラを現場に持ち込み、時系列観測する必要がある。しかしながら、航海の機会に限られること、水圧という厄介な存在によって、なかなか測定を行うことは出来なかった。そこで、酸素によって消光を起こす蛍光色素を用いた「二次元酸素プロトド」という酸素濃度を可視化するセンサを開発し、これを海底に持ち込んで堆積物-水境界の酸素プロファイルの時系列観測した。センサに使用する蛍光色素には感度の高いものを選び、酸素極小層（ $\sim 50\mu\text{M}$ ）での測定に最適化した。場所は相模湾・初島沖の水深 1170m、観測期間は 2008 年 1 月 21 日から 31 日、測定は一時間間隔で自動的に行い、必要となる電源は初島観測ステーションから供給した。この結果、245 枚の酸素濃度プロファイルと、海底断面のモノクロ画像をそれぞれ得た。これらの画像を解析した結果、以下の現象を確認した。(1) 酸素が浸透する深さは 5~8mm であった。(2) 小さなゴカイによる活動により、巣穴の付近にはより多くの酸素が供給された。その場所では、酸素が検出される深さは~10mm に達した。(3) 堆積物中・あるいは直上の酸素濃度は時間によって変動した。(4) 堆積物直上の水中の酸素濃度は、微地形や流れの影響を受け変動した。(5) 酸素が検出されない深さで、メイオベントスが活動していることを確認した。本発表では、以上の結果を酸素濃度プロファイルとともに紹介する。

キーワード: 堆積物-水境界, 酸素, オプトド, メイオベントス

Keywords: sediment-water interface, oxygen, optode, meiobenthos

## 造礁性サンゴ骨格の結晶組織が示す aragonite と halite の共沈 New evidence for halite co-precipitation during coral calcification

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In the last JpGU Meeting, we reported halite grains in coral skeleton through the observation of massive coral skeleton of *Porites lobata* by Analysis Transmission Electron Microscope (ATEM). Each halite grain typically shows a square shape and its grain size is around 80 nm. The spatial distribution of halite grains is inhomogeneous and seems to be independent on the arrangement of growth lines.

We observed new evidence that the halite grains in coral skeleton could precipitate during coral calcification. The electron diffraction patterns from some selected areas including both an aragonite and a halite grain show that there are special crystallographic orientation relationships between them. In consideration of misfit ratios between some selective bond lengths of halite and those of aragonite, crystallographic orientations of halite and aragonite seem to be a kind of hetero-epitaxial relationship.

This is the first observation for a primary precipitated mineral phase other than aragonite in coral skeletons. The halite phase in coral skeleton will provide a new perception for understanding the process of coral calcification.

Keywords: reef-building coral, calcification, biomineral, aragonite

## サンゴのホウ素同位体組成から復元された20世紀半ば以降の北西太平洋熱帯域のpH変動 Ocean acidification in the tropical Northwest Pacific since the mid-20th century reconstructed from coral boron isotope

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Ocean acidification has been accelerating as a result of absorption of increasing anthropogenic CO<sub>2</sub> in the atmosphere emitted by fossil-fuel combustion and land-use practices since the Industrial Revolution, which can be resulting in decreased surface ocean pH and posing a critical threat to marine ecosystems (e.g., Sabine et al., 2004; Orr et al., 2005). By the end of the 21st century, predictions based on different scenarios indicate that ocean pH will decrease by 0.3-0.4 pH units. Only a few long-term continuous observations of sea surface pH have been derived from Station ALOHA off the Hawaiian Islands in the North Pacific, near the Bermuda Islands, and near the Canary Islands in the North Atlantic. A decreasing pH trend in the western North Pacific surface waters for 1983-2007 was estimated from the observational data of oceanic CO<sub>2</sub> partial pressure and related properties (Midorikawa et al., 2010). To elucidate the natural variability of ocean pH and assess the actual trend in ocean acidification more accurately, we must go further back in time. For these reasons, we rely on paleo-pH archives or other related parameters.

Massive corals, an informative archive of past ocean environments, precipitate annually banded calcium carbonate skeletons at a relatively rapid rate (about 1 cm per year), allowing for accurate chronological control and high-resolution sampling. Because of pH-dependent isotopic fractionation between the two dominant boron species in seawater, boron-isotopic systematics in marine carbonates provide a potential proxy for ocean pH in the past (e.g., Hemming and Hanson, 1992). Nevertheless, only two previous investigations provided boron-isotope time series from long-lived corals from the Great Barrier Reef in the South Pacific for the last 300 years. Unlike seawater temperature and salinity records (Asami et al., 2005; Felis et al., 2009), no coral-based reconstruction of long-term pH variation in the North Pacific has been reported.

Here, we generated an annually resolved 60-year-long (1940-1999 A.D.) record of seawater pH from boron isotope composition in a *Porites* coral collected in Guam Island, located in the Western Pacific Warm Pool which contains the highest annual sea surface waters and serves as a heat engine for the earth climate. The first long-term continuous boron isotope-pH proxy record in the North Pacific from the coral provides evidence of a slight ocean acidification trend (equivalent to 0.05-0.08 pH units for surface water) since the mid-20th century, although the critical factors that affect interannual variability remain unknown (Shinjo et al., 2013). From this perspective, the results of this study will provide improved constraints on global atmosphere-ocean interaction models and understanding of the future coral reef ecosystems.

キーワード: サンゴ骨格, ホウ素同位体組成, pH, 海洋酸性化, 北太平洋

Keywords: coral skeleton, boron isotope composition, pH, ocean acidification, North Pacific



## 有孔虫細胞軟組織の NanoSIMS による窒素同位体比マッピング 15N/14N mapping of the isotope labeling cultured foraminifera using ultra thin section

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Shallow water benthic foraminifera, *Ammonia beccarii*, survive under anoxic conditions in conjunction with possible endobionts. Based on the amino acid analysis, those endobionts are expected to utilize nitrate pool in the foraminifera. However, nitrogen cycles in the foraminiferal cell and endobionts are still unclear. Here, we obtained two dimensional-nitrogen isotopic compositions of *A. beccarii* which had been incubated under oxic and anoxic conditions with <sup>15</sup>N-labeled nitrate. After observing with transmission electron microscope to confirm cellular ultrastructure and endobiont distribution, same ultra thin section was examined for nitrogen isotopic composition analysis using secondary ion mass spectrometer. Nitrogen isotopic compositions were measured with spatial resolution better than 400 nm. <sup>15</sup>N-enriched parts were found in certain structures in the cell, but not in the endobionts in this experiment.

キーワード: 底生有孔虫, 硝酸塩呼吸, 共生微生物, 高分解能二次イオン質量分析装置

Keywords: Benthic foraminifera, nitrate respiration, symbiotic microbe, NanoSIMS

## Snowball Earth and GCM simulation Snowball Earth and GCM simulation

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Numerical simulation of snowball Earth, using out-of-date supercomputer program has been performed recently in USA, France and Germany. It seems to be difficult to reconstruct Snowball state by their simulation, while freezing more than 55% of ocean. If continents are gathered along the equatorial region such as Rodinia in the case of Sturtian and Marinoan Snowball Earth in Neoproterozoic, total surface irradiance (TSI) seems plausible to be 95% of present day and CO<sub>2</sub> level as same as today. However, if the atmospheric CO<sub>2</sub> is 2-6 times more than today, Snowball state cannot appear (Voigt et al., 2011). More realistic CO<sub>2</sub> concentration of Neoproterozoic Earth was 20-50 times more than today. In addition, the temperature fluctuation of Snowball Earth period, from Sturtian to Marinoan, was -40 °C to +40 °C and vice versa within a short period <10 m.y. which seem to be impossible because input and output of CO<sub>2</sub> by plate tectonics usually takes time more than several hundreds of millions years.

GCM simulation exaggerates positive feedback of CO<sub>2</sub> too much. It is time to remodel GCM, considering the amount of clouds and its effect.

## 原生代・顕生代での氷期における炭素循環変動 Glaciation carbon cycle in Neopaleozoic and Phanerozoic by numerical carbon cycle box model to fix carbon isotope ratio

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In Ediacaran period, some environmental changes are proposed (e.g. Oxidation, nutrient and carbon cycle) before the Cambrian explosion and macroscopic multicellular metazoan first appeared and their sizes became drastically large. It suggests that carbon cycle in ocean changes in Ediacaran period. Therefore, we assumed box model that there were two carbon reservoirs in Ocean and fluxes are taken as the first order reaction of each reservoir (Rothman et al., 2003; Ishikawa et al., 2012). Thus, we could estimate both  $\delta^{13}C_{carb}$  and  $\delta^{13}C_{org}$  by changes of parameters to trace analyzed  $\delta^{13}C_{carb}$  and  $\delta^{13}C_{org}$  curves from drilling core samples in Three Gorges through the Ediacaran to the early Cambrian (Tahata et al., 2012; Kikumoto et al., 2013; Ishikawa et al., 2012). The  $\delta^{13}C_{carb}$  in Three Gorges shows negative excursions in Gaskiers glaciation (ca. 580 Ma), Shuram excursion (ca. 570-550 Ma) and Precambrian/Cambrian boundary (ca. 542 Ma). On the other hand, the  $\delta^{13}C_{org}$  in Three Gorges show constant ca. -30 per mill in early Ediacaran and correlation to  $\delta^{13}C_{carb}$  after Shuram excursion.

The parameter sets suggested carbon cycle changes in Ediacaran period. This Reconstructed Three Gorges carbon cycle quantitatively estimated carbon cycle changes in these periods. The results indicate the rate of remineralization need to increase before the Shuram excursion and the rate of organic carbon burial increase to ca. 100 times in the late stage of Shuram excursion. The increase of remineralization might indicate step-by-step changes of dominant metabolism from anaerobic respiration to aerobic respiration. In addition, the change of organic carbon burial is possibly consistent with the first appearance of mobile metazoan and zooplankton.

The parameters in early Ediacaran apply to carbon cycle in Marinoan glaciation before Ediacaran period. On the other hand, parameters in modern Ocean apply to carbon cycle in P-T boundary. It has possibility that there is glaciation in P-T boundary. The DOC reservoir size differed in Marinoan and P-T boundary. The different DOC reservoir size cause different carbon isotope changes in Marinoan glaciation and P-T boundary.

Keywords: Glaciation, Carbon cycle, Ediacaran, Marinoan, Phanerozoic

中国南部のエディアカラ系炭酸塩岩に見られる天水続成の証拠とガスキエス氷期での陸上露出  
Evidence for meteoric diagenesis during Gaskiers glaciation recorded in the Ediacaran carbonate in South China

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炭素同位体比は大気・海洋の環境変化を反映して汎世界的に変動する。中でも地球史を通じて複数回生じた無機炭素同位体のエクスカージョンは、生物の進化や絶滅などのイベントと同調しているため、その原因が活発に研究されている (e.g. Grotzinger et al., 2011). 多細胞動物が大きく進化したエディアカラ紀 (635-542 Ma) においても、少なくとも2回の負のエクスカージョンが記録されている (Fike et al., 2006; Sawaki et al., 2010). 南中国に分布するエディアカラ系堆積岩である揚子プラットフォームは変成度が低く、解像度の高い無機炭素同位体比プロファイルが多く報告されている (e.g. Jiang et al., 2011). これらは負のエクスカージョンを引き起こしたエディアカラ紀の特異的な古海洋環境と海洋酸化の影響を反映していると考えられるが、その原因は十分に解明されていない。そこで本研究では、約20パーミルに達する無機炭素同位体値 (全岩) の変動幅が記録される (e.g. Kunimitsu et al., 2011) 湖南省北西部 Yangjiaping セクションについて、ストロンチウム同位体及びセメント部分の無機炭素・酸素同位体を測定し、その原因を探るとともに古環境について考察した。

Yangjiaping セクションは層厚約470mで、下位から水礫岩で構成される Nantuo 層、炭酸塩岩・黒色頁岩・リン酸塩岩・チャートで構成される Doushantuo 層、炭酸塩岩とチャートで構成される Dengying 層の順に露出する。Kunimitsu et al. (2011) は、全岩の無機炭素同位体変動に基づき Doushantuo 層を下位から Unit 1-Unit 3 に区分しており、変動幅の大きな無機炭素同位体変動は Unit 3 に記録される。Unit 2 上部?Unit 3 および Dengying 層の粗粒炭酸塩岩試料についてカソードルミネッセンス法を用いて形成順序を調べ、各段階の無機炭素・酸素同位体値を測定したところ、Unit 2 上部-Unit 3 下部および Dengying 層では、全岩とセメント部分の無機炭素・酸素同位体値に大きな差は見られなかったが、Unit 3 中部?上部にかけてセメントの無機炭素同位体が25パーミル、酸素同位体が7パーミル程度の全岩の値より低いことが分かった。また、ストロンチウム同位体値は0.7079-0.7105をとり、Unit 3 と Dengying 層中部-上部にかけて値の上昇が見られた。

セメント部分の無機炭素・酸素同位体分析から、Yangjiaping セクションの Doushantuo 層 Unit 3 に見られる全岩の無機炭素同位体変動は、天水続成の影響を受けてきた二次的な同位体値の付加によるものである。Unit 2 上部-Unit 3 における炭酸塩岩の岩相は極浅海の環境を示しており、海水準低下により堆積場は陸上に露出したと思われる。この時、粒子間に存在していた有機物は酸素に富む天水続成環境で酸化され、続成水の炭素同位体比を著しく低下させた。また Unit 3 におけるストロンチウム同位体の上昇傾向は陸源フラックスの増加を示しており、その原因はエディアカラ紀中頃 (580 Ma) に起きたガスキエス氷期にともなう大陸風化の強化である可能性が高い。本研究の分析結果から、ガスキエス氷期が起きた時期の揚子プラットフォームの極浅海域は陸上に露出したことが判明した。

キーワード: 南中国, エディアカラ系, 天水続成, ガスキエス氷期, 炭素同位体  
Keywords: South China, Ediacaran, meteoric diagenesis, the Gaskiers glaciation, carbon isotope

## 南中国三峡地域の前期カンブリア紀の地層の窒素同位体比変動 Nitrogen isotope chemostratigraphy of the Early Cambrian platform sequence at Three Gorges, South China

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地球は唯一高等生物が存在する天体である。そこで、高等生命につながる後生動物出現と進化は地球・生命進化の解明においてもっとも重要な問題であるが、その原因は未だ解明されていない。私たちは、後生動物の出現と初期進化の原因を解明するために、南中国でエディアカラ紀からカンブリア紀の地層の掘削と化学層序の一連の研究を系統的に行ってきた。その結果、海洋中の生命必須元素の変化は後生動物進化に大きな影響を与えたことが分かってきた。そこで、本研究では、生命必須元素のなかでも、特に重要な海洋栄養塩である窒素に着目し、カンブリア紀初期の海洋硝酸塩濃度の変動を解読し、その変動を復元した。

南中国には、エディアカラ紀からカンブリア紀の地層が保存良く存在しており、その地層の研究は当時の表層環境を解読するのに適す。また、三峡地域は当時の大陸棚内の浅海に位置していたと考えられている。

Kikumoto et al.(2014) は炭酸塩岩や黒色頁岩中の炭質物中の有機窒素の窒素同位体比を分析し、エディアカラ紀前期から中期までは窒素同位体比が高く、中期からカンブリア紀最初期は低く、初期カンブリア紀中期以降に再び高くなるという変動を得た。その変動から海洋中の硝酸濃度の変動を復元し、エディアカラ前期?中期までの海洋中の硝酸濃度は枯渇していたが、エディアカラ紀中期からカンブリア紀最初期に富み、初期カンブリア紀中期後に、再び枯渇したと提唱した。一方、海洋中のリン濃度はエディアカラ紀前期では高く、エディアカラ紀中期以降に減少する。エディアカラ紀前期から中期までは海洋のリン濃度と硝酸濃度には相関が見られ、硝酸濃度の増加のタイミングは海洋リン濃度の減少の時期と一致するとされた (Shimura et al., 2014)。つまり、海洋中の硝酸濃度は海洋中のリン濃度が枯渇したため、相対的に硝酸が富みたとされた。一方、カンブリア紀中期以降に窒素同位体が高くなることに関しては、いまだ多くの問題点が残る。一つ目は、先行研究では、初期カンブリア紀中期以前の低い窒素同位体比は水井沱層の黒色頁岩で見られ、それ以降の高い窒素同位体比は石碑層中部より上位の炭酸塩岩で見られるため、窒素同位体の変化が岩相の違いによるのかが明らかにされていなかった。二つ目は、窒素同位体変動の途上の部分のデータが得られていないので、その変動が遷移的か、急激なのかが不明であった。また、その変動の詳細な時期も不確かであった。そして、窒素同位体比の変動時の他の proxy の挙動が明らかでなかった。そこで、本研究ではこれらの問題を解決するために、その欠損部分の掘削を行い、炭酸塩岩や黒色頁岩中の堆積物中の有機窒素の窒素同位体比を分析した。

本研究で用いられた岩石試料は、南中国三峡地域で採取された水井沱 (Shuijintuo)?石碑 (Shipai) 境界の部分である。

得られた窒素同位体比は Shuijintuo 層では-2 から+2 ‰まで上昇し、その後、Shipai 層ではおよそ+1 から+3 ‰で安定した値を示した。本研究の結果、窒素同位体の変動は岩相の違いとは関係ないことが分かった。窒素同位体比と全有機窒素含有量には明瞭な相関は見られなかった。一部のデータに全体の窒素同位体トレンドとは優位に低い値が見られたが、それらと全有機窒素含有量にも明瞭な相関は見られなかった。また、窒素同位体比の増加は Shuijintuo 層最上部の黒色頁岩層で見られた。その変動は遷移的であり、急激な変化ではなかった。また、炭素同位体比と対比した結果、炭素同位体には明瞭な変化が認められなかった。このような結果は、堆積場の違いなどではなく、この時期に海洋表層環境が変化したことを示し、特に窒素同位体比の上昇は表層の硝酸含有量が低下したことを示す。つまり、カンブリア紀初期に富硝酸な環境が終了し、一次生産の上昇とともに硝酸が枯渇し、現在の海洋と同様に脱窒の働きが大きくなったことを示す。つまり、カンブリア初期に現在型の海洋窒素循環が確立されたことを示す。一次生産の増加は、大気・海洋中の酸素濃度の上昇をもたらすと考えられる。そのような酸素量の増加がカンブリア爆発の増加につながったことを示唆する。

キーワード: Nitrogen isotopes, Chemostratigraphy, Cambrian

南中国 Doushantuo 層に産する原生代樹枝状多細胞藻類化石  
Dendroid multicellular thallophytes preserved in a Neoproterozoic black phosphorite in southern China

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Both metaphytes and metazoans are reported from the well-preserved multicellular assemblage in the Neoproterozoic Doushantuo phosphorite in Weng'an of the Guizhou province, southern China. Here, a new form of dendroid multicellular thallophytes is documented. The new thallus is slightly heteromorphic. Several lateral branches extend from upper portion of the main axis, bearing terminal vegetative vesicles, carpognial vesicles, monosporangium-like discoidal vesicles and urn-shaped pseudoparenchymatous structures. The vegetative vesicle gives rise to a club-shaped pseudoparenchymatous structure, characterised by the medulla?cortex thallus differentiation, which may represent the early stage of the thallus. An oogamous conceptacle arising from one carpognial vesicle is a highly specialised goblet-shaped conceptacle. The discovery and identification of these new dendroid multicellular thallophytes not only document the first fossil-histological evidence for the heteromorphism of Precambrian organisms but also provide a potential insight for our enhanced understanding of the life cycle of the Precambrian red algae.

キーワード: 新元古, Doushantuo 層, 多細胞藻類, 樹枝状, 異形  
Keywords: Neoproterozoic, Doushantuo, multicellular thallophytes, dendroid, heteromorphic

## オーストラリアにおける新原生代マリノアン氷期後の海洋生物バイオマス変動 Marine biomass changes after the Neoproterozoic Marinoan Glaciation in Australia

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The late Neoproterozoic Marinoan glaciation (ca. 635 Ma) was one of the most severe ice ages in the Earth history. It is thought that the glaciation affected the biosphere and caused some succeeding evolutionary events, such as the occurrence of the Lantian biota, the first known macroscopic multicellular eukaryotes (Yuan et al., 2011, 2013). We analyzed sedimentary organic molecules from post-Marinoan deposits in three Australian cores and a section: the Wallara-1 drillhole in the Amadeus Basin, the GILES-1 drillhole in the Officer Basin, the SCYW79-1A drillhole in the Adelaide Geosyncline, and the Moonlight Valley type section in the Kimberley region.

The analysis identified more than 10 types of sedimentary organic molecule, and some of these were used as indicators of biomass for this time. The trends and correlations among the indicators through the researched formations revealed that sum of pristane and phytane (biomass of photosynthetic organisms), 2-alpha-methylhopane (biomarker of cyanobacteria), aryl isoprenoids (photosynthetic organisms and/or green sulfur bacteria), and Cholestane (biomarker of eukaryotes) relative to total organic carbon (TOC) had a positive peak(s) in the lowermost Ediacaran System, which represents an increase in biomass of photosynthetic organisms and eukaryotes immediately after the retreat of the Marinoan glacier, probably caused by an increased nutrient flux to the sea. Except for aryl isoprenoids, those indicators relative to TOC increased through the upper part of the lowermost Ediacaran formations, which may correspond to a recovery and/or evolution of eukaryotes after the Marinoan glaciation.

Yuan, X., Chen Z., Xiao, S., Wan, B., Guan, C., Wang, W., Zhou, C. & Hua, H. (2013) The Lantian biota: A new window onto the origin and early evolution of multicellular organisms. *Chinese Science Bulletin* 58, 701-707.

Yuan, X., Chen, Z., Xiao, S., Zhou, C. & Hua, H. (2011) An early Ediacaran assemblage of macroscopic and morphologically differentiated eukaryotes. *Nature Letter* 470, 390-393.

キーワード: 有機地球化学, 新原生代, エディアカラ紀, マリノアン氷期

Keywords: Organic Geochemistry, Neoproterozoic, Ediacara, Marinoan Glaciation

## 全球凍結と初期動物多様化時における海洋酸化メカニズム Oceanic oxidation mechanisms spanning the Snowball Earth and early animal diversification

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The late Neoproterozoic (780 million years ago (Ma)) to early Cambrian (520 Ma) interval witnessed the rise and evolution of early animals. Oceanic oxidation is believed to be crucial in driving the early animal evolution. However, the oxygenation mechanism in seas during this critical period remains unknown. Here we found (i) oceanic anoxia before and during the Marinoan global glaciation (MGG) (660-635 Ma), (ii) surface-water reoxidation immediately after the MGG (635 Ma), (iii) intermediate-water oxidation in the mid-Ediacaran (600 Ma), (iv) deep-water oxidation in late Ediacaran (580 Ma), (v) oceanic anoxia at the end of the Ediacaran (541 Ma), and (vi) reoxidation in the early Cambrian (535 Ma). Thus, a stepwise marine oxygenation took place from shallow to deep water through the Ediacaran epoch, and every major changes in oxygen levels coincided with an important revolutions of marine life, suggesting a coevolution of ocean chemistry and early animals occurred during this period.

キーワード: エディアカラ紀, クリオジェニアン紀, 新原生代, 酸素, バイオマーカー

Keywords: Ediacaran, Cryogenian, Neoproterozoic, oxygen, biomarkers



## 日本の三疊紀後期イジェクタ堆積物の地球化学的検討：とくに衝突隕石の起源について

### Geochemical identification of projectile from the Upper Triassic ejecta deposits in Japan

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Our previous studies have revealed that the Sakahogi section in central Japan contains an impact ejecta layer in the Late Triassic, which was derived from an extraterrestrial impact event. This ejecta layer is characterized by platinum group element (PGE) positive anomalies and Os isotope negative excursion together with enrichments in Ni and Cr, and abundant occurrences of Ni-rich magnetite grains and microspherules. PGE anomalies in the Late Triassic sediments were also discovered from deep-sea claystone layers at three bedded chert sections in southwest Japan as follows: (i) Unuma section in the Inuyama area, Mino Belt, (ii) Hisuikyo section in the Kamiaso area, Mino Belt, and (iii) Enoura section in the Tsukumi area, Chichibu Belt. Combined PGE and various isotope data from these ejecta layers are insightful so as to identify the meteoritic material which has caused the Late Triassic impact event. Here we report the PGE element ratios, and Cr and Os isotope compositions of these ejecta layers to understand the projectile component.

The Ru/Ir and Pt/Ir ratios of all the claystone samples from the study sites are plotted along the mixing line between chondrites and upper continental crust. Although a chondrite cannot be distinguished from iron meteorites by using PGE/Ir ratios, the claystone layers show Cr/Ir ratios between  $10^4$  to  $10^5$ , indicating that the claystone layers are clearly contaminated by chondritic material. The Os isotope compositions ( $^{187}\text{Os}/^{188}\text{Os}$  ratios) in the claystone have a narrow range from 0.126 to 0.128 and these values are well similar to those of chondrites. The Cr isotope data are useful to identify the extraterrestrial components in the ejecta deposits because meteorites of different classes have a distinct  $^{54}\text{Cr}$  isotope anomaly. The presence of positive  $\epsilon^{54}\text{Cr}$  anomaly in all claystone samples strongly suggests that a carbonaceous chondrite-like material was involved in the studied ejecta layers. Consequently, these geochemical lines of evidence indicate that the Upper Triassic ejecta layers in the Japanese accretionary complexes have been most likely derived from a carbonaceous chondrite.

キーワード: 隕石衝突, 白金族元素, オスミウム同位体, クロム同位体

Keywords: impact event, platinum group element, osmium isotope, chromium isotope

## 原生代初期、ガーナベリミアン帯アキシムープリンセスタウン地域における海底層序復元 1 Stratigraphic Sequence in the Axim-Princess Town section of the coastal Paleoproterozoic Greenstone Belt in the Birimian

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古原生代では Grate Oxidation Event や、ヒューロニアン氷河期(約 23 億年前)が報告され、急激で地球規模の気候/環境変動があったと考えられている (e.g. Holland, 1994, Kopp et al, 2005). しかし、これらの地質学的証拠は浅いプラットフォーム上の地層に残されたものであり、より深い海洋底における堆積環境については不明である。これは、原生代に入ると深い海を含む地層が衝突帯中に付加され、露頭分布が限られ、変形変成作用の影響を受けるため層序の復元などが難しいためである。

我々は古原生代における比較的深い海の環境変遷を明らかにするために、変形/変成が少ない 23?19 億年前の地層が分布するガーナ、ベリミアン (Berimian) 帯の堆積層について、地質調査により層序復元を行った。

調査地域であるベリミアン海岸グリーンストーン (BCG) 帯は、22 億年前の花崗岩と共に東西約 10km に渡って連続した地層が露出する。西部は蛇紋岩帯、東部には枕状溶岩が報告されており、原生代初期の海洋地殻断面が見られることが予想される。我々は、全体の地質構造の把握を行い、連続層序部分を明らかにし、代表的な地層における柱状図を作成および試料採取を行った。本地域は、東に傾斜した片理を持つ組織から数百mの西フェルゲンツであり、1カ所のみ非対称褶曲構造が識別できるが、基本的には東上位の変形の少ない地層が連続する。厚い火山岩碎屑岩から黒色頁岩からなり、地層中には斜交層理・級化層理などの堆積構造が残っており上下判定は可能である。また、変成鉱物として変成温度の低い緑色角閃岩類が広く確認でき、緑色片岩相を被っている

地層は、実測で層厚 1000m 以上の厚い火山碎屑岩からなり、20-50 m厚の上方細粒化層した火山碎屑層と黒色頁岩層の互層が挟まれており、上方ほど堆積層の頻度が増え、薄層化する。最下部はフェアミーなどが見られ溶結した組織が見られるため、陸上で噴火堆積した部分も考えられる。上方にむけて細かな平行葉理をもつタービダイト性火山岩や黒色頁岩が増加し深海化する。陸源物質はほとんど混入がなく、海洋性島弧の断面層序が残っている可能性を示す。黒色頁岩中に含まれる有機炭素の安定同位体組成は  $\delta^{13}\text{C} = 24.3 \pm 3.7 \text{ ‰}$  であった。当時の海底は有機物が沈殿し、分解できない嫌気的海域が広がっていたと考えられる。

キーワード: 原生代初期, ベリミアングリーンストーン帯, 海底環境

Keywords: Paleoproterozoic, Berimian Greenstone belt, island arc ocean floor environment

## 原生代前期ガーナ・エンスタマンガン鉱床の地球化学的特徴：海洋酸化還元環境への示唆

### Geochemistry of the Nsuta Mn deposit in Ghana: Implications for the Paleoproterozoic ocean redox state

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Oxygenation of the atmosphere and oceans may have influenced the ocean chemistry and diversified contemporaneous life. A number of large manganese (Mn) deposits are distributed in the Paleoproterozoic sedimentary successions that were formed during the great oxidation event (GOE) around 2.4-2.2 Ga (Maynard, 2010 *Econ. Geol.*). Due to the high redox potential of Mn, occurrences of Mn deposits have been regarded as important evidence for a highly oxidized environment during the Paleoproterozoic (Kirschvink et al., 2000 *PNAS*). Furthermore, because Mn oxides are efficient scavengers of various elements, including bio-essential elements such as Mo, formation of large Mn deposits may have affected the seawater chemical composition and ecology during the Paleoproterozoic. However, due to lack of detailed geochemical records constraining the genesis of each Mn deposit, the relationships among the formation of Mn deposits, the evolution of atmospheric and ocean chemistry, and the diversification of early life are still ambiguous.

In this study, we report the Re-Os isotope compositions, rare earth element (REE) compositions, and abundance of manganophile elements in the Mn carbonate ore and host clastic sedimentary rock samples collected from the Nsuta Mn deposit of the Birimian Supergroup, Ghana. The Nsuta deposit is one of the largest Paleoproterozoic Mn deposits, although its genesis remains controversial (Melcher et al., 1995 *Mineral. Mag.*; Mücke et al., 1999 *Miner. Deposita*). The composite Re-Os isochron age (2149 ± 130 Ma) of the Mn carbonate and sedimentary rock samples is consistent with the depositional age of the sedimentary rocks (?2.19 Ga) obtained from U-Pb zircon age of the volcanic rocks (Hirdes and Davis, 1998 *J. Afr. Earth Sci.*), suggesting that the timing of Mn ore deposition was almost equivalent to the host rock sedimentation. The PAAS-normalized REE patterns show positive Eu anomaly in all samples and a positive Ce anomaly only in the Mn carbonate ore. These REE patterns suggest possible contribution of Eu-enriched fluids derived from hydrothermal activity and Ce enrichment due to the oxidation of Ce(III) by Mn(IV) during ore formation. Among the manganophile elements, only Mo is enriched in the Mn carbonate ore compared to the host sedimentary rocks. The profile of manganophile elements is similar to that of modern hydrothermal Mn oxide (Kuhn et al., 2003 *Chem. Geol.*), although the Mo/Mn ratio is much lower. These geochemical lines of evidence provide the following plausible genetic model for the Nsuta deposit: (1) Mn(II) was derived from hydrothermal fluids, (2) Mn(II) was oxidized to Mn(IV) oxide by the oxygenated seawater, (3) the precipitation of Mn oxide is almost concurrent with the deposition of the host sedimentary rocks, (4) Mn oxide was diagenetically transformed to Mn carbonate ore by the reaction with organic matter.

The geochemical features of the Nsuta deposits suggest that, as in the present oxic oceans, Mn oxide was a potential sink for several trace elements in the Paleoproterozoic oceans. The low Mo/Mn ratio in the Mn carbonate ore may reflect the large difference between the chemical compositions of Paleoproterozoic and present seawater. As the Paleoproterozoic black shales also tend to show low Mo abundance (Scott et al., 2008 *Nature*), the observed low Mo/Mn in the Mn carbonate ore suggests low Mo inventory in the Paleoproterozoic seawater. In the presentation, we will also discuss the oceanic redox condition responsible for the low Mo inventory during the Paleoproterozoic.

キーワード: 原生代前期, 大酸化イベント, マンガン鉱床, レニウム-オスミウム, 親マンガン元素, ビリミアン累層群

Keywords: Paleoproterozoic, Great Oxidation Event, Mn ore, Re-Os isotope, manganophile elements, Birimian Supergroup

## 原生代初期における大気酸素濃度変動と安定性に関する地球化学的研究 Geochemical study on the variation and stability of atmospheric oxygen in Paleoproterozoic

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地球大気中の酸素濃度は、さまざまな地質記録から、原生代初期（24.5-22 億年前）に急激に上昇したことが示唆されている。同時期はヒューロニアン氷河時代と呼ばれ、大規模な氷河時代が、少なくとも3回繰り返したことが知られている。とりわけ、第2（ブルース）氷河時代、第3（ゴウガンダ）氷河時代の直後に酸素濃度の上昇が生じたことが、地球化学的データから示唆されている。しかしながら、それら二つの氷河時代間の温暖期において酸素濃度がどのような安定状態にあったのかは未だ明らかではない。

そこで本研究では、ブルース氷河時代とゴウガンダ氷河時代間の温暖期を記録したカナダ・ヒューロニアン累層群エスパニョーラ層及びサーペント層の堆積岩試料に対して、海洋環境の酸化還元状態によって挙動が変わる元素（酸化還元敏感元素）の分析を行うとともに、炭素同位体分析、硫黄同位体分析などを行った。そして、当時の大気海洋系における酸化還元状態の推定を通じて、大気酸素レベルの変遷及びその安定状態について検討を行った。

その結果、エスパニョーラ層及びサーペント層において、酸化還元敏感元素（Fe, Mn, Mo, V, Cr, U, Re, Os など）の濃集はみられないことが分かった。その一方で、Re 及び Os のアイソクロン年代は約 31 億年前という年代値を示し、ヒューロニアン累層群の堆積年代（24.5-22.2 億年前）よりも明らかに古いことが分かった。このことは、堆積物中の Re や Os が堆積時の海水中から供給されたものではなく、おそらくは浸食された有機物をホストとする碎屑物として再堆積したものであることを示唆している。堆積時の海水から Re, Os の供給がほとんどないこと、また約 31 億年前の Re, Os 同位体システムが酸化的風化を受けずに閉鎖系を保ったまま再堆積していることから、堆積時の大気と海洋はともに Re や Os の酸化が卓越しない貧酸素環境であったことが示唆される。このことは、酸化還元敏感元素の濃集がみられないことや、堆積当時の海洋硫酸濃度が低かったことを示唆する硫黄同位体の分析結果とも調和的である。

先行研究の結果と本研究の結果をあわせて考えると、ブルース氷河時代直後に上昇したことが示唆される酸素レベルは、再び低下したことが示唆される。すなわち、ブルース氷河時代直後の酸素濃度上昇は一時的なものであった可能性が高い。ゴウガンダ氷河時代以前においては酸素濃度がいったん上昇してから低いレベルへと可逆的に変動したのに対し、ゴウガンダ氷河時代を経て酸素濃度の安定状態間の不可逆的な遷移が起きたと考えられる。

## 32億年前の海底環境復元: DXCL 掘削試料の炭素・硫黄同位体比について Reconstruction of 3.2Ga sea floor environment: Carbon and sulfur isotopic ratios of DXCL drill cores.

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西オーストラリアのピルバラ海岸グリーンストーン帯には、32~31億年前の海底堆積物層 (デキソンアイランド層およびクリバービル層) が分布している。堆積環境の高精度復元を目的として2007年と2011年にDXCL陸上掘削が行われ、4本の掘削コア (DX, CL1, CL2, CL3) が得られた。先行研究によると、CL3以外のコアでは炭素同位体比 ( $\delta^{13}\text{C}$ ) は岩相と相関なく約-30‰前後を示し、燃焼法によって得られたDXコア中の黒色頁岩の硫黄同位体比 ( $\delta^{34}\text{S}$ ) は変動幅が大きく、非常に高い値 ( $\delta^{34}\text{S} = -10.1 \sim +26.8 \text{‰}$ ,  $n=93$ : 坂本, MS2010; Kobayashi, MS2013) を示した。これは報告されている太古代初期の堆積性硫化物の同位体比 ( $\delta^{34}\text{S} = -16.8 \sim +8.7 \text{‰}$ ,  $n=351$ : Strauss, 2003) と大きく異なっている。

本研究ではDXCL掘削試料における炭素・硫黄同位体変化をCL3コアを含めた全層について比較した。また特に黄鉄鉱硫黄同位体比のばらつきが大きかったDXコアについては、その原因を解明するためにNanoSIMSによる硫黄同位体比の微小領域分析を試みた。

(岩相) クリバービル層は下位の黒色頁岩部層 (CL1: 66.1m, CL2: 44.4m) と上部の縞状鉄鉱部層からなる。特にCL3コア (200m) は黒色頁岩部層最上部と縞状鉄鉱部層からなり、黒色頁岩、炭酸塩岩、縞状鉄鉱層からなる。デキソンアイランド層 (DXコア: 100.4m) は、黒色頁岩と灰色チャート、黄鉄鉱層の互層からなる。顕微鏡観察により、数mm幅の黄鉄鉱層の中には数十~数百 $\mu\text{m}$ の自形黄鉄鉱の層や直径約10 $\mu\text{m}$ 、殻厚約2 $\mu\text{m}$ の微小球殻状黄鉄鉱の層がある。地層の切断関係や形態により、微小球殻状黄鉄鉱が続成作用の初期の段階に形成していることが分かる。

(硫黄同位体分析) 局所分析: 微小球殻状黄鉄鉱を含む薄片を標準試料と共に樹脂に包埋し、東京大学大気海洋研究所所有のNanoSIMS50 (二次元高分解能二次イオン質量分析装置) を使用して同位体比のマッピングを行った。全岩分析: 粉末試料を燃焼してSO<sub>2</sub>ガスを単離し、そのガスを用いて同位体分析を行った。機器には九州大学有機宇宙地球化学研究室所有のFISONS instruments社製NA1500 NCS元素分析計およびThermo Finnigan社製DELTA plus XL同位体比質量分析計を使用した。

(炭素同位体分析) 粉末試料に対してLarson et al., (2008) に基づき菱鉄鉱の塩酸処理を行い、高知大学海洋コア総合研究センターのThermo Finnigan社製の元素分析オンライン質量分析計Delta Plus Advantageを使用した。

(結果) 微小球殻状黄鉄鉱は球殻内部で5~10‰ほどの同位体分別を起こし、値の高い部分が内側にリング状に、低い部分が外側と中心部という同心円状の分布をしていた。またCL3コア ( $n=27$ ) からは $\delta^{34}\text{S} = +1.33 \sim +21.52 \text{‰}$ ,  $\delta^{13}\text{C}_{\text{org}} = -30.79 \sim -28.57 \text{‰}$ ,  $\text{C}_{\text{org}} = 0.09 \sim 1.65 \text{wt\%}$  という結果が得られた。

(考察) 炭素同位体比は、DX-CLコアを通して約400mの間ほとんど-30~-28‰の値をとり、同一種類の炭素質物質が海洋底に沈殿している事がわかった。これはシアノバクテリアのような光合成細菌の $\delta^{13}\text{C}_{\text{org}}$ 値と一致する (Schidlowski, 1987)。当時の海洋表層部ではシアノバクテリアが活動し、その遺骸が沈殿したと思われる。また黄鉄鉱層の形成は、シアノバクテリアが沈殿する有機物に富む嫌気的な海底堆積物中で起こる。特に球殻状に形成した黄鉄鉱内部では硫酸塩に関して閉鎖系となり、硫酸還元菌によるレイリー分別が進んだ。その結果フィードバックを起こし、球殻内部では当時の海洋硫酸塩の硫黄同位体比 (+2‰: Ohmoto, 1992) よりも同位体的に重い黄鉄鉱が形成していったと考えられる。一般的に硫酸還元菌が関与する場合、生成する硫化物の硫黄同位体比は負の値をとり同位体的に軽い方向にシフトするが、本層では+20‰以上の値を示している。当時の海洋底の堆積性硫化物は高い硫黄同位体比をもつ状態であった可能性がある。

キーワード: 太古代, 炭素同位体, 硫黄同位体, 黄鉄鉱, 二次イオン質量分析装置, 硫酸還元菌

Keywords: Archean, carbon isotopic ratio, sulfur isotopic ratio, pyrite, SIMS, sulfate reducing bacteria

## 南アフリカ、Onverwacht 層群における初期太古代の硫黄非質量依存同位体分別 S-MIF geochemistry of the Early Archean in the Onverwacht Suite, South Africa

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The recent study of sulfur mass independent fractionation (S-MIF) in the Archean sedimentary rocks represented that multiple sulfur isotope ratios ( $^{32}\text{S}/^{33}\text{S}/^{34}\text{S}/^{36}\text{S}$ ) could be useful new tracer for Archean sulfur cycles. Farquhar et al. (2000) first discovered that Archean sedimentary rocks before 2.4 Ga have  $\Delta^{33}\text{S}$  anomaly, whereas no such anomaly was found in younger samples. This contrast implies the rise of atmospheric oxygen content that fundamentally changed atmospheric sulfur cycle. The hypothesis are based on the studies from Western Australia and South Africa (Kaufman et al., 2007; Ono et al., 2009; Zerckle et al., 2013). High-resolution stratigraphic studies provide a detailed view into the late Archean marine sulfur cycle, which can help our understanding of both atmospheric and biological processes. In the early Archean, S-MIF data are almost from hydrothermal sulfate and sulfide. For comparing early and late Archean data precisely, it is necessary to investigate stratigraphical and petrological distributions and variations of the multiple sulfur isotopes. We have studied Early Archean sedimentary sulfides which are well preserved in the Barberton Greenstone Belt, South Africa. Sulfur isotope analysis of extracted sulfide of sedimentary rocks from Barberton Greenstone Belt, show a clear MIF ( $>1\text{‰}$ ) and  $\delta^{34}\text{S}-\Delta^{33}\text{S}$ ,  $\Delta^{33}\text{S}-\Delta^{36}\text{S}$  correlation. The Noisy Complex which consists of fluvial sediments and diamictite show negative  $\delta^{34}\text{S}-\Delta^{33}\text{S}$  correlation, and  $\Delta^{36}\text{S}/\Delta^{33}\text{S}$  slope of -0.72. On the other hand, the Kromberg Formation which consists of deep marine sediments show positive  $\delta^{34}\text{S}-\Delta^{33}\text{S}$ , and scattered  $\Delta^{36}\text{S}/\Delta^{33}\text{S}$  slope.  $\delta^{34}\text{S}-\Delta^{33}\text{S}$ ,  $\Delta^{33}\text{S}-\Delta^{36}\text{S}$  relation from each stratigraphic level shows somewhat different trend, possibly reflecting local environment and/or bacterial sulfate reduction activity.

キーワード: 南アフリカ, 硫黄, 非質量依存同位体分別  
Keywords: South Africa, Sulfur, MIF

## 地球史 46 億年における大気酸素濃度 Atmospheric oxygen in the Earth's 4.6-billion-year history

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The oxygen content of the Earth's surface environment is regarded to have increased in two steps; the Great Oxidation Event (ca. 2.4 Ga) around the Archean-Proterozoic boundary and the Neoproterozoic Oxygenation Event (ca. 800-550 Ma). These two events are supported by geochemical or paleobiological evidences; however, the estimation of the oxygenation level of the surface environment through time still have many problems to solve. We will review and discuss the previous researches for the better quantitative estimation of the atmospheric oxygen content in the Earth's 4.6-billion-year history.

初期マントルにおける化学成層と対流攪拌：惑星サイズの効果  
Convective stirring versus compositional stratification in the early mantle of terrestrial planets of various sizes

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Systematic numerical studies of magmatism in the convecting mantle of terrestrial planets suggest that how the compositional differentiation by magmatism in the earliest mantle affects its subsequent history depends on the size of the planets. In large planets like the Earth and Venus, the global scale magmatism induced by the high initial temperature of the mantle does not differentiate the mantle so much because of a strong positive feedback that arises between magmatism and mantle convection: Ascending flow of mantle convection induces decompression melting, but the buoyancy of the melts further enhances the ascending flow itself. This ascending flow enhanced by melt buoyancy strongly stirs the mantle and suppresses prominent compositionally stratified structure to develop in the early mantle. In Mars, the positive feedback still works, but the convection does not stir the mantle so strongly and the initial global scale magmatism makes the mantle compositionally stratified; the subsequent mantle evolution occurs as a convective relaxation of the compositionally stratified structure. In the moon and Mercury, the positive feedback itself does not work, and the convective current is mild even in the earliest stage of the history of the mantle. In the moon where the heat flux from the core is negligible and the gravity is small in deep mantle, in particular, a compositionally stratified structure formed in early mantle survives the subsequent stirring by such a mild convective flow.

キーワード: 惑星サイズ, 火成活動, マントル対流, 化学成層  
Keywords: planetary size, magmatism, mantle convection, compositional stratification



## 月惑星表面のクレータ記録からみた後期重爆撃期 Lunar and Planetary Cratering Records: Evidences for and against the Cataclysmic Late Heavy Bombardment

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後期重爆撃の有無は、月科学だけでなく地球科学、惑星科学における最重要未解決問題である。アポロ試料中のインパクトメルト岩の放射年代は38~40億年に集中しており、このことから一部の月科学者は39億年前に天体衝突が活発な時期があったと考えてきた[e.g., Tera et al., 1974]。これを後期重爆撃期仮説と呼んでいる。一方、この説に反対する研究者も少なくない。アポロ試料はImbriumやSerenitatisといった比較的若い(39億年)特定の衝突盆地からの放出物に汚染されているために一様な年代を示しているだけ、という主張である。本発表では、月惑星表面のクレータ記録にもとづいて後期重爆撃の有無について議論する。

キーワード: 後期重爆撃期, クレータ, 月  
Keywords: Late Heavy Bombardment, Crater, Moon

## 親鉄元素からみるレイトベニアのタイミング Timing of late veneer on Earth: a siderophile element perspective

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The short-lived  $^{182}\text{Hf}$ - $^{182}\text{W}$  decay system (half life is ca. 9 Myr) has long been recognised as a powerful tracer for accretionary and differentiation processes on the early Earth. Recent advances in analytical technique made it possible to conduct high-precision ( $\pm 5$  ppm or better) W isotope ratio measurements and have allowed exploitation of  $^{182}\text{W}/^{184}\text{W}$  variations (expressed in the conventional  $\epsilon^{182}\text{W}$  notation) in a wide variety of geological samples. To date, the presence of  $\epsilon^{182}\text{W}$  anomalies have been documented for the 3.8 Ga Isua supracrustal belt in West Greenland, the 2.8 Ga Kostomuksha komatiites, the  $\geq 3.8$  Ga Nuvvuagittuq greenstone belt in Northeastern Canada and the 4.03 Ga Acasta gneiss complex in Northwestern Canada, all of which exhibit similar positive  $\epsilon^{182}\text{W}$  anomalies up to 15 ppm relative to modern terrestrial samples ( $\epsilon^{182}\text{W} \simeq 0$ ). These  $^{182}\text{W}$  enrichments have been interpreted to represent the composition of anciently isolated domains in Earth's mantle that escaped addition of the chondritic late veneer ( $\epsilon^{182}\text{W} \simeq -2$ ). This hypothesis is apparently consistent with the idea that  $\sim 0.5\%$  of the Earth's mantle was added after the cessation of core formation, required to account for the overabundance of highly siderophile elements (HSEs) in modern mantle. In order to test this hypothesis, we produced the HSE concentration data for basaltic amphibolites in the 4.03 Ga Acasta gneiss complex, meta-komatiites and meta-dunites in the  $\geq 3.8$  Ga Saglek-Hebron segment in Northern Labrador, Canada with the motivation in the search for the pre-late veneer mantle almost devoid of HSEs. The results demonstrated that the relative and absolute HSE abundances in all these rocks are akin to their late Archean to modern equivalents, indicating the delivery of late-accreted materials prior to 3.8-4.0 Ga at the period of late heavy bombardment on the Earth-Moon system. Considering the results of other studies demonstrating high-HSE contents of the mantle sources for the 3.8 Ga Isua rocks and the 2.8 Ga Kostomuksha komatiites, we can now conclude that  $^{182}\text{W}$  enrichments are largely decoupled from HSE depletions, inconsistent with the pre-late veneer hypothesis. Further studies are necessary focusing on the siderophile element behaviors in Eoarchean rocks to advance in the knowledge of late accretion on Hadean mantle and the source of  $^{182}\text{W}$  enrichments.

キーワード: 親鉄元素, レイトベニア, 太古代, マントル

Keywords: siderophile element, late veneer, Archean, mantle

## 冥王代における後期重爆撃による大陸の破壊と溶融 Destruction and melting of Hadean continent by Late Heavy Bombardment

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冥王代すなわち約 40 億年前より以前にできた岩体は世界中のどこにも見つかっていない。しかし近年、冥王代の放射性年代をもつジルコンを含む堆積岩が発見され、冥王代にはすでに大陸地殻があったと考えられるようになった。この大陸地殻は、いったいなぜ消えてしまったのだろうか。消失の原因として冥王代末期の天体衝突の集中「後期重爆撃」による破壊や溶融が挙げられるが、定量的な推定はあまりなされていない。

本研究ではこれを解析的に計算する式を導出し、後期重爆撃によって大陸地殻の消失を説明することが困難であることを明らかにした。具体的には、後期重爆撃を Cataclysm, Soft-Cataclysm, Standard の三つのモデルで表し、冥王代の大陸地殻が掘削される量と溶融する量を推定した。推定方法は、以下の通りである。

まずは、月面の巨大衝突盆地 (Cataclysm モデル) のデータと、力学的数値シミュレーション (Soft-Cataclysm モデル) および月面のクレーター数密度 (Standard モデル) を定式化したものから、小惑星のサイズ分布を考慮して後期重爆撃の規模を推定した。小惑星のサイズ分布は、実際の観測によって与えられた分布を累乗近似し、ベキ指数をパラメーターとした。このベキ指数によって、結果は大きく変化する。そして最後に、クレーターのスケールリング則を用いて、大陸地殻の破壊と溶融を推定した。推定される量は、総掘削体積、総溶融体積、掘削および溶融領域による地球表面のカバー率、の四つである。

結果としては、後期重爆撃のいずれのモデルであっても、いくつかの巨大衝突によって大陸成長曲線と同程度の体積を溶融する可能性はあるが、溶融領域が地球表面を覆うことはできないとわかった。冥王代の大陸地殻は地球表面に点在していたと想像されるため、これら全てが溶融されるとは考えにくい。すなわち、後期重爆撃によって冥王代の岩体の消失を説明することは困難である。

キーワード: 後期重爆撃, 冥王代, 大陸地殻, 小惑星, クレーター, 天体衝突

Keywords: Late Heavy Bombardment, Hadean, continental crust, asteroid, crater, impact

## 西オーストラリア・ジャックヒルズ変堆積岩ベルトから衝撃変成ジルコンの発見 The first recovery of impact-shocked zircons from the Jack Hills metasedimentary rocks, Western Australia

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The first 500 million years of the Earth history remain poorly understood because terrestrial rock records during Hadean era (>4.0Ga) are scarcely preserved, probably due to surface and/or tectonic erosion and intense meteorite bombardment. The Late Heavy Bombardment (LHB) is the period from ca. 3.85-3.95, an intense flux of asteroidal bodies into inner solar system originally proposed to have impacted the Moon. To date, the oldest impact structure on the Earth is the 2.02 Ga Vredefort Dome, South Africa, and another oldest evidence of bolide impact is 3.47-3.24 Ga spherule layers in the Barberton Greenstone Belt, South Africa (e.g. Lowe et al., 2003). The impact chronology from these spherule layers suggest that the impactor flux was significantly higher 3.5 Ga than today (Jhonson & Melosh, 2012).

Geological conditions during Hadean era can be deduced from detrital zircon grains as old as 4.4 Ga preserved in metasedimentary rocks at Jack Hills in the Narryer Gneiss Complex, Western Australia (e.g. Compston & Pidgeon, 1986; Wild et al., 2001). Jack Hills metaconglomerates deposited in ca. 3 Ga contain detrital zircons with ages continuously spanning from 3.0 to 4.4 Ga. Previous investigations of these grains have suggested the existence of a thermal excursion during LHB era (Abbott et al., 2012; Bell and Harrison, 2013), but temperature approach of detrital zircons do not restrict impact-related heating.

Here, we first report zircons with shock-induced textures, such as granular (polycrystalline) texture, from the Jack Hills metaconglomerate. Granular-textured zircons have been frequently reported from impact ejecta layers and craters, such as K-Pg boundary, the Chicxulub crater (e.g. Bohor et al., 1993; Krogh et al., 1993) and also from shock experiments (Wittmann et al., 2006). Polycrystalline zircon grains recovered from the Jack Hills metaconglomerates represents several micro-meter sized crystallites of zircon in a glassy ZrSiO<sub>4</sub> matrix that may resulted from shock-induced amorphization and subsequent recrystallization (Wittmann et al., 2006). Several grains show the granular texture with abundant micro-vesicles and tiny ThSiO<sub>4</sub>, suggesting incipient melting and vaporization. The first recovery of shock-induced zircons from the Jack Hills metaconglomerate would provide significant clues on the early Earth environment and on constructions/destructions of Earth early crust.

キーワード: 初期太古代, 冥王代, ジャックヒルズ, ジルコン, 衝撃変成作用  
Keywords: early Archean, Hadean, Jack Hills, zircon, shock metamorphism

## アカスタ片麻岩体に産する苦鉄質岩石類の微量元素多様性 Trace element variety of mafic rocks in the Acasta Gneiss Complex

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The Hadean from birth of the Earth to 4.03 Ga is the earliest period of the history of the earth, and defined by no preservation of rock records in the earth. Eoarchean crustal records are also rare, so that the details of early Earth are not revealed yet.

Acasta Gneiss Complex (AGC), located in the western part of the Slave Province, Canada, is one of the Early Archean terranes, and mainly consists of 3.6-4.0 Ga felsic and layered gneiss suites and mafic rocks. Minor mafic rocks are distributed all over the AGC and occur as rounded to elliptical enclaves and inclusions in the felsic and layered gneisses. These field occurrence of the mafic rocks suggest that they were formed before the formation of granitoid precursor of felsic gneisses and have potential to demonstrate the Early Archean mantle evolution. However, the AGC is subjected to numerous metamorphic and alteration events. The Acasta mafic rocks mainly consist of amphibolites with hornblende, plagioclase and quartz, suggesting that they underwent at least amphibolite facies metamorphism. No relict igneous minerals are preserved. At some localities, hornblendites with over 90 % modal abundance of hornblende occur as restites of anatexis. This study reveals the effects of alteration process by using whole-rock major and trace element compositions and constrained the Early Archean mantle characteristics from the least altered samples.

The compositions of the amphibolites range from basalt to basaltic andesite ( $\text{SiO}_2=48-57$  wt. %,  $\text{MgO}=2.1-9.8$  wt. %) and negative correlations can be seen between  $\text{Al}_2\text{O}_3$  and MgO contents and  $\text{Na}_2\text{O}$  and MgO contents respectively. The hornblendites have higher MgO and lower  $\text{Al}_2\text{O}_3$  and  $\text{Na}_2\text{O}$  contents than amphibolites, supporting the geological evidence that the hornblendites were derived from residue of anatexis. Amphibolites are divided into three groups based on their major elements and primitive mantle (PM)-normalized trace element patterns: Low-Al, Intermediate-Al and High-Al amphibolite respectively.

The Low-Al amphibolites are plotted between the Intermediate-Al amphibolites and hornblendites on the  $\text{Al}_2\text{O}_3$  vs MgO diagram. They have relatively higher LREE contents than the Intermediate-Al amphibolites. They display negative Zr and Ti anomalies on the PM-normalized trace element patterns. Those characteristics are similar to those of hornblendites. On the other hand, PM-normalized trace element patterns of the High-Al amphibolites are highly scattered. The geochemical characteristics of the amphibolites suggest that the Low-Al amphibolites were formed as a residue with incomplete melt loss due to the partial melting of the Intermediate-Al amphibolites, whereas the High-Al amphibolites as the melts addition. The geological and geochemical evidence indicates that the compositions of almost mafic rocks at the AGC were affected by secondary partial melting, but some mafic rocks, the Intermediate-Al amphibolites, possibly preserve their primary characteristics.

Except for Nb, the Intermediate-Al amphibolites have flat PM-normalized trace element patterns. Their negative Nb anomalies suggest that they were generated at the subduction setting, implying slab-dehydration process already occur in the Early Archean.

キーワード: 太古代, 苦鉄質, マントル

Keywords: Archean, mafic, mantle

## 地球表層の大陸地殻成長曲線 Growth curve of continental crust on the surface of the Earth

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大陸地殻の主要構成岩石である花崗岩は水惑星地球を特徴づける。地球史において大陸地殻が地球表層でいつ、どのくらい形成され、消滅したか具体的に探ることは固体地球進化のみならず、地球生命の進化にも重要である。大陸地殻の成長の研究史において、地質学、地球物理、地球化学の様々な手法からモデルが提案されてきた。熱史や化学進化のモデルによる研究は、地球史前半に大量の大陸地殻形成を示唆する (Fyfe, 1978; Armstrong, 1981) 一方で、地質証拠からは堆積作用等によるリサイクルの影響を考慮しても 20 億年前以前に形成された大陸地殻は 20%以下しか残っておらず、特に冥王代のもは例外的なごく少量のジルコンを除けば全く残っていない (川砂ジルコン法, Rino et al., 2008) 一方で、顕生代の造山帯の研究から大規模構造侵食や島弧沈み込みが明らかにされた。また地球物理の研究から第 2 大陸が発見され、その量は最低でも地表の大陸地殻の 6 倍 (520-660km)、その周辺も合わせると 10 倍のオーダーに達すると推定されている。(Kawai et al., 2009, 2013)

本研究では、現在では失われた大陸地殻について地質証拠に基づいて議論するための方法論として世界的な大不整合に注目した碎屑性ジルコンに注目して過去の大陸地殻の年代頻度分布を探ることを提案する。世界的な大不整合は過去の大陸縁辺であり、その上の砂岩などの堆積岩に含まれる碎屑性ジルコンは過去の川砂ジルコンとみなすことができる。

Pilbara, Kaapvaal, Zimbabwe, Wyoming の各クラトンに約 2.6 Ga の世界的な大不整合を挟んで覆う堆積岩に含まれる碎屑性ジルコンを分離し、LA-ICP-MS (京都大学平田研究室) により U-Pb 年代分析した。さらによりグローバルに議論するため、その他すでに報告されている碎屑性ジルコン年代のデータも含めたコンパイルを作成した。データ数は今後の充実を必要としているが、予察的にこれを 2.6 Ga, 1.0 Ga, 0.6 Ga の各年代における大陸地殻の年代頻度分布として以下の様な議論を行った。

Rino et al. (2008) による現在の川砂ジルコンの年代頻度分布と、本研究で得られた 2.6 Ga, 1.0 Ga, 0.6 Ga の各年代における碎屑性ジルコンの年代頻度分布を累積相対頻度分布曲線の形に表した。これらの曲線の形状から、地球史前半 2.6 Ga 以前には急激な大陸地殻の成長とともに、激しいマントルへの大陸地殻の沈み込みがあったこと、その後大陸地殻は成長を続けるものの 1.0 Ga 付近で大陸地殻の量は極大を迎え、それ以降現在まで減少していることが示唆された。

このような定性的な大陸地殻の成長に関する議論に加え、海洋の Sr 同位体比進化 (Shields and Veizer, 2002) を用い、過去の大陸地殻の存在量を見積もる計算を行った。海洋の Sr は風化による大陸地殻からのフラックスと海嶺の火山活動によるマントルからのフラックスの主に 2 つの混合で同位体比が決まる。風化の影響を受ける海面上に露出した大陸面積と、海面下まで含めた大陸地殻の存在量は本来異なるが、大陸地殻の存在量と大陸から海洋に流入する Sr のフラックスについて部分的な比例関係を仮定した。この計算による見積もりの結果、2.6 Ga には現在の約 75 % にまで成長した大陸地殻が地球表層に存在し、1.0 Ga には現在の大陸地殻の約 1.5 倍、その後現在まで大陸地殻は減少しているという大陸地殻の成長モデルを提案した。

キーワード: U-Pb 年代, 碎屑性ジルコン, 世界的な大不整合, 大陸地殻成長

Keywords: U-Pb age, detrital zircon, global unconformity, growth of continental crust

## 初期太古代ラブラドルネーン岩体中の縞状鉄鉱層の地質学的・地球化学的研究 Geological and geochemical studies about the Eoarchean-aged Banded Iron Formations in Nain Province, Northern Labrador.

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Banded iron formations (BIFs) are chemical sediments, deposited in seawater before the Paleoproterozoic, and are often utilized as proxies for chemical compositions of seawater. However, the scarcity of >3.6 Ga supracrustal rocks including BIFs hampers the use of BIFs for estimate of the seawater composition, especially bioessential elements, in the early earth. Recently, Konhauser et al. (2009) showed secular change of Ni/Fe ratios of BIFs through geologic time, and suggested that the Archean seawater was enriched in dissolved Ni, suitable for methanogenic bacteria. But, their data show quite large variations in Ni/Fe ratios at the same ages from the modern value to about ten times value. Therefore, more comprehensive investigation of the BIFs through geological time is necessary to estimate secular change of chemical composition of seawater. For the purpose, we performed comprehensive investigations of geology, geochronology, stratigraphy and geochemistry of the oldest supracrustal rocks, in >3.96 Ga Nulliak Supracrustal rocks in the Nain Province, Northern Labrador, Canada (Shimojo et al., 2013).

Based on the lithostratigraphy and accompanied rocks, we classified into two types of BIFs: BIFs interlayered with metabasite in the Nulliak Island and BIFs accompanied with carbonate and/or chert layers, respectively. The former are Algoma-type BIFs, which was deposited in deep-sea near basaltic volcanism. The latter are uncommon in the Early Archaean, which are possibly formed in shallow-water environment.

Their PAAS-normalized REE+Y patterns display positive La, Eu and Y anomalies, suggesting that they were deposited in a mixing zone of seawater and hydrothermal water. In addition, transitional element contents such as Ni and Zn (>50 ppm) are high, similar to other Archean BIFs (Konhauser et al., 2009, Mloszewska et al., 2012). But, HFSE (e.g. 1~20 ppm in Zr contents) and Al<sub>2</sub>O<sub>3</sub> (0.5~2 wt%) contents are variable, and positively correlated with REE+Y and the transitional element contents, suggesting that the variation in the REE+Y contents is due to detrital inputs so that samples with low Zr and Al<sub>2</sub>O<sub>3</sub> contents preserve the detritus-free compositions. The samples with low detritus inputs show a negative correlation between Eu/Eu\* and REE and Y/Fe ratios, and between Eu/Eu\* and LREE/REE and Y ratios, respectively. The similar correlations are reported for iron-rich suspended particulates collected from the TAG hydrothermal field (German et al., 1990). Therefore, the REE+Y variations can be explained by continuous scavenging processes by iron-oxyhydroxide particles. Moreover, no Ce/Ce\* anomaly is consistent with anoxic seawater in the Early Archaean.

In addition, transition metals (Ni, Zn, Co)/Fe ratios correlate negatively with Eu/Eu\*. The correlations were also shown in BIFs in the Isua Supracrustal Belts and the Nuvvuagittuq Supracrustal Belts (Bolhar et al., 2004; Mloszewska et al., 2012), suggesting that their variations are due to same scavenging processes by iron-oxyhydroxide particles as REE+Y. Namely, the transition metals/Fe ratios of BIFs don't provide direct estimate of those concentrations of seawater. We normalize their transitional metals by rare earth elements (e.g. Sm), which are adsorbed on iron-oxyhydroxide similar to the transition metals. Sm-normalised transitional metals contents of the Archaean BIFs are higher than those of Proterozoic BIFs, suggesting that the Archaean seawater was enriched in transitional metals such as Ni and Zn, which are essential for protein synthesis of the early life.

**Reference** : Konhauser et al., 2009. *Nature* 458, 750-754. ; Shimojo et al., 2013. *Goldschmidt 2013*, Florence, Italy.; German et al., 1990. *Nature* 345, 516-518. ; Bolhar et al., 2004. *EPSL* 222, 43-60. ; Mloszewska et al., 2012. *EPSL* 317-318, 331-342.

キーワード: 初期太古代, 生命必須元素, 縞状鉄鉱層

Keywords: Eoarchean, bioessential elements, Banded Iron Formations

In-situ iron isotope analysis of pyrite in ca. 3.8 Ga metasediments from Isua supracrustal belt, Greenland  
In-situ iron isotope analysis of pyrite in ca. 3.8 Ga metasediments from Isua supracrustal belt, Greenland

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The timing of emergence of life still remains one of the unresolved questions in the early Earth. Early life could be identified and characterized by its metabolic processes, which must be deposited and preserved in the old rocks. The oldest (ca. 3.8Ga) sedimentary rocks on Earth occur in the Isua supracrustal belt (ISB), southern West Greenland. These rocks have been subjected to until amphibolite facies metamorphism (Nutman, 1986; Hayashi et al., 2000). Despite the contribution of the intense thermal metamorphism, carbon isotope compositions from the Isua metasediments suggested the evidence for biological carbon fixation. Microbial dissimilatory iron reduction (DIR) is also considered to be one of the earliest metabolisms on Earth.  $\sigma^{56}\text{Fe}$  value of  $\text{Fe}^{2+}_{aq}$  generated by DIR is expected to have lower value, whereas negative  $\sigma^{56}\text{Fe}$  values lower than -1 ‰ are not found in the sedimentary record prior to 2.9Ga. Here, we report the *in-situ* iron isotope analysis of pyrite in sedimentary rocks from the ISB, using femtosecond laser ablation multi-collector ICP-MS technique (fs-LA-MC-ICP-MS). We obtained a large variation of iron isotope data from -2.41 to +2.35 ‰ in  $\sigma^{56}\text{Fe}$  values, from 212 points of pyrite grains in 15 rock specimens, including metachert, muddy metachert, BIF, carbonate rock and conglomerate. The distribution of  $\sigma^{56}\text{Fe}$  values varies depending on the lithologies and depth gradient, whereas no correlation could be found between  $\sigma^{56}\text{Fe}$  values and the metamorphic zone.

Low  $\sigma^{13}\text{C}$  values of graphite in ISB muddy metachert suggested the existence of biological carbon fixation(e.g., Schidlowski et al.,1979).  $\sigma^{56}\text{Fe}$  values of pyrite grains from the shallow water samples show lower  $\sigma^{56}\text{Fe}$  values, which suggested the occurrence of microbial DIR in the Early Archean.

Keywords: Early archean, Isua supracrustal belt (ISB), iron isotope ratio, pyrite, microbial dissimilatory iron reduction (DIR)



## カナダ, ラブラドル地域の太古代初期の Nain 岩体に含まれる炭質物の起源 The origin of carbonaceous material in the Early Archean Nain Complex, northern Labrador, Canada

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Presence of early life in the Early Archean is still controversial, and it is a key issue to find evidence for early life from the Early Archean rocks. Carbon isotope ratio ( $\delta^{13}\text{C}_{org}$ ) of carbonaceous matter (CM) is widely used as an indicator of existence of life (Schidlowski, 2001). CM in the 3.80 Ga metasediments of the Isua Supracrustal Belt (ISB), southern West Greenland has low  $\delta^{13}\text{C}$  values, interpreted as evidence for organism in the Early Archean (Rosing, 1999). Recently, Ohtomo et al (2013) showed the nano-scale microstructure of the CM, evident for originating from organisms. In contrast, it is presumed that CM in the Nuvvuagittuq Supracrustal Belt (~3.75Ga) has a secondary metamorphic origin because the crystallization temperature (~380 °C) of the CM estimated from LA-Raman spectrums is much lower than than metamorphic temperature (~640 °C) (Papineau et al., 2011). Moreover, a putative banded iron formation in the Akilia Island (~3.83 Ga) including apatites with carbonaceous inclusions with the low  $\delta^{13}\text{C}$  provides another evidence for the life, but the precursor is still controversial (Fedó and Whitehouse, 2002). Thus, there is no obvious evidence for presence of life in the Early Archean except for that from ISB.

Shimojo et al. (2013) showed that >3.96Ga metasediments exist in the Nain Complex, northern Labrador, Canada. The Nain Complex is ca. 100 million years older than the Akilia association, which has the oldest supracrustal rocks in the world. The purpose of this research is to reveal the origin of the CM in the sedimentary rocks in the Nain Complex.

We selected pelitic gneisses (n=70), conglomerates (n=14), carbonate rocks (n=39), cherts (n=30), chert nodules in carbonate rocks (n=3) and amphibolites (n=5) from over 2000 samples over the Nain Complex based on the metamorphic grade, geography, their field occurrence and degree of alteration. Among the metasedimentary rocks (n=156), 54 specimens including pelitic gneisses (n=21), conglomerates (n=4), carbonate rocks (n=26) and chert nodules in carbonate rocks (n=3) contain CM. Seven CM-bearing rock samples were selected for  $\delta^{13}\text{C}_{org}$  analysis: pelitic gneisses (n=4), conglomerates (n=1), carbonate rocks (n=1) and chert nodules (n=1), and 3 carbonate rock samples for  $\delta^{13}\text{C}_{carb}$  analysis, respectively.

Metamorphic grade was estimated for mineral paragenesis and garnet-biotite thermometry. Among the seven CM-bearing rock samples, the six samples were metamorphosed under up to the amphibolite facies condition, and a sample under the lower granulite facies condition, respectively. The metamorphic temperatures are consistent with the estimated crystallization temperature of the CM calculated by Raman spectral parameters.

$\delta^{13}\text{C}_{carb}$  values range from -3.75 to -2.63 ‰. Because it is well known that secondary alteration and metamorphism decrease a  $\delta^{13}\text{C}_{carb}$  value (Schidlowski et al., 1979), a primary  $\delta^{13}\text{C}_{carb}$  value was estimated to be higher than -2.63 ‰. As a result, the  $\delta^{13}\text{C}_{carb}$  value of marine bicarbonate was at least -2.63 ‰ in the Early Archean.

$\delta^{13}\text{C}_{org}$  values of pelitic gneisses range from -28.86 to -14.07 ‰. The  $\delta^{13}\text{C}_{org}$  values of conglomerate, carbonate rock and chert nodule are -17.52, -5.72 and -10.60 ‰, respectively. Metamorphism, generally speaking, increases a  $\delta^{13}\text{C}_{org}$  value of CM due to partial thermal decomposition, especially methane degassing, suggesting that the variation in the  $\delta^{13}\text{C}_{org}$  values is due to secondary thermal decomposition. The correlation of the  $\delta^{13}\text{C}_{org}$  values with distribution of organic matter under microscopic observation also supports the partial decomposition and consequent increase of the  $\delta^{13}\text{C}_{carb}$  values. As a result, the lowest  $\delta^{13}\text{C}_{org}$  value is a maximum estimate of the  $\delta^{13}\text{C}_{org}$  value.

The minimum fractionation between the  $\delta^{13}\text{C}_{org}$  and  $\delta^{13}\text{C}_{carb}$  reaches 25 ‰, indicating biologic origin for the CM. This work presents the organism has already existed ca. 3.96 Ga.

キーワード: 炭質物, ラブラドル, 初期生命, 炭素同位体比  
Keywords: CM, Labrador, early life, carbon isotopic ratio

## 重元素同位体比から探る鉱化熱水の起源 Sr-Nd-Pb isotopic compositions of hot spring water in the Toyoha Mine, Hokkaido Japan: Implications for the origin of hy

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Chemistry and dynamics of slab-derived fluids in subduction zones have been rigorously studied by high pressure experiments, geochemical and hydrological modellings, and geophysical observations [1-5]. Surface manifestation of deep slab-derived fluids are now suggested by geochemistry, such as slab fluid-like chemical affinities found in volcanic rocks [6,7] and in hot spring waters [8]. In this study, we aim to examine the presence (or absence) of slab derived fluid signatures in hot spring water related with the Toyoha Mine ore deposits in Hokkaido, one of the largest hydrothermal vein-type deposits in Japan. We applied Sr-Nd-Pb isotope analyses of the hot spring water and compared the results to those from the volcanic rocks and the ore minerals from the Toyoha Mine.

For this purpose, we have examined a ferric co-precipitation pre-concentration method for the hot spring water from the Toyoha Mine. This was necessary because the abundances of Nd and Pb were very low, less than several ppb for Nd, in particular. The method has previously been applied to brines with high chlorine concentration at Arima hot spring [9], and the method worked well with the Toyoha hot spring water. The concentrated sample has been analyzed by Q-ICP-MS and MS-ICP-MS for both element abundances and Sr-Nd-Pb isotopic compositions. We examined origin of the hot spring water by using Sr-Nd-Pb isotope systematics in comparison with the data from the ore deposit, volcanic rocks related with the ore deposition, and the basement rocks of the Toyoha Mine. A recent study has shown that Sr-Nd-Pb isotopic ratios of sulfide ores in the Toyoha Mine exhibit a high contribution of slab-derived fluid from the Pacific Plate slab [10]. Our preliminary results on the hot spring water suggest that the water may also preserve the slab-fluid signatures and/or may also be affected by the chemical components in the basement rocks.

[1] Schmidt and Poli, 1998, EPSL [2] Hacker et al., 2003, JGR [3] Iwamori, 1998, EPSL [4] Arcay et al., 2005, PEPI [5] Cagnioncle et al., 2007, JGR [6] Pearce et al., 2005, G3 [7] Nakamura et al., 2008, NGeo [8] Kusuda et al., in revision [9] Nakamura et al., submitted [10] Hieda, 2013, Master Thesis, Univ. of Tokyo

キーワード: 温泉水, 同位体, 豊羽, 鉱床, 熱水  
Keywords: hot spring, isotope, Toyoha, mine, ore

## 熱水性鉱床生成過程におけるスラブ起源流体の寄与の解明 The contribution of slab-fluids to the formation of hydrothermal vein-type deposits

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It has been recently pointed out that "geofluids" released from the subducting plates are involved in various products in subduction zones, such as arc magmas, deep-seated hot springs and hydrothermal vein-type deposits. Systematic investigations of these various materials are needed for identifying the geochemical characteristics of the geofluids. Nakamura et al. (2008) revealed the heavy isotopic compositions of slab-fluids derived from two subducted plates (the Pacific plate and the Philippine Sea plate) which contribute largely to the genesis of arc magmas in Central Japan.

In this study, we focus on the hydrothermal vein-type deposits in Japan. It has been previously considered that hydrothermal fluids that form sulphide mineral (pyrite, chalcopyrite, sphalerite, galena etc.) deposits were originated from magmatic and/or meteoric waters [2]. However, we reported that Pb isotopic compositions of the sulphide ore samples were plotted between Philippine Sea plate (PHS)-fluid and Pacific plate (PAC)-fluid, suggesting that ore fluids responsible for the hydrothermal deposits are directly derived from deep slab-fluids. Here we report multi-isotopic compositions (Pb-Nd-He) of sulphide ores, associated volcanic rocks, and the surrounding country rocks from the Toyoha polymetallic (Zn-Pb-Ag-Cu-Sn-In) vein-type deposit (one of the largest hydrothermal vein-type deposits in Japan) in order to understand the relationship between slab-fluid and formation of vein-type deposit in more detail.

**Results and Discussion:** We collected twenty-six sulphide ore samples, and fifteen associated volcanic and country rocks from the Toyoha Mine. The  $^{206}\text{Pb}/^{204}\text{Pb}$  values of sulfide ore samples are significantly larger than those of the Muine volcanic rocks which have been long thought to be genetically related to the formation of Toyoha deposit. In addition, the  $^3\text{He}/^4\text{He}$  values of Toyoha galena samples range between 5 and 6 times the atmospheric ratio, implying the significant contribution of the mantle component, and strongly suggest that there is a contribution from deep-derived fluid to the Toyoha ore fluid. The correlation between  $^{207}\text{Pb}/^{204}\text{Pb}$  and  $^{143}\text{Nd}/^{144}\text{Nd}$  shows that the relative contribution of PAC fluid component in the Toyoha ores is significantly higher than that involved in the Muine volcanic rocks. It can be estimated that more than ~80% of Pb of the Toyoha ore deposit is derived from slab-fluids. Based on the present measurements and mass balance calculations, it is very likely that the slab-fluids supplied the major part of Pb and other metals concentrated in the Toyoha district.

Keywords: Pb isotopic composition, hydrothermal deposit, slab-fluid

## 太古代熱水変成作用：珪化作用とその海水組成や生命進化への影響 The Archean hydrothermal alteration: Significance of silicification for seawater composition and biological evolution

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The earth is the active planet, where higher forms of life live. Presence of liquid water on surface of planet is necessary to organisms: thus a planet with the liquid water is called a habitable planet. But, enrichment in bioessential elements is also important because they are demanded for their activity. In addition, it is required that they are continuously supplied to biosphere through the elemental cycle. Especially, phosphate is one of the most important nutrients because the DNA and RNA contain large amounts of phosphate contents. Nickel is a bioessential element for methanogen, which was more active in early Earth. However, phosphorus, iron, and nickel are highly depleted in modern seawater because oxic modern seawater causes precipitation of iron oxyhydroxide, which effectively remove the phosphorus and nickel through their adsorption on iron precipitates. The evolution of seawater composition through geologic time accounts for the apparent paradox, namely ancient seawater was enriched in the phosphorus and nickel contents (Planavsky et al., 2010; Konhauser et al., 2009). But, the mechanism of high phosphorus and nickel contents in seawater is still ambiguous. This works presents silicification plays important roles not only on the supply of the phosphorus and nickel into seawater but also on preventing adsorption of the elements on iron hydroxide.

Comparison between major element compositions of modern altered and non-altered MORB (Alt & Honnorez, 1984) indicates present-day hydrothermal alteration increased phosphorus contents relative to titanium contents in the altered basalts because altered MORBs commonly contain over four times higher phosphorus contents than the fresh equivalents (e.g. Alt & Honnorez, 1984, CMP). Therefore, the hydrothermal fluid has relatively low phosphorus content. On the other hand, comparison between Archean altered and non-altered MORB indicates the Archean altered basalts contain relatively lower phosphorus contents than the fresh equivalents (Komiya et al., 2002, IGR, Nakamura & Kato, 2004, GCA). The different behavior of phosphate during the hydrothermal alteration of basalts suggests higher phosphate contents in the Archean hydrothermal fluids. In addition, silicified basalts in the Archean greenstone belts are completely depleted in phosphorus, indicating much amounts of phosphorus were supplied into seawater. Comparison between nickel contents of altered and non-altered basalts and peridotitic komatiites indicates the altered rocks are more enriched in nickel under the moderate hydrothermal alteration condition, contrast to previous hypothesis (Konhauser et al., 2009). However, silicified basalt and peridotitic komatiite are completely depleted in sodium, phosphorus and nickel except for potassium, indicating silicification effectively supplied nickel and others to ocean. It is considered that formation of banded iron formation caused effective removal of nickel and phosphorus from seawater. Especially, recent study of their rare earth element patterns, namely Y/Ho and Sm/Yb ratios, indicate iron oxyhydroxide were precipitated much more from seawater in the Early Archean, suggesting phosphorus and nickel were more efficiently removed from seawater. Higher silica content of seawater in the early Earth accounts for the apparent paradox. The high silica content of ancient seawater had a significant role of the preventing adsorption of phosphorus and nickel on iron oxyhydroxide as well as supplying more phosphorus and nickel to seawater at the hydrothermal alteration.

We propose that high silica contents of ancient seawater resulted in high phosphorus and nickel contents of seawater in the early Earth.

キーワード: 珪化作用, 初期地球, 古海水組成, 栄養塩と生命進化, 玄武岩とコマチアイト

Keywords: Silicification, Early Earth, Paleo-seawater, Nutrient and biological evolution, Basalt and komatiite

## 原始海底熱水系における超好熱メタン菌の窒素固定 Potential nitrogen fixation by hyperthermophilic methanogens on the early Earth

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Hyperthermophilic hydrogenotrophic methanogens are considered to represent one of the most important classes of primary producers in hydrogen (H<sub>2</sub>)-abundant hydrothermal environments throughout the history of Earth. Despite extensive studies of methanogenesis, comprehensive research on nutrient anabolism in hyperthermophilic methanogens is limited. We first investigated the physiological properties and isotopic characteristics of experimental cultures of hyperthermophilic methanogens during the fixation of dinitrogen (N<sub>2</sub>), an abundant but less-bioavailable compound in hydrothermal fluids. We found that these hyperthermophilic methanogens actively assimilated N<sub>2</sub> via molybdenum (Mo)-iron (Fe) nitrogenase under broad ranges of Mo and Fe concentrations relevant to present and past oceanic and hydrothermal environments. Furthermore, the methanogens produced more <sup>15</sup>N-depleted biomass than that previously reported for diazotrophic photosynthetic prokaryotes. These results indicate that diazotrophic methanogens can be broadly distributed in seafloor and subseafloor hydrothermal environments, where the availability of the transition metals is variable and organic carbon and nitrogen compounds and ammonium are extremely scarce. The possible emergence and function of diazotrophy coupled with methanogenesis 3.5 billion years before the present may be inferred from the nitrogen and carbon isotopic records of kerogen and fluid inclusions from hydrothermal deposits.

## 西オーストラリア・クリバービル地域の形成史 Reconstruction of tectonic history of the Cleaverville area in Coastal Pilbara Terrane, western Australia

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The Dixon Island - Cleaverville formations of the Coastal Pilbara Terrane, Western Australia, is one of the most complete sections of a volcano-hydrothermal sequence of the immature island arc (Kiyokawa & Taira, 1998). These formations composed of the Dixon Island (DX) Formation, Dixon pillow basalt and the Cleaverville (CL) Formation. The CL Formation is unconformably overlain by the Lizard Hills Formation. The Lizard Hills Formation was formed in syncline basin (66 Hill Member) during collisional D1 deformation and pull-apart basin (44 Hill Member) during sinistral slip D2 deformation (Kiyokawa et al., 2002).

In this study, depositional ages of the CL Formation and the Lizard Hills Formation (44 Hill Member and 66 Hill Member) were examined by the analysis of U-Pb zircon dating. Zircons were measured using SHRIMP2 at National Institute of Polar Research. Metamorphic age of the DX Formation was obtained by the whole-rock 87Rb-86Sr isochron using TIMS (Thermo TRITON and MAT253) at the Pheasant Memorial Laboratory, Institute for the Study of the Earth's Interior at Misasa.

As a result, U-Pb zircon age of felsic tuff in the CL Formation is 3108(+14/-7) Ma. Detrital zircon ages of the 44 Hill Member showed main peaks at 3280-3200Ma and 3030-3020Ma. Detrital zircon ages of the 66 Hill Member also showed peaks at 3300-3200Ma, 3100-3050Ma, and minor group of 3700Ma. The Rb-Sr data define clear correlation line in the 87Rb-87Sr evolution diagram which corresponds to an age of 2210+/-60 Ma.

In conclusion, sedimentation age of the DX formation is 3195+/-12Ma (Kiyokawa et al., 2002) and the CL Formation is 3108(+14/-7) Ma. The average of sedimentation rate in DX-CL formations is 2~3mm/ky as total thickness between these ages is 250m. After the sedimentation of the CL Formation, syncline basin (the Sixty-Six Hill Member) was formed by D1 during 3088~3020 Ma. D2 faulting with pull-apart basin (44 Hill Member) was formed after the quartz porphyry (3020Ma) and the massive tonalite became to expose on land surface. The Rb-Sr age in the DX Formation as 2210+/-60 Ma corresponds to the timing of Ophthalmanian orogeny (2145~2215Ma) in the southern margin of the Pilbara Craton (Rasmussen & Sheppard, 2005). The DX-CL formations probably had been affected by wide scale metamorphism at this timing.

## 34.5 億年前南アフリカバーバートン玄武岩の Lu-Hf 同位体システムティクスと初期マントル進化 Lu-Hf isotope systematics of 3.45Ga Barberton basalts : implications for early mantle evolution

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Bulk Silicate Earth(以下,BSE)の分化過程は、地球全体における元素分布を支配し、地球内部の温度分布や熱進化、マントル対流などのダイナミクスを大きく左右したと考えられる。従って、BSEの分化過程を理解することは、地球の進化を議論する上で必要不可欠である。そのための強力な手法の一つに Lu-Hf 放射性同位体地球化学がある。この手法は 2000 年以降急速にその研究報告が増え、従来から用いられてきた Sm-Nd 系と組み合わせることで、地球形成初期の深部溶融の可能性等、幾つか新しい知見が Lu-Hf 系列の研究によって得られている (Rizo et al., 2011)。

しかし、Lu-Hf 壊変系列を太古代試料に適用した先行研究のデータをコンパイルしていくと、二つの不確実性の存在が浮かび上がる。一つは、変成変質の影響をしっかりと評価している試料とそうでない試料が混在したまま、議論が展開されている点。もう一つは、コマチアイトの Hf 同位体組成と玄武岩の Hf 同位体組成を同列に扱って議論をしている点である。変成変質の影響をしっかりと吟味した試料だけで議論していくことは当然として、地球史を通じたマントルの分化を議論する際、異なるタイプの岩石の同位体比を同列に扱うことの妥当性にはまだ不明な点が多く、どちらかの試料で揃えて議論していくことも必要であろう。特に、今回のコンパイルからは、 $\epsilon_{Hf}$  が顕著に正を示し始め、幾つかの先行研究で現世のプレートテクトニクスが始まったと主張されている 35 億年前後の試料が、他の年代の試料と異なり、コマチアイトに限られていることが確認された。

そこで、本研究では、35 億年前後の玄武岩の Hf 同位体比を提出するため、34.5 億年前の南アフリカバーバートンの玄武岩の高精度 Hf 同位体分析を行った。現在は、Kromberg Complex から採取され 7 種 8 サンプルの分析を終え、その結果は全 ± 8 サンプルで、 $2801 \pm 690\text{Ma}(\text{MSWD}=49.2, \sigma, N=8)$  という年代値を示し、また、岩石学的地球化学的情報からより初生的な情報を保持していると判断される試料のみを用いると、そのアイソクロン年代は  $3890 \pm 1100\text{Ma}(\text{MSWD}=9.62, 2, \sigma, N=4)$  となった。更に、分析試料の形成年代が 3450Ma とし計算した初生  $^{176}\text{Hf}/^{177}\text{Hf}$  は  $0.28043 \pm 0.00051$  で、この結果をコンドライトからの相対的なずれで表すと、 $\epsilon_{Hf}(3445\text{Ma})$  は  $2.66 \pm 0.66$  となる。このことは、バーバートンの玄武岩のソースマントルが 35 億年より以前に既に溶融を経験し、液相濃集元素に枯渇していたことを示す。また、他地域の太古代玄武岩の同位体組成と併せて、マントル Hf 同位体進化線を推定すると、その線は 40 億年前に分化イベントを経験し、Lu/Hf 比が 0.296 になっていたとすると説明できることが分かった。この Lu/Hf 比は、BSE のそれよりも有意に高く、MORB ソースマントルの Lu/Hf 範囲内となる。従って、太古代初期のマントルは、現在の上部マントルと同程度の Lu/Hf 分別を経験していたことが分かった。更に、既に報告されている Nd 同位体比と組み合わせて議論を行い、バーバートン地域のコマチアイトや玄武岩の同位体的類似性を確認し、バーバートン地域のコマチアイトと玄武岩の作り分けを含む形成モデルの提案をした。また、マントル分化が地球深部で行われていた可能性と、その痕跡が何らかのメカニズムによって希釈されてきた可能性を示した。発表当日は、データ数をさらに増やし、より精緻な議論を上記の内容に関して行う予定である。

キーワード: マントル進化, 玄武岩, バーバートン, Lu-Hf, 太古代, 同位体分析  
Keywords: Mantle Evolution, Basalts, Barberton, Lu-Hf, Archean, Isotopic Analysis

## 『隠された貯蔵庫』の主成分元素組成と生成条件 Major element composition and forming condotion of the hidden reservoir

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マグマオーシャンの固結とそれに続くマントル-地殻分化は、固体地球の進化や水圏の進化に大きな影響を与えた可能性がある。しかし、その詳細は未だ不明な点が多い。先行研究で、コンドライト隕石と地球の地殻・マントルを合わせた組成 (BSE) の間に  $^{142}\text{Nd}/^{144}\text{Nd}$  値の差があることが報告されているが、これはケイ酸塩に不適合な元素に富んだ貯蔵庫が初期地球で形成されたのち地球内部に隠されたか、地球外部に失われたことに由来するものと示唆されている。この『隠された貯蔵庫』の組成や起源については様々な説が提案されてきているが、それらは主成分元素組成には焦点を当ててこなかった。しかし、主成分元素組成は隠された貯蔵庫の密度を知り、それが果たして上昇して初期地殻を形成したのか、それともマントル中で沈降したのかを調べる上で非常に重要である。よって本研究では、この隠された貯蔵庫の主成分元素組成を求めめるために、過去と現在のマントルの  $^{142}\text{Nd}/^{144}\text{Nd}$ 、 $^{143}\text{Nd}/^{144}\text{Nd}$  系の制約の下、隠された貯蔵庫をつくる融解条件を推定した。

Solomatov and Stevenson(1993)によれば、固結していくマグマオーシャン中で、メルトが分離するのは圧力 10GPa 以下の上部マントル浅部である可能性が高い。この推定に基づいて、本研究では隠された貯蔵庫は 10GPa 以下で生成されると仮定した。そしてこの仮定のもと、コンドライト隕石と BSE の間の  $^{142}\text{Nd}/^{144}\text{Nd}$  値の差に整合的な Sm/Nd 比を計算し、この Sm/Nd 比を満たす部分融解度を推定した。この計算により、部分融解度は 1 GPa で < 5.2%、3 GPa で < 3.2%、7 GPa で < 1.4% となった。そしてこれらの部分融解度と先行研究の実験データを用いて隠された貯蔵庫の主成分元素組成を推定すると、それぞれ不適合元素に富んだソレアイト、ピクライト、コマチアイトとなった。

過去のマントルが現在よりも高温だったと考えると、マントルはより深部で融けていたことになる。一方で、本研究によって部分融解度は小さいと推定されている。マントル深部で融解が起こり、かつ小さな部分融解度となるには、リソスフェアが厚いことが必要である。マントルが高温の時に厚いリソスフェアがある可能性は、Korenaga(2009)によって示唆されている。これらの結果から、隠された貯蔵庫の主成分元素組成は微量元素に富んだピクライトからコマチアイトである可能性が高い。

Solomatov and Stevenson(1993), *Journal of Geophysical Research*, **98**, 5407-5418

Korenaga(2009), *Geophysical Journal International*, **179**, 154-170

キーワード: 隠された貯蔵庫, 初期地殻,  $^{142}\text{Nd}/^{144}\text{Nd}$

Keywords: hidden reservoir, proto-crust,  $^{142}\text{Nd}/^{144}\text{Nd}$



## 西オーストラリア・ノースポール玄武岩から推定される太古代マンツルの分化と物質循環 Differentiation and material recycling of Archaean mantle estimated from North pole basalt, Western Australia

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Mid-ocean ridges and hotspots are the prominent surface manifestations of mantle upwelling with different mechanisms. In these domains, two types of basalts, i.e., mid-oceanic basalt (MORB) and oceanic island basalt (OIB) occur. Recent statistical analysis on the global data set of the Sr-Nd-Pb isotopic compositions demonstrates that modern MORB and OIB are clearly separated: MORB is derived from a mantle source that has undergone long-term depletion in a "melt component", while OIB is derived from a mantle source with long-term enrichment in the melt component through the recycling of subducted plate material (Iwamori and Albarede, 2008; Iwamori et al., 2010). Therefore, when plate recycling started to develop the geochemical domains is of great importance to understand the material differentiation and evolution of the Earth.

In this study, we present new trace element and Sr-Nd isotope composition of Archaean MORB and OIB, in order to discuss the differentiation of the mantle at that period and compositional evolution of the mantle for a longer period of the Earth's history. The basaltic rocks of ca. 3.5 Ga from North Pole in northwestern Australia have been analyzed, which include have been classified as MORB and OIB by their geological occurrence and stratigraphy in by Komiya et al. (2002). The rocks have undergone greenschist to amphibolite facies transition metamorphism (Komiya et al., 2002). The original rock compositions may have been modified by metamorphism. In order to examine potential metamorphic modification of the bulk rock composition, so we have measured composition of igneous clinopyroxene which shows original igneous texture, in addition to bulk composition, with special reference to equilibrium/disequilibrium partitioning of trace elements between clinopyroxene and the bulk rock estimate the effect of metamorphism using partition coefficient.

The composition of North Pole MORB (NP MORB) and OIB (NP OIB) show slightly different trace element patterns. Some spikes in alkaline elements and alkaline earth metal elements and variability of the initial Sr isotopic compositions may result from metamorphic modification effect. The initial Nd isotopic compositions of NP MORB and NP OIB are similar to each other. However, most of the samples have  $\epsilon\text{Nd} < 0$ , which is not typically expected for a mantle-derived basalt. characteristic is typical for felsic rocks. The apparent elemental partitioning between partition coefficient of clinopyroxene and the estimated 'melt', as well as a relatively clear correlation between Sm/Nd and Nd isotopic ratio, suggests that metamorphism has also disturbed Nd isotopic compositions even for clinopyroxene which preserves igneous texture, resulting in  $\epsilon\text{Nd} < 0$  of the bulk rocks. The isochron may show the metamorphic age of ca. 3.1 Ga. These approaches, therefore, may provide a quantitative measure for metamorphic geochemical modification of us, we need to gain the original composition from Archaean rocks, and will be useful, or even compulsory to discuss the true mantle signatures. to discuss the differentiation of mantle.

Keywords: Archaean, North Pole, basalt, mantle, isotope, differentiation

## 碎屑性モナザイトのU-Pb年代測定によるアフリカ大陸構造発達史の推定 Development of the African continent constrained from U-Pb chronology of detrital monazite

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Monazite, a light rare earth element phosphate, occurs as an accessory mineral in peraluminous felsic rocks and metamorphic rocks from subgreenschist- to granulite-facies. Because monazite has high U and Th and low common Pb contents, it is suitable for precise U-Pb chronology. In addition, monazite is moderately resistant to chemical and mechanical weathering, detrital monazites are well preserved and potentially record the timing and nature of peraluminous igneous activities and a wide range of metamorphic events in their provenance area. Consequently, detrital monazites from large rivers can provide valuable insights into orogenic events in the drainage basins on a continental scale (Hietpas et al., 2013). In this study, we have determined U-Pb ages of ca. 100 detrital monazite grains from the Nile and Niger Rivers, which give chronological information on orogenic events in the African continent with a high time resolution.

The African continent comprises several Archean-Paleoproterozoic cratons, which are rimmed by orogenic belts. A significant part of igneous and metamorphic basement rocks are covered by sediments and therefore inaccessible to in situ sampling at present. Considering that detrital monazites sampled from river sands would partly be derived from the currently inaccessible basement rocks over an extensive area, U-Pb dating of detrital monazite from large rivers can provide chronological information of the basement rocks complementary to studies of the exposed geology. The samples used in this study were collected at the river mouths of the Nile and Niger Rivers. The sand samples used in this study were previously used for zircon U-Pb dating and Hf isotopic studies by Iizuka et al. (2013). Monazite grains were newly concentrated from the river sand samples using the conventional magnetic and heavy liquid separation techniques. Monazites were randomly hand-picked from the aliquots of monazite concentrates and mounted in an epoxy mount. Before analysis, each grain was imaged by BSE using FE-SEM to check elemental zonation and the presence of inclusions. Monazite U-Pb isotopic dates were measured using 200nm-FsLA-ICP-MS. Reference monazite 44069 (U-Pb age 425 Ma) is used to correct for instrumental Pb/U fractionation.

The monazite grains from the Nile River gave U-Pb ages between 560 and 2100 Ma with a dominant population at 580-800 Ma. Furthermore, the U-Pb age population indicates a sharp peak at 600 Ma. The age peak at 600 Ma of Nile River suggests metamorphic and/or felsic igneous events occurred at that time in the drainage basin, probably related to the collision of the East and West Gondwana continents.

The monazite age population of Niger River is dominated by Neoproterozoic ages with the most prominent peak at 580 Ma and peaks at 625 and 645 Ma. The peaks shown in the Niger River monazite (580 Ma and 620-630 Ma) correspond with the timing of previously known orogenic events in Northwest Africa. A peak at 620-630 Ma is consistent with a metamorphic event at ca.  $625 \pm 29$  Ma, likely related to the collision of the West Africa Craton and West Gondwana continent (Agbossoumonde et al., 2007). The other peak at 590-600 Ma is consistent with a ca.  $576 \pm 4$  Ma post-collisional igneous event at the Pan-African Belt in Cameroon (Kuekam et al., 2013).

The age difference in the most prominent peaks of Nile and Niger monazites suggests that the timing of orogenic event in Northwest Africa was prior to that of in East Africa by ca. 10 Ma.

The accumulated monazite age distribution shows populations at 580-590 Ma, 630-640 Ma and 710-720 Ma, corresponding with the timing of Snowball Earth glaciation events. The chronological correspondence can be interpreted that the multiple Pan-African orogenic events during the Gondwana supercontinent assembly enhanced the rates of erosion and weathering via supermountain building that in turn decrease atmospheric carbon dioxide concentration resulted in glaciation.

キーワード: モナザイト, U-Pb 法, LA-ICP-MS, 汎アフリカ造山運動

Keywords: monazite, U-Pb age, LA-ICP-MS, Pan-African

## 海洋下部地殻における脱水素反応と生命活動 Significance of serpentinization of lower crust in deep-sea hydrothermal biosphere

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現在確認されている最古の生命化石は西オーストラリアのピルボラ地方にある、35 億年前の海嶺熱水脈から見つかったものとされている。海底熱水脈中の古細菌（アーケア）は、海洋カンラン岩層の蛇紋岩化に伴う脱水素反応によって生成された、水素や硫化水素をエネルギー源としていたと考えられている。（東京工業大学 上野准教授）しかし、海洋地殻表層より 7~8 km 以上深いカンラン岩層から発生した水素と古細菌活動域には深さ方向に大きなギャップが存在する。また、35 億年前の海洋地殻は現在よりさらに厚い（50 km 以上）との研究結果もあるので、アーケアがエネルギー源とした水素は、カンラン岩層より上部から発生していた可能性が考えられる。

中央海嶺の断裂により海洋地殻に進入した海水は下部地殻の斑レイ岩層で超臨界の熱水を形成している。斑レイ岩層にもカンラン石が含まれるので、カンラン石の蛇紋岩化に伴う水素形成はおこりうる。また、古細菌は熱水条件下でも安定に存在できるので斑レイ岩層内での熱水熱水に生息している可能性がある。そこで、斑レイ岩層から岩石を採取し、分析を行っていく。

キーワード: 原始生命, 蛇紋石化, 斑レイ岩

Keywords: the oldest biosphere in early Earth, serpentinization, gabbroic rocks

蛇紋岩熱水系における炭化水素の生成メカニズムの解明：強アルカリ性白馬八方温泉の同位体解析  
Production mechanism for hydrocarbons in serpentinite-hosted hydrothermal systems: Hakuba Happo hot spring

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Serpentinite-hosted hydrothermal systems have been considered to be important environment for birth or evolution of earlier life. Serpentinite is a rock that results from the geological processes of hydration and metamorphic transformation of ultramafic rock from the Earth's mantle. Although ultramafic rocks are rarely exposed at the surface of the Earth today, they were likely to be an abundant component of the early crust owing to the higher potential temperatures compared to the present-day mantle [Komiya et al., 2004]. The presence of hydrocarbons has been reported in serpentinite-hosted systems at not only seafloor but also continental settings [e.g., Charlou et al., 2002; Proskurowski et al., 2008; Etiope et al., 2011; Szponar et al., 2013]. However, production mechanisms of the hydrocarbons in serpentinite-hosted hydrothermal systems so far has not been satisfactorily understood. In this study, we conducted chemical and isotopic analyses of hydrocarbons from a continental serpentinite-hosted hydrothermal system; Hakuba Happo hot spring in central Japan. Hakuba Happo hot spring is situated in the ultramafic rock body and is a site where serpentinization processes are likely to be ongoing at low-temperature of 50-60 °C [Suda et al., 2014]. The water at Hakuba Happo is strong alkaline (pH >10.5) and rich in H<sub>2</sub> and CH<sub>4</sub>. Gas and water samples were obtained directly from two drilling wells in November 2013. Water temperature, pH, dissolved oxygen level (DO), oxidation-reduction potential (ORP) and salinity were measured at the sampling points using portable sensors. The water temperatures and chemistries were almost exactly the same as that at previous investigations conducted in 2010 and 2011. The hydrocarbon constituents of CH<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, C<sub>3</sub>H<sub>8</sub>, iso-C<sub>4</sub>H<sub>10</sub> and normal-C<sub>4</sub>H<sub>10</sub> were detected from gas samples of Hakuba Happo hot spring. We report the isotopic analyses of hydrocarbons and discuss the process of hydrocarbons generation in serpentinite-hosted hydrothermal systems. °C

キーワード: 蛇紋岩熱水系, 炭化水素, 同位体分析, 無機的合成

Keywords: serpentinite-hosted hydrothermal system, hydrocarbon, isotopic analyses, abiotic synthesis

## 南部マリアナ前弧しんかい湧水域の地質と生物 Geology and biology of the Shinkai Seep Field in the Southern Mariana Forearc

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世界最深部マリアナ海溝チャレンジャー海淵北東 80 km に位置する「しんかい湧水域 (Shinkai Seep Field; SSF)」は、マントルかんらん岩に伴う、シロウリガイを中心とする化学合成生態系である。これまでにシロウリガイ類は、堆積物の分解に起因するメタンの湧水系に生息するもの (日本海溝・南海トラフ・相模トラフなど) と、高温の海底熱水系に生息するもの (ガラパゴスリフト・沖縄トラフなど) の大きく 2 種類が知られていたが、SSF においてマントル物質の冷湧水系に生息するシロウリガイ類が初めて発見されたこととなった。

SSF は、2010 年 9 月の YK10-12 航海における「しんかい 6500」による南部マリアナ前弧のマントルかんらん岩のマッピング調査の際に幸運にも発見された。しかし、発見時には、マントルかんらん岩とシロウリガイ類の採取には成功したものの、海水や堆積物の採取は行えなかった。その後、2012 年 1 月の R/V Thomas G. Thompson による TN273 航海において、深海曳航式サイドスキャンソナー (IMI-30) による SSF の反射強度マッピングを実施し、高解像度の反射強度イメージを取得した。その結果、SSF はローカルな堆積性のマウンドに存在している可能性が示されたと同時に、そのようなマウンドが南部マリアナ前弧に多数存在している可能性が示された。

この新しい化学合成生態系の地質・地球化学・生物学・微生物学を理解するため、次の科学目的を掲げて 2013 年 9 月に YK13-08 航海において「しんかい 6500」による調査を実施した: (1) SSF において、「しんかい 6500」の潜航により冷湧水ベントの発見・探査・湧水の採取を行うこと (2) 反射強度マップで示されるマウンドに SSF と同様な湧水系が発達している、という仮説が提示できるのでその検証を行うこと (3) 年代学を含め、南部マリアナ前弧の地質学的背景の理解、すなわち SSF という蛇紋岩生命圏の存在するセッティングの理解を完全なものとする。

YK13-08 航海では、第 1362 潜航、第 1365 潜航および第 1366 潜航において、SSF を再訪し、堆積物コア試料採取、生物採取、ニスキンおよび保圧採水器による採水、溶存酸素および温度測定を実施すると共に、炭酸塩チムニーを発見し、サンプリングに成功した。また、第 1363 潜航と第 1364 潜航においては、SSF の西方約 7 km の斜面の地質調査を実施し、その部分がすべて蛇紋岩化したかんらん岩から構成されていることを確認した。一方、今回の潜航調査の限りでは、SSF 以外に新たな湧水系を発見することができず、また、反射強度イメージで示されるすべてのローカルな堆積性のマウンドが湧水系に対応している訳ではないことが確認された。本講演では、YK13-08 航海における成果を紹介し、SSF の地質と生物の議論を行う。

キーワード: 化学合成生態系, 蛇紋岩, しんかい湧水域

Keywords: chemosynthetic community, serpentinite, Shinkai Seep Field

## 中央インド洋海嶺熱水噴出域の生物相 Deep-sea hydrothermal vent fauna on the Central Indian Ridge

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深海熱水噴出域では、熱水噴出によって形成される地球化学的環境に応じて生物が分布している。この講演では、中央インド洋海嶺に分布する4つの熱水噴出域の生物群集で観察された生物種の見直しと更新を行い、中央インド洋海嶺に分布する熱水噴出域における生物分布の帯状構造、およびインド洋熱水生物地理区内外における生物群集の関連性について報告する。インド洋熱水噴出域における生物群集の知見は非常に限られているが、インド洋熱水噴出域生物群集の調査によって明らかになる知見は、世界中の海底に分布する熱水噴出域生物群集の歴史的および短期的な生物分散の一般化にとって、非常に重要なものとなるだろう。

キーワード: 化学合成生物群集, 生物地理, 群集類似度

Keywords: chemosynthetic biological community, biogeography, faunal similarity

## 地球年代学と生物多様性解析の融合による熱水系進化解析の試み A trial on evaluating hydrothermal system evolution using geochronological dating and biological diversity analyses

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To elucidate the evolution of hydrothermal activities, we conducted an interdisciplinary study including geochemistry and biology to develop a method of obtaining reliable age information. Because there was a small amount of constraint on the lifetime of activity at hydrothermal sites, this study is one of the principal goals of the TAIGA-project, "Trans-crustal Advection and In-situ biogeochemical processes of Global sub-seafloor Aquifer" funded by a Grant-in-Aid for Scientific Research on Innovative Areas. As geochemical dating techniques, two methods applicable for hydrothermal ore minerals were developed and improved to fill the gap of the time-ranges in the conventional dating methods: electron spin resonance method and uranium-thorium disequilibrium method. Cross checks between the two methods generally showed good agreement for the range of hundreds to thousands of years. Except for the extreme values for each hydrothermal site, geochemical ages exceed 9ka for the southern Mariana Trough and for 16ka for the Okinawa Trough, respectively. As biological analysis, the biodiversity among faunal communities in the targeted areas was analyzed at the species and DNA levels. In the southern Mariana Trough, *Alviniconcha* gastropods and *Neoverruca* barnacles clearly show the greater genetic diversity with greater distances from the ridge axis, which fairly corresponds to the geochemical ages for ore minerals. In the Okinawa Trough, *Bathymacrea* limpet showed greater genetic diversity at the Hakurei site in the Izena Hole where the ore minerals show oldest ages among the studied sites (Fig.).

Species and genetic diversity of the local fauna were not always correlated to geochemical dating, either in the southern Mariana Trough region or in the Okinawa Trough region. Although the results are not simple, comparison of age information obtained from analyses of these two disciplines potentially provides important constraints for discussion of the history and evolution of hydrothermal activities.

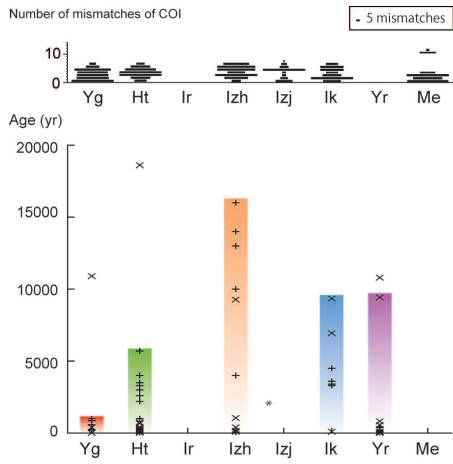
Figure caption (upper): Genetic divergence of COI gene indicated as mismatches in base sequences of *Bathymacrea secunda* limpet of the Okinawa Trough. Scale bars are shown as five mismatches of partial COI sequences. (lower) Geochemical age range determined from the sulfide and sulfate deposits in Okinawa Trough. Active sites are shown from approximately SW to NE. The left-hand side is the southwestern end. Colored bars represent reliable age ranges for respective sites. The localities are denoted as follows: Yg, Daiyon-Yonaguni Knoll; Ht, Hatoma Knoll; Ir, Irabu Knoll; Izh, Hakurei-site in Izena Hole; Izj, JADE-site in Izena Hole; Ik, Iheya North Knoll; Yr, Yoron Hole; Me, Minami-Ensei Knoll.

キーワード: 地球年代学, 生物多様性解析, 海底下の大河, 電子スピン共鳴, ウラン-トリウム非平衡, 塩基置換解析  
Keywords: geochronology, biodiversity, TAIGA-project, ESR, U-Th disequilibrium, mitochondrial mismatch analysis

BPT24-03

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## 白亜紀のウミガメ化石から発見した化学合成群集：竜骨群集と鯨骨群集をつなぐもの Chemosynthesis-based ecosystem discovered on a Cretaceous sea turtles from Japan

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深海の熱水やメタン湧水に成立する化学合成生態系は、鯨類などの大型脊椎動物遺骸にも成立する。シンカイヒバリガイやチューブワームなどの化学合成動物の遺伝子解析結果によると、これらの分類群は脊椎動物遺骸環境への適応を経て、深海の熱水・メタン湧水環境への適応を果たしたとされる（「進化の飛び石仮説」Distel et al., 2000）。新生代では鯨類が、中生代には長頸竜類（首長竜類）の遺骸に化学合成生態系が成立していたことが知られている（鯨骨群集、竜骨群集と呼ばれている）。中生代には首長竜以外にも多数の海生爬虫類が繁栄していたが、首長竜以外の海生爬虫類遺骸にも化学合成生態系が成立していたのか不明であった。

今回、北海道中川町仁尾川の上白亜系カンパニアン階から産出したオサガメ科のウミガメ類（*Mesodermochelys* sp.）の背甲からハイカブリナ科腹足類、ハナシガイ類（二枚貝）が共産した。いずれもメタン湧水群集や鯨骨、竜骨群集などの主要な分類群であり（Jenkins et al., 2007; Kaim et al., 2008, 2009 など）、ウミガメ類の遺骸にも化学合成生態系が成立していた可能性が高い。

今回の発見は海生爬虫類が繁栄した白亜紀において、首長竜以外の海生爬虫類にも化学合成生態系が成立していたことを意味する。ウミガメ類は白亜紀末の大量絶滅を逃れた稀な海生爬虫類の一つである。したがって K-Pg 境界を生き延びたウミガメ類の遺骸に成立する化学合成生態系が、中生代の竜骨群集と新生代の鯨骨群集をつないでいた可能性がある。

キーワード: ウミガメ, 化学合成群集, 竜骨群集, 鯨骨群集

## 首長竜類遺骸に成立する化学合成生態系—共産化石、生物浸食の分布に着目して— A chemosynthetic community on plesiosaurid carcass: with focus on distributions of microbes and invertebrate fossils

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### はじめに

化学合成生態系はメタン湧水や熱水噴出孔など点在する環境に成立するが、どのようにたどり着くのだろうか。ここで重要なのが、鯨骨群集と呼ばれる鯨類などの大型脊椎動物の遺骸がつくる生態系である。

海底に沈んだ鯨類遺骸の腐敗過程で生じる硫化水素を基にしてメタン湧水や熱水噴出孔と類似の生態系が形成される。この生態系は鯨骨群集と呼ばれ、点在する湧水・熱水への生物分布の「飛び石」として機能すると考えられている (Smith et al. 1989)。この事象を検証する上でも地質時代の大型脊椎動物遺骸に成立する生態系の変遷が重要である。ところが、地質時代の大型脊椎動物遺骸に成立する生態系の詳細な復元がこれまで行われてこなかった。

本研究では、化学合成生態系が成立していた中生代白亜紀の首長竜遺骸 (Kaim et al., 2008a) を対象に、1) 首長竜遺骸に共産する化石の詳細な分類を行い、周囲の湧水生態系から産出する化石と比較し、首長竜遺骸が化学合成動物の分布の「飛び石」として機能していたかを明らかにし、2) 骨、微生物、共産大型生物の空間分布を明らかにして首長竜遺骸に成立する生態系を復元した。

### 対象の標本と研究手法

・本研究では Kaim et al. (2008a) によって報告された首長竜化石 (北海道大学総合博物館収蔵 UHR33109; 北海道羽幌町白地畝沢沿いの上部白亜系チューロニアン階~コニアシアン階から産出) を使用した。関節した椎骨、肋骨、腹肋骨、左腸骨から成る。

・産地周辺の地質調査を実施し、産出層の堆積環境を調べた。標本の外表面観察、X線CT撮影像の観察を行い、層理面の推定や大型化石の分布、骨表面の保存状態を調べた。外表面の観察終了後、層理面に垂直に、また、複数の骨部位、異なる骨表面の保存状態を含むようにダイヤモンドワイヤーソーで切断し、研磨した。切断面は実体顕微鏡と偏光顕微鏡 (反射)、走査型電子顕微鏡 (SEM) を用いて観察し、生物活動に伴う穿孔痕などを記載した。

・共産化石を剖出し、実体顕微鏡や SEM による観察を行い、可能な限り詳細に分類した。産出化石を北海道各地の白亜紀メタン湧水産の化石 (Kaim et al., 2008b; Kaim et al., 2009) と比較した。

・以上の情報を統合して首長竜遺骸に成立する化学合成生態系の復元と地理的分布への寄与の有無を検討した。

### 結果

【骨表面の保存状態】元の表面組織が残っている箇所、骨表面が破壊され内部組織が露出している箇所、その中間の3段階に分けて記載した結果、上部の骨表面はほとんど破壊されていたのに対し、下部ではほぼ元の表面組織が保存されていた。断面においても、上部の骨ほど海綿骨がより露出していた。

【共産化石】共産化石の81%は *Abyssochrysoidea* 超科の化学合成腹足類 (巻貝) であった。この巻貝の分類を詳細に検討した結果2科3属が含まれることが明らかになった。共産化石は上部に多く分布していた。

【骨表面の穿孔痕】骨の表面には数10  $\mu\text{m}$  から数mmの大型穿孔痕と最大直径約8  $\mu\text{m}$  以下でフィラメント状の微小穿孔痕が見られた。大型穿孔痕は次の3タイプに区分できた。タイプA: 開口部をもたないか開口部が小さいような中に空間のある穴、タイプB: 開口部の大きな穴、タイプC: 直径50  $\mu\text{m}$  でトンネル状の穴。大型穿孔痕は骨上部に密集していた。また微小穿孔痕を、密集部の厚さに応じて0.1 mm以上、0.1 mm未満で区分したところ、骨上部ほど微小穿孔痕の密集部が厚かった。微小穿孔痕付近にはパイライトが存在していた。

### 考察

首長竜遺骸から産出した化学合成巻貝の3属はすべて白亜紀メタン湧水から産出していた。つまり、首長竜遺骸が分布の「飛び石」として機能していた可能性が高い。

微小穿孔痕は、そのサイズと形態、硫化水素の存在を示すパイライトが穿孔痕近傍にあったことなどから硫酸化細菌が形成者だったと推定した。大型穿孔痕のうち、開口部の小さな穿孔痕 (タイプA) は鯨骨内の有機物を摂取するホネク

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イハナムシと同様の生活様式を持つ生物の痕跡だと考えられる。Abyssochrysoidea 超科の化学合成巻貝はバクテリアマットを摂食することが知られている。これらの情報を統合すると、骨には硫黄酸化細菌が繁茂し、それを Abyssochrysoidea 超科巻貝が接触し、同時にホネクイハナムシ状の生物が骨内有機物を摂取するため穿孔痕を作っていたという生態系像が描ける。また、上部に微少・大型穿孔痕や化学合成腹足類が多く分布していたことは、上部ほど埋没までに要する時間が長く、その時間の積分効果で説明できる。

#### まとめ

- ・白亜紀では首長竜遺骸が化学合成動物の分布の「飛び石」として機能していたことを明らかにした。
- ・骨、微生物、共産大型生物の空間分布を明らかにして首長竜遺骸に成立する生態系を復元することができた。

キーワード: 竜骨群集, 首長竜, 空間分布, 穿孔痕, 化学合成腹足類, 分布の「飛び石」

Keywords: Reptile fall, Plesiosauridae, distribution patterns, borings, chemosynthetic molluscs

サウスダコタ州南西部の上部白亜系冷湧水炭酸塩岩から産出する化石棘皮動物の古生態学的研究  
Paleoecology of the Upper Cretaceous echinoderms from cold seep carbonates in South Dakota, USA

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冷湧水域は「化学合成群集」と呼ばれる特殊な生物群が分布する場所として知られており、その群集には多様な分類群が含まれているが、従来、棘皮動物はほとんど報告されていなかった。しかし近年、化学合成群集としての棘皮動物の例が現生・化石共に報告され始めている。だがこれらに関する研究は未着手のものが多く、特に化石においては、冷湧水炭酸塩岩マウンドからの棘皮動物化石の報告のみで、各棘皮動物と冷湧水の関係は定かではない。

冷湧水炭酸塩岩より産出する化石棘皮動物の冷湧水メタンとの関わりの程度を、その分類や化学分析を通じて明らかにすること、そしてこの特殊な環境に棘皮動物類がどのように進化適応したのかを明らかにすることを目的とし、北米 South Dakota 州南西部に分布するカンパニアン階 Pierre 頁岩中に多く存在する冷湧水炭酸塩岩マウンド群のフィールド調査を行った。冷湧水炭酸塩岩マウンドを計 21 ヶ所調査し、マウンドと、そこに付随する化石の採集・産状の観察を行った。さらに化石骨格の続成作用を把握したうえで、化石棘皮動物の骨格中の  $\delta^{13}\text{C}$  値を測定し、その値を冷湧水域外より産出する棘皮動物化石の値と比較することで、これら化石棘皮動物が湧出するメタンと実際にどの程度関連した生活をしてきたのかを調べた。

フィールド調査の結果、産出する化石種の多様度が隣接する炭酸塩岩同士でも異なることがわかった。この種の多様度の差は、炭酸塩岩の形成環境の差によるものであると考えられる。化石種の多様度が高い場所では、炭酸塩岩が長期間海中露出していたと考えられ、棘皮動物を含む表在性の生物が生活するのに適した環境を提供していたと推測される。

$\delta^{13}\text{C}$  値を測定した結果、続成作用の影響が弱いと考えられる冷湧水の化石ウミユリは -25 ‰前後のものが多く、冷湧水外に棲む現生のウミユリ (-10 ‰) や他の棘皮動物 (-10 ‰) よりもかなり低い結果となった。また、冷湧水のウミユリは他のウミユリには見られない特異的な形態をしており、 $\delta^{13}\text{C}$  値の結果と合わせて考えると、ウミユリは冷湧水環境に適応進化し、化学合成に関与した生活をしてきた可能性が高いと推測される。一方冷湧水のウニの  $\delta^{13}\text{C}$  値は約 -12 ‰と比較的低いが、冷湧水のウミユリと比べると高い値を示した。しかしこれらのウニ類に関しては、骨格内の微細構造の観察や Mg 濃度の計測の結果から続成作用の影響が強いと考えられるため、 $\delta^{13}\text{C}$  値は初生値から変化している可能性もある。ウニ類は冷湧水以外の環境から産出するものと比較してもウミユリほどの大きな形態の差は認められないため、これらのウニ類は化学合成には関与しておらず、冷湧水に付随する炭酸塩岩を住処として移住してきた可能性も考えられる。

キーワード: 冷湧水, 棘皮動物, 古生態, 化学合成群集

Keywords: cold seep, echinoderms, paleoecology, chemosynthetic community

分子系統解析から考える深海性二枚貝シロウリガイ類における化学合成共生細菌の  
宿主転換の可能性  
Molecular phylogenetic evidence for host switching in chemoautotrophic symbionts of  
deep-sea *Calyptogena* clams

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*Calyptogena* clams are living in deep-sea chemosynthetic habitats and globally distributed in seeps and hydrothermal vents. They are nutritionally dependent on chemoautotrophic sulfur oxidizing bacteria, which are harbored within their gill epithelial cells. The *Calyptogena* symbionts are thought to be vertically transmitted via clam's egg to the next generation. Both host and symbiont are thought to coevolve, because topologies of the phylogenetic trees of them form a mirror image. However, their phylogenetic trees have not been robust enough for analyzing their coevolutional relationship, because of using partial gene sequences of host (mitochondrial *cox1* and *rrnL* genes) and symbiont (16S rRNA gene). The possibility of lateral acquisition of the symbiont has been reported in some *Calyptogena* lineages. To improve the phylogenetic trees of *Calyptogena* clams and of symbiont, we sequenced the mitochondrial genomes of *Calyptogena* clams, and several their symbiont genes, and analyzed the phylogenetic trees by using the concatenated sequences.

Mitochondrial genomes of *C. phaseoliformis*, *C. okutanii* and *C. fossajaponica* were sequenced. Based on these mitochondrial genome sequences, primer sets for PCR of mitochondrial genes of other *Calyptogena* clams were designed. Using them, 11 mitochondrial genes (*cox1*, *cox2*, *cox3*, *nad1*, *nad3*, *nad4*, *nad5*, *cytb*, *atp6*, *atp8* and *rrnL*) of other 8 *Calyptogena* species (*C. fausta*, *C. kawamurai*, *C. kilmeri*, *C. laubieri*, *C. nautilei*, *C. pacifica*, *C. soyoae*, *C. stearnsii*) were amplified by PCR and sequenced. Eight genes (16S rRNA, 23S rRNA, *uvrA*, *uvrD*, *mfd*, *groEL*, *groES* and *gyrB*) of symbionts of these *Calyptogena* clams were also sequenced. Phylogenetic trees of clams and symbionts were constructed by maximum likelihood and Bayesian analysis based on concatenated 11 mitochondrial and 8 symbiont genes, respectively.

The reliabilities of phylogenetic trees of the hosts and their symbionts were significantly improved by using the concatenated genes sequences (Fig.1). Bootstrap values and posterior probabilities of internal nodes were better supported than those of the previous phylogenetic trees using partial gene sequences. Topological congruence of host and symbiont that was supported by bootstrap value (100%) and posterior probabilities (1.0), was shown in *C. okutanii*, *C. soyoae*, *C. kilmeri*, *C. pacifica* and *C. fausta*. These results suggested that these symbionts were cospeciated with their host clams (green boxes in Fig.1). Although the topologies of host and symbiont were congruent with *C. fossajaponica* and *C. phaseoliformis*, there were the low bootstrap values and low posterior probabilities in the host clade.

Topological incongruence between host and symbiont trees was shown in *C. kawamurai* - *C. laubieri* clade and *C. nautilei* - *C. stearnsii* clades (Fig.1) Congruence of topologies was rejected by approximately unbiased test using sitewise log-likelihoods (red branches in Fig.1). This result suggested that these symbionts have not cospeciated with their host clams. Host switching of the symbionts in the clades of *C. kawamurai* - *C. laubieri* and *C. nautilei* - *C. stearnsii* were examined by coevolution software, which compared the topologies of host and symbiont. Host switching is the event that symbiont is transferred from a host to a new host in a different lineage during speciation. The host switching of symbiont between *C. kawamurai* and *C. laubieri* was suggested by this software. Moreover, both clams are living in different depths of the same area (blue box on Fig.1). However, this software did not suggest the host switching of symbionts between *C. nautilei* and *C. stearnsii*. They are living in different areas. In this study, we show the phylogenetic relationships of cospeciation and non-cospeciation species with the symbionts among examined 11 *Calyptogena* species. It was suggested that topological incongruence of host and symbiont trees in clade of *C. kawamurai* - *C. laubieri* may be due to the host switching

キーワード: 共生, シロウリガイ, 共進化, 宿主転換

Keywords: symbiosis, deep-sea *Calyptogena* clams, coevolution, host switching

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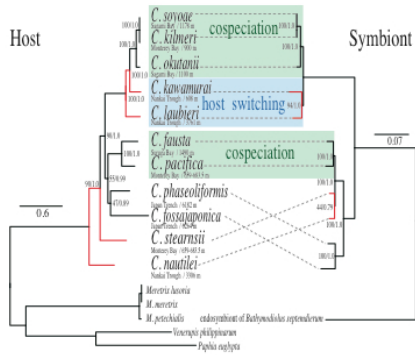


Fig1. cospeciation and host swithing on *Calyptogenia* clam and symbiont trees.  
 Numbers in the nodes correspond to maximum likelihood bootstrap values and posterior probabilities.  
 Reg branches correspond to topological congruence rejected by approximately unbiased test using  
 sitewise log-likelihoods.

## 殻形態から識別されたノチールシロウリガイの2形態型 Two forms of *Calyptogena (Ectenagena) nautilei* recognized in shell morphologies

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ノチールシロウリガイ *Calyptogena (Ectenagena) nautilei* Okutani and Métiévier, 1986 は、天竜海底谷の6個体を基に記載され、その後、熊野沖大陸斜面、第一南室戸海丘、銭洲海嶺及び潮岬海底谷から発見されている (Fujikura et al., 2000; Okutani et al., 2002; Kojima et al., 2004; Anma et al., 2010). Okutani et al. (2002) は、天竜海底谷、熊野沖大陸斜面及び第一南室戸海丘の個体を観察した結果、本種の殻の外形に多様性があることを示した。本研究では、模式標本及び Okutani et al. (2002) で観察された個体を含む複数産地の個体を観察した。その結果、殻形態と貝殻内表面の特徴により、2つの形態型に区別することが出来たので報告する。

観察した標本は、天竜海底谷の完模式標本 MNHN 26983 (Nautile Dive KD-3)、副模式標本 MNHN 26984 (Nautile Dive KD-5)、副模式標本 MNHN 26985 (Nautile Dive KD-3) の3個体、熊野沖大陸斜面の4個体 (Shinkai 6500 Dive 615)、潮岬海底谷の5個体 (Shinkai 6500 Dive 889, 890, 891)、第一南室戸海丘の8個体 (KAIKO Dive 189, 192, 193) である。すべての個体について、光学顕微鏡及び肉眼で貝殻表面の観察を行った。潮岬海底谷の2個体については、SEMによる殻表面及び断面の観察も行った。

形態型1は、天竜海底谷の個体、形態型2は熊野沖大陸斜面、第一南室戸海丘及び潮岬海底谷の個体に認められた。両形態型は貝殻内表面の構造により区別することができる。形態型1の内表面は平滑であるが、形態型2の内表面は直径約 61-548  $\mu\text{m}$  の穴状構造をもつ。さらに、形態型1は、左右殻の鉸板に殻頂下洞をもち、右殻の鉸歯に殻頂下主歯の前歯をもち、套線が湾入することからも、形態型2と区別することができる。

キーワード: オトヒメハマグリ科, ノチールシロウリガイ, 殻形態, 穴状構造

Keywords: Vesicomidae, *Calyptogena (Ectenagena) nautilei*, Shell morphology, Hole-like structure

## 相模湾初島沖化学合成生物群集域における深海底長期映像のアーカイブ Archives of long-term deep seafloor videos at chemo-synthetic biological community off Hatsushima Island in Sagami Bay

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More than 20 years of multidisciplinary long-term observation, including visual observation, has been carried out with a cabled observatory on deep seafloor at a depth of 1175 m off Hatsushima Island in Sagami Bay since the first deployment in 1993, experiencing entire replacement for upgrade in 2000. The observatory was installed at a cold seepage site where large chemo-synthetic biological communities mainly consisted of vesicomyid clams exist. The observatory is composed of several kinds of sensors, including video cameras, a hydrophone, CTD sensor and seismometer in order to observe biological phenomena visually and also to investigate environmental fluctuation on deep seafloor.

All those data obtained with the underwater unit are transmitted through a submarine cable to the shore station in Hatsushima Island. The video signal was recorded on S-VHS videotape before the replacement of the observatory in 2000 and mainly on DVCAM videotape after the replacement, both with acoustic signal obtained with a hydrophone on soundtrack as audible sound. The shore station is usually uninhabited, and daily visual monitoring of seafloor, 30 minutes a day before the replacement and 26 minutes a day after the replacement, has been performed automatically. The videotape has been replaced once a week on the day when manual observation is performed usually for 6 hours. As for lighting, six halogen lights were attached at first and two of them were turned on simultaneously by turn for usual observation considering lifetimes. However, most of those lights were broken by 2008 and since then an LED light is used which is darker but has longer lifetime than the halogen lights, resulting narrow view.

Although visual observation has been performed about ten hours a week, more than 20 year observation produced thousands of videotapes. Archiving those videotapes becomes important because they degrade over time and the devices to replay them are going out of production and the opportunities to utilize them are being lost.

Meanwhile, vocalizations of sperm whales were found in the acoustic signal recorded on the soundtrack of the videotapes and, in order to utilize them as one of the *in situ* data for the remote species identification, archiving the videotapes started under one of the research project in Core Researches for Evolutional Science and Technology (CREST) founded by Japan Science and Technology Agency (JST) since December 2011. At the end of the fiscal year 2013, more than half of those videotapes will be archived. Although the main target of the CREST project is acoustic data, video signals on the videotapes are converted to MPEG-2 files for S-VHS tapes and both AVI and MPEG-2 files for DVCAM tapes before extracting acoustic data.

In those video images, not only the long term change of the clam colony but also some episodic events, such as spawning of the clams, sudden increase of snails and other unidentified events have been recognized, which would be invaluable data for the investigation of chemo-synthetic ecosystems. Those archived video images will be able to supply researchers outside the project in near future. However, there still exists a problem that the number of hard disks in which the video images are stored is very large even though it is less than a thousand.

キーワード: 相模湾初島沖, 長期ビデオ観察, ビデオアーカイブ

Keywords: off Hatsushima Island in Sagami Bay, long-term visual observation, archives of videos



## 新潟県新第三系より産するシロウリガイ類化石の古生態と湧水場の地球化学的環境 Paleoecology of Neogene vesicomys from Niigata, Japan and their adaptations to geochemical environments of cold seeps

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現生シロウリガイ類は種によって異なる硫化水素濃度に適応し、またメタン湧水場や熱水噴出孔、鯨類遺骸、石油湧出場など様々な生息場に生息していることが知られている。化石シロウリガイ類は世界中の特に新第三系から報告されているが、それらの多様性や進化の背景を理解するうえで重要と考えられる湧水場の地球化学的環境に対する化石シロウリガイ類の適応は明らかでない。本研究では化石シロウリガイ類の古生態およびそれらが適応していた地球化学的環境を、新潟県の新第三系分布域の2か所より産する化石の産状、炭酸塩の同位体比や組織をもとに検討した。

下部鮮新統黒倉層は主に上部漸深海で堆積した灰色～暗灰色シルト岩からなる。十日町市松之山松口の越道川河岸の露頭では、60 cm 厚の塊状灰色シルト岩中に中礫サイズの炭酸塩コンクリーションが含まれる。これらのコンクリーションから化石シロウリガイ類 *Archivesica kannoi* が産する。コンクリーションとシルト岩との境界が漸移的な場合もある。*A. kannoi* の大型個体（殻長約 90 mm）の周囲に多数の小型個体（殻長平均約 20 mm）がその他の二枚貝類や巻貝類、ツノガイ類とともに同一のコンクリーション中に含まれる。周囲のシルト岩中からはツキガイ科二枚貝類が産し、また炭酸塩で充填された生痕も見られる。コンクリーションは主にミクライト質な Mg カルサイトからなり、黄鉄鉱結晶を多く含む。ミクライトの炭素同位体比は化石を含む含まないに関わらず -43.3~-27.1 ‰ (vs. PDB) と非常に低い値を示し、それらがメタン起源であることを示唆する。化石を含むコンクリーションにのみ岩片状炭酸塩（長径約 5 mm）が含まれ、それらは三角形から長円形の断面を示し Mg カルサイトのマトリクスと多数の細粒なドロマイト結晶からなる。ドロマイトの形成は硫酸還元による硫酸の除去と関連があり、それは硫化水素の活発な生成を示唆する。以上から、*A. kannoi* は周囲よりも活発な硫酸還元により硫化水素濃度が比較的高い場に生息していたか、あるいは *A. kannoi* による海水中からの硫酸の十分な供給が活発な硫酸還元を促していたことが考えられる。

上部中新統能生谷層は上部漸深海の深海扇状地のタービダイトとして堆積した灰色砂岩暗灰色シルト岩互層からなる。上越市中ノ俣の中ノ俣川河岸の露頭では、中礫サイズの炭酸塩コンクリーションが灰色含油砂岩直下の暗灰色シルト岩中に含まれる。これらのコンクリーションまたはシルト岩中より化石シロウリガイ類 *Calypptogena pacifica* が産し、一部は生息姿勢を保つ。化石とコンクリーションは幅 30 cm、層厚 5 cm の狭い範囲に産し、またその 50 cm 下位のシルト岩中にはパイプ状のコンクリーションが層理面と平行に含まれる。これらのコンクリーションは主にミクライト質のカルサイトからなる。ミクライトの炭素同位体比は -21.7~-13.2 ‰ と低い値を示し、それらが石油起源であることを示唆する。薄片下では化石を含むコンクリーションは多数のペロイドを含む。パイプ状のコンクリーションの空洞は刃状カルサイトで縁取られ、それは -22.6 ‰ と低い値を示すことから、これらのパイプが湧出の導管として作用していたと考えられる。*C. pacifica* は現世のメタン湧水場に生息しているが、本種は中新世には局所的な石油湧出場にも適応していたことが示唆される。

キーワード: シロウリガイ類, 新第三紀, 硫化水素濃度, 石油湧出  
Keywords: vesicomys, Neogene, sulfide concentration, petroleum seep

## シチヨウシンカイヒバリガイ共生系は実験室でも化学合成できるのか? Recent trials of laboratory culture with chemosynthetic organisms

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深海化学合成生態系には化学合成独立栄養細菌と共生関係を持つ動物が生息していることが知られている。本研究で用いたシチヨウシンカイヒバリガイ (*Bathymodiolus septemdierum*) はエラ上皮細胞内に硫黄酸化細菌を共生させており、共生細菌は熱水に含まれる硫化水素 ( $H_2S$ ) を利用しエネルギーを作り出し、二酸化炭素から有機物を合成している。このような共生関係の構築、維持機構は十分解明されていない。しかし、共生メカニズムを詳細に解明するためには共生関係を維持したまま飼育し、詳細な生態観察や実験を行うことが極めて重要であるにも関わらず、その飼育方法は未だ確立されていない。そこで本研究では  $H_2S$  を添加維持できる水槽 (小西&和辻, 特許 2011-219498) を用いて、シチヨウシンカイヒバリガイを飼育し、どのくらいの期間共生細菌が化学合成能を保持できるかを無機炭素取り込み量を指標として検証を行った。

飼育に用いた個体は 2012 年 4 月及び 2013 年 3 月に実施された研究船「なつしま」による航海で無人探査機「ハイパードルフィン」により採取した。本航海では伊豆小笠原弧明神礁のシチヨウシンカイヒバリガイを採取し、現場の水温 (約 4 °C) に保ったまま研究室に持ち帰った。研究室では、まず硫化水素を継続的に供給できる硫化水素添加水槽に 個体を入れ 3 ヶ月及び 14 ヶ月飼育した。過去の知見から、 $H_2S$  を添加しないで飼育した個体は 3 ヶ月で共生細菌がなくなることが知られている。今回、 $H_2S$  添加水槽での飼育個体の共生細菌が機能的であるかを確認するために無機炭素取り込み実験を行った。実験では、 $^{13}C$  標識重炭酸ナトリウムを添加した海水で満たしたガラス瓶に、上記飼育個体を 1 個体ずつ計 6 個体入れた。飼育水槽の  $H_2S$  を含む海水を添加するもの ( $H_2S$  有) としないもの ( $H_2S$  無) の 2 つに実験群を分け、14 日間の飼育を行った。ガラス瓶内の溶存酸素量の減少分を飼育個体の酸素呼吸量とみなし、 $H_2S$  添加の有無とヒバリガイの呼吸量との関連を検討したが、明確な関係性は認められなかった。また、エラ組織から抽出した DNA による菌叢解析を行ったところ、14 ヶ月の飼育を行っても生息域と同じ共生細菌のみが検出され、他の化学合成独立栄養細菌は獲得していないと考えられた。またすべての個体のエラ組織と共生細菌が認められないアシ組織について、有機物の炭素同位体比を分析した結果、 $H_2S$  を添加した条件で、有意に高く同位体ラベルした炭素が有機炭素として取り込まれていることが確認された。このことから生息域から採取されて 14 ヶ月以上経っていても共生細菌が維持され炭素固定能が失われず、 $H_2S$  により無機炭素取り込みが昂進されることが示唆された。本実験結果は硫化水素添加水槽で飼育した場合にシチヨウシンカイヒバリガイの共生細菌をかるうじてではあるものの、少なくとも機能的な状態で保持することができ、実験室内でもシチヨウシンカイヒバリガイを化学合成させることが可能であることが示唆された。

キーワード: laboratory culture, chemosynthetic organisms, *Bathymodiolus septemdierum*

Keywords: laboratory culture, chemosynthetic organisms, *Bathymodiolus septemdierum*

## 室戸半島四万十帯に分布するノジュールの産状と内部構造 Distribution and internal structure of the nodules occurring in the Shimanto sedimentary rocks, Muroto Peninsula, Shikoku

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深海底面上に近年多く発見されているノジュールは、陸上の露頭では母岩から容易に分離できるコンクリーションとして観察される。ノジュールは生痕化石や体化石が核となり、その周囲に鉱物が凝縮・沈殿して形成されると考えられているが、具体的な形成過程は解明されていない。室戸半島は、四国東部第三系四万十帯 (23-56 Mya) に属しており、地域住民に「鉄丸石」と呼ばれているノジュールが見つけれられている。これらのノジュールは、現在も南海トラフで進行している付加体形成プロセスと同じプロセスを経て形成されたと予想され、現在の深海底面で行われている現象を推測できる点で重要である。本研究では、鉄丸石の分布・産状・形状・内部構造の分析を行い、ノジュールの形成プロセスの推定を行った。

室戸半島の吉良川～椎名漁港までの海岸線沿いにノジュールの分布を調査した結果、ノジュールは室戸半島全域に分布することがわかった。ノジュールが集中している露頭としていない露頭があり、集中している露頭では、100 m<sup>2</sup> の範囲内に 50 個以上のノジュールが観察できた。ノジュールが集中していた露頭は、室戸層の吉良川河口・平尾、津呂層の奈良師・ホテル明星前・六々谷、日沖メランジュの三津の 6 か所に見つかった。室戸半島の露頭は、砂岩層・泥岩層・砂泥互層が特徴的であるが、ノジュールが見つかったのは主に泥岩層の中であった。砂泥互層においても、そのうちの泥岩層中に堆積面に平行な方向に長く伸びた形状で露出していることが多かった。泥岩層に露出しているノジュールの中には、泥の表面より突き出したノジュールの上面に沿うように砂岩層が曲がっているように見えるものもあった。よって、ノジュールの産出には泥岩層が重要だと考えられる。また、ノジュールの分布を Laughland & Underwood (1993) の温度構造と比較した結果、温度構造との相関は認められず、ノジュールの分布は主に岩相に支配されているように思われた。

ノジュールの産出数が多かった 6 か所で、50 個ずつノジュールの大きさとアスペクト比を計測した。アスペクト比とは、ノジュールの形状を楕円とみなして長軸の長さで短軸の長さとの比率である。ノジュールの形状は、主に長軸方向の長さが 1.2-25 cm、短軸方向の長さが 1-18 cm であり、各地点ともアスペクト比が 1.3-1.4 となり、球形に近い形状であることが分かった。しかし、室戸層の平尾付近の露頭だけは異なっており、短軸の長さが 4cm 以下のものはすべてアスペクト比が 3 以上であった。これは、元々ほぼ同じ大きさだったノジュールが変形したと考えれば説明できる。この地点では、高いビトリナイト反射率が報告されている (Laughland & Underwood, 1993)。

18 個のノジュールを切断し内部断面を観察したところ、ノジュールの内部は大部分が母岩とよく似た黒色又は褐色のマトリックスで構成されていた。直径約 8 cm のノジュールの中央部に長さ 0.4 cm の不定形の小さい白いコアを観察できた。また、複数のサンプルに細粒の黄鉄鉱が散在しているのを観察することができた。黄鉄鉱の粒子は、サンプルによっては見られないこともあった。黄鉄鉱の形状は、主に丸みを帯びた三角形や四角形であり、粒の大きさは一辺の長さが 50-450 μm である。観察できた黄鉄鉱の形状より、無機的に形成されたものと推測された。マトリックスには黒色と褐色の部分が見られた。それぞれ部分が、幅 1-2 mm の帯状でノジュールの外側からノジュールの中心軸に向かって湾曲しながら伸びている様子が観察できた。エネルギー分散型 X 線分光分析 (EDS) を用いて化学分析を行った結果、黒色部と褐色部では含まれている鉱物の種類が異なることが分かった。即ち、主に方解石や石英から構成される部分とアルミニウム・マグネシウム・鉄が多く含まれる部分とがあり、特に後者は粘土鉱物と思われる。

室戸半島の四万十帯ではノジュールが泥岩層に多く露出していることが明らかとなり、ノジュールは静かな深海底面に堆積した泥の表面付近で形成されたと考えられる。ノジュールの断面に小さいコアを観察できたことから、当時深海底で生息していた蠕虫様生物の生痕が核となって形成されたものである可能性が高い。生物蹂躪によって環境水中の物質移動が促進された結果、その周囲の泥において選択的にコンクリーション化が起きたと考えるのが妥当である。一部の露頭では堆積面に平行に伸長したノジュールだけが見られたが、変形前のノジュールがほぼ同じ形状であったと仮定すれば、今後これらのノジュールの形状が付加体形成による変形の指標となる可能性がある。

キーワード: ノジュール, 四万十帯, 泥岩層, 黄鉄鉱, 生痕化石

Keywords: noduie, Shimanto belt, mudstone layer, pyrite, trace fossil

## 神奈川県中央部に露出する更新統中津層群大塚層から産出する冷湧水性化学合成化石群集の新露頭 New localities of fossil cold-seep assemblages from the Pleistocene Otsuka Formation of the Nakatsu Group, central Japan

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神奈川県相模原市を流れる相模川北東岸には更新統中津層群上部の大塚層が露出する。相模川北東岸の中津層群は下位から小沢層、神沢層、清水層、大塚層、塩田層が露出する (Ito, 1985)。今回、大塚層から新たに2地点の冷湧水性化学合成化石群集が産出する露頭を報告する。大塚層は主に塊状の泥岩層からなり、軽石質凝灰岩層 (層厚数 cm から 10 数 cm) と薄い砂岩層を狭在する。

今回報告する2地点の新たな露頭 (Loc.1 と 2) は塊状泥岩中にツキガイ類化石が産出し、散在的な自生炭酸塩コンクリーション (大きさ数 cm から 10 数 cm) を共産する。Loc.1 はスコリアと軽石 (粒径 0.5~2 mm) が散在し、最大層厚 7 cm のレンズ状の細粒砂岩層が狭在する。17 個体の大型二枚貝化石は大部分が合弁のツキガイ類化石からなり、露頭表面上の高さ 0.4m、幅 1m から散在的に産出した。この地点の化石は殻が溶解しほぼ失われている。計測したほぼ全ての合弁個体の接合面は層理面に対してほぼ垂直に配列し、殻頂方向を上向きに配列していた。Loc.2 はスコリアと軽石 (粒径 0.5~2 mm) と小礫サイズの軽石が散在する。42 個体の大型二枚貝化石は大部分が合弁と離弁のツキガイ類化石からなり、露頭表面上の高さ 2m、幅 1.2m から散在的に産出した。この地点も Loc.1 と同様に化石の殻は溶解しほぼ失われている。計測した合弁個体と離弁個体はそれぞれ 27 個体と 15 個体であった。多くの合弁個体の接合面は層理面に対して殻頂方向を上向きに配列し、対して計測した離弁の殻の接合面は層理面に対して平行に配列し、convex-down が 8 個体、convex-up が 4 個体であった。

ツキガイ類は殻頂方向を堆積物に対して上向きにして生息することが知られている (Stanley, 1970; Kondo, 1990; 菅野, 1993)。従って、今回報告したツキガイ類化石は当時の生息姿勢を保っていると解釈した。

キーワード: 中津層群, 冷湧水性化学合成化石群集, 更新世  
Keywords: Nakatsu Group, fossil cold-seep assemblage, Pleistocene

## 日本の白亜紀化学合成生態系 Cretaceous chemosynthetic communities in Japan

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プレート境界沿いの深海底には、熱水やメタン冷湧水といった硫化水素やメタンなどの還元物質を含む流体が湧き上がっている。そのような環境には化学合成生態系が成立する。化学合成生態系に動物が進出した最古の記録はシルル紀であるが、その後、地質時代を通じて群集組成が変化している。その変化は、プレート・テクトニクスや深海底でおきた海洋無酸素事変などと密接に関連していると考えられている。現在の化学合成生態系を構成する軟体動物類の多くは白亜紀から古第三紀に化学合成生態系に進出しているようである。さらに、化学合成生態系が成立する4つの「基本環境」、すなわち、熱水噴出孔、メタン湧水、鯨骨、沈木のうち、熱水と湧水に成立する大型生物を含む化学合成生態系はシルル紀にまで遡るが、“鯨骨”と沈木に成立するそれは白亜紀が最古である。

ところで、日本列島は数億年にわたってプレート境界であり続けており、化石の産状や種構成などから化学合成群集とみなされた化石群集は、日本周辺の白亜紀以降の付加体・前弧海盆・背弧海盆堆積物から豊富に産出する。実は、上述した現在型化学合成生態系の進化史解明に、本邦から産出した化学合成化石群集の記録が大きく関わっている。そこで、本発表では、特に本邦から産出した白亜紀化学合成生態系をレビューし、これまでの研究のレビューを行う。

キーワード: 化学合成群集, メタン湧水, 熱水噴出孔, 鯨骨群集, 鯨骨群集, 沈木群集

Keywords: chemosynthetic community, whale bone, sunken wood, hydrocarbon seep, hydrothermal vent, cold seep

## Rapid change of atmosphere in the Hadean Earth: Beyond Habitable Trinity on a tightrope

## Rapid change of atmosphere in the Hadean Earth: Beyond Habitable Trinity on a tightrope

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Surface environment of Hadean Earth is a key to bear life on the Earth or not. All of previous works assumed that high PCO<sub>2</sub> has been decreased to a few bars in the first a few hundreds millions of years (e.g., Zhanle et al., 2011). However, this process is not easy because of material and process barriers as shown below. Four barriers are present.

First, the ultra-acidic pH (<0.1) of 4.4Ga ocean prevented the precipitation of carbonates at mid-oceanic ridge or its pseudo-system through water-rock interaction after the birth of primordial ocean. To overcome this barrier, primordial (anorthosite + KREEP) continents must have been above sea-level to increase pH rapidly through hydrological process.

Second, major cap rocks on the Hadean oceanic crust must have been komatiite with minor basaltic rocks to precipitate carbonates through water-rock interaction and transport them into mantle through subduction at higher than the intermediate P/T geotherm on the Benioff plane. If not, carbonate minerals are all decarbonated at shallower depths than the Moho plane. Komatiite production depends on mantle potential temperature which must have been rapidly decreased to yield only Fe-enriched MORB by 3.8Ga.

Third, the primordial continents composed of anorthosite with subordinate amounts of KREEP basalts must have been annihilated until 4.0Ga to alter pH to be possible to precipitate carbonates by hydrothermal process. The value of PCO<sub>2</sub> must have been decreased down to a few bars from 35 bars at TSI (total surface irradiance) = 75% under the restricted time limit. If failed, the Earth must have been Venus state which is impossible to bear life on the planet.

Fourth is the role of tectonic erosion to destroy and transport the primordial continent of anorthosite into deep mantle by subduction. Anorthosite + KREEP was the mother's milk grow life on the Earth, but disappeared by 4.0Ga or even earlier, but alternatively granites were formed and accumulated on the Earth to supply nutrients for life. This is time-dependent process to increase new continents.

Fifth is the water content 3-5km thick, if the value was over, no way to bear life nor evolution afterwards.

After all, the Hadean Earth has passed the really naive tightrope processes to bear life. If any of above five conditions was lost, life has not been appeared.

## 世界古地理と生命進化：その3 古生代 Global paleogeography and life evolution: 3. Paleozoic

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In modern oceans, there is no remaining information about past oceans older than 200Ma. For reconstructing paleo-plate motions with respect to collision-amalgamation of continents, on-land geology, in particular, orogenic belts that cemented older continents provide a sole source of information.

The onset of the Paleozoic is marked by the Gondwana semi-supercontinent formation at 540Ma around the South Pole. During the Paleozoic, Gondwana broken up, whereas Laurentia aggregated to form a real supercontinent by 430 Ma. Immediately after that, Gondwana began to be rifted, and its fragments and other blocks such as Baltica, Kazakhstan, Siberia, N China, South China, Indochina, and smaller pieces of Cimmeria, were dispersed; most of these were eventually amalgamated to form the northern half of Pangea, i.e., Laurasia.

The mode of mantle dynamics was represented by the high MORB production rate during 540-350Ma, almost the same as that in the Cretaceous, but it dropped after 350 Ma, probably by the activation of Pacific superplume. According to such continental assembly/ disassembly, sea-level changed remarkably as represented by the glaciation/deglaciation; the major Gondwana glaciations during the Carboniferous-Permian with 3 more minor episodes; the Paleozoic-Mesozoic transition interval might be close to the snowball Earth condition with extremely cold climate. The continent dispersion/amalgamation likely drove the development of remarkable floristic provincialism, e.g., Gondwana, North America, and Angara, that particularly reflected the formation of Laurentia. Not only the post-Ordovician land trees, this also controlled the diversification pattern of soil bacteria, moss, and land animals. Biodiversity changes including mass extinctions occurred in accordance with the secular change in seawater Sr isotope ratio; extremely high in the Cambrian with high bio-diversification, and the minimum at the G-L boundary (Permian) with onset of the greatest mass extinction.

キーワード: 古地理, 古生代, 超大陸, ゴンドワナ, パンゲア, 生命進化  
Keywords: paleogeography, Paleozoic, supercontinent, Gondwana, Pangea, evolution

## ネオジウム同位体シグナルからみた後期白亜紀北西太平洋における中／深層水形成 Neodymium isotopic signature for deep/intermediate water formation in the late Cretaceous northwestern Pacific

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白亜紀は、地球史において最近の典型的な温室地球時代として知られており、大気中の二酸化炭素濃度の増加に対する気候感度を推定する際の極相のひとつとして多くの研究が行われてきた。未だに大気中の二酸化炭素濃度の推定には不確定要素が多いものの、海洋水温は様々な緯度や海域において解析され、表層水温の緯度勾配や表層・深層水温の時代変遷等が明らかにされてきた。

近年では、地球表層におけるエネルギー循環の担い手の一つとして、当時の海洋循環に関する研究も盛んに行われるようになってきた。しかし、これらの研究の多くは大西洋を対象としたものであり、白亜紀においては唯一の大洋であり、全球のエネルギー循環に大きな影響を及ぼしたと考えられる太平洋においてはほとんど議論が行われてこなかった。これは、太平洋においては白亜紀の堆積物を含む多くの海洋プレートが海溝部での沈み込みに伴い消失していることが大きな要因となっている。そこで、本研究では、白亜紀の北西太平洋の大陸プレート上に堆積した前弧海盆堆積物を研究の対象とすることで、これまで議論が不十分であった、白亜紀における太平洋の海洋循環の一端を明らかにすることを試みた。研究の対象とした蝦夷層群は、当時の太平洋の北西部に位置しており、水深約 400m 程度の海盆に堆積したものである。この堆積物中に含まれる魚歯化石を抽出し、そのネオジウム同位体組成を計測することで、白亜紀後期チュールロニアン期後期からカンパニアン期初期における北西太平洋の海洋循環を議論する。

魚歯化石から得られたネオジウム同位体組成は $-1$  から  $-2 \text{ } \epsilon\text{-unit}$  程度を中心として分布し、極めて高い値を示した。先行研究によりカンパニアン期からマーストヒリチアン期の赤道太平洋（シャツキー海台）で得られた、 $-4$  から  $-5 \text{ } \epsilon\text{-unit}$  という値と比較してもより高く、これまで得られている白亜紀のネオジウム同位体組成の中でも最も高い値の一つに相当する。これは、北西太平洋の島弧による火成活動に由来すると想定される radiogenic なネオジウムを多く含む水塊が存在していたことを示すと考えられる。太平洋の赤道付近で得られている値とも異なることを考慮すると、当時の蝦夷層群が堆積した北西太平洋北緯約 40 度付近には、北西太平洋由来の中、ないし深層水の形成があったと考えることが妥当である。この北西太平洋における中／深層水の形成は、気候モデルによる解析からも示唆されており、特に、白亜紀前期から中期にかけての最温暖期から寒冷化傾向に向かう白亜紀後期においては、北西太平洋で深層水が形成されることが予測されていた。この中／深層水がどの程度の水深にまで達していたか、については現時点では議論することができないが、本研究により、白亜紀後期における海洋循環系の新たな一面が明らかになった。

キーワード: 白亜紀, 海洋循環, ネオジウム同位体, 北太平洋, 深層水, 中層水

Keywords: Cretaceous, Ocean circulation, Neodymium isotopes, North Pacific, Deep water, Intermediate Water



白亜紀温室地球の初期寒冷化のカギ：北太平洋縁辺域のシャンパーニュ階—マーストリヒト階泥質堆積物  
Campanian-Maastrichtian clay-rich sequences along North Pacific Margin: Early Cooling History of Cretaceous Greenhouse

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北太平洋沿岸域には日本, 極東ロシア, およびカナダ・アメリカの太平洋岸という広い範囲にわたって白亜紀の陸源堆積物が分布している。複数のセクションで生層序や化学層序の研究が進められ, アプト階からマーストリヒト階に対比されている。大型化石や微化石の生層序に加え, 炭素同位体比 ( $\delta^{13}\text{C}$ ) 層序はこれらの層位範囲の中で重要な層準-例えば OAE2 層準-を特定することに貢献してきた。泥が卓越するが故, 一部のセクションでは保存が極めて良好であり酸素同位体比の測定が可能である炭酸塩化石が産出する (Moriya et al., 2003)。

本研究ではシャンパーニュ階からマーストリヒト階について検討する。この範囲の炭素同位体比層序については, 最近欧州を中心に総括がなされ (Voigt et al., 2012), 汎世界的な寒冷化の初期フェーズが記録されていることがわかってきた (Moriya, 2011; Friedrich et al., 2012)。北部「古太平洋」は莫大な熱容量を持っていたと考えられ, その古海洋環境は, この時代以降の温室地球から氷室地球への転換に関する環境変化を理解するうえで重要な視点を供給すると考えられる。

北海道とサハリンに分布する蝦夷層群とその相当層, およびカナダ太平洋岸 (ブリティッシュコロンビア) に分布するナナイモ層群について検討を進めている。蝦夷層群からは, 明瞭な 1.4-2 ‰ の負の  $\delta^{13}\text{C}$  のエクスカージョンが見られている。サハリンでは, シャンパーニュ期/マーストリヒト期境界は生層序と古地磁気によって時代を固定することで炭素同位体比のシャンパーニュ階/マーストリヒト階境界事件 (CMBE) とその付随イベントが同定されている。

ナナイモ層群の古地磁気と生層序 (Haggart et al., 2011; Ward et al., 2012) から,  $\delta^{13}\text{C}$  層序における CMBE が推定される相違範囲を中心に検討を進めたところ, これに対応する 1.5 ‰ の負のエクスカージョンがノースアンバーランド層上部に確認された。このことにより, サハリン, 北海道, およびブリティッシュコロンビアの CMBE 層準を高精度で対比することが可能になった。

キーワード: 白亜紀, 温室地球, 寒冷化, カンパニアン, マーストリヒシアン

Keywords: Cretaceous, Greenhouse, Cooling, Campanian, Maastrichtian

生痕化石によって乱された生痕化石：Chondrites と Phycosiphon に乱された Phymatoderma と，その古生態学的意義  
Composite trace fossils: Phymatoderma reburrowed by Chondrites/Phycosiphon and its paleoecological implications

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Composite *Phymatoderma* specimens from the Pliocene deep-sea Shiramazu Formation in Japan, particularly those reburrowed by *Chondrites* and *Phycosiphon*, were analyzed to reveal the differences caused by the activities of these trace-makers. *Phymatoderma* reburrowed by *Phycosiphon* is significantly larger than non-reburrowed *Phymatoderma*, whereas *Phymatoderma* reburrowed by *Chondrites* shows no significant difference in burrow diameter compared with non-reburrowed *Phymatoderma*. The recognized size selectivity (i.e., preference for larger burrows) by the *Phycosiphon* trace-makers can be explained by considering the different feeding strategies of these two ichnogenera; namely deposit-feeding *Phycosiphon*-makers, which must have processed a significant mass of sediment to obtain sufficient organic matter, whereas chemosymbiotic *Chondrites*-producers, which did not require a lot of sediment to obtain nutrients. In order to test these interpretations, records of the Phanerozoic trace fossils reburrowed by *Chondrites/Phycosiphon* were compiled. Consequently, the *Phycosiphon* -preference toward relatively larger burrows was recognized, which supports the results of this study. The compilation also indicates that the burrow size has become a limiting factor for the *Phycosiphon*-producers that tried to rework the sediments within previous subsurface burrows, at least for 80 million years.

## 古生物多様性評価に対する地質年代単元の長さの影響 The influences of durations of geologic time units on diversity assessments

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The study on global diversity change has been at the center of paleontological studies during the past quarter-century. It is well known that the diversity estimates are readily biased by unevenness of sampling density and there have been many debates on how to remove sampling overprints. In addition, taxonomic richness in a given chronological interval can be also biased by variation in time interval duration because the piled up diversity becomes much greater as the interval gets longer. However, there is no simple solution for this problem because the rate of taxonomic turnover is not uniform through time; that's why we can define discrete chronostratigraphic units with various durations. In addition, actual data registered in the Paleobiology Database indicate less correlation between sampled-in-bin taxonomic richness and time interval duration.

In the present study, the following simple computer simulations were performed to understand biases on diversity estimates derived from variation in time interval duration of chronologic units. A total of one million hypothetical taxa originated and went extinct at each time step (= 0.1 Ma) during the Phanerozoic at a given rate. In the present simulations, most (80%) of the turnovers were set to be concentrated at the boundary between intervals. The following different conditions were adopted for the turnover rates and sampling probability per time step within the interval; 1) fixed independent of the interval duration or 2) inversely proportional to the interval duration. The sampled-in-bin richness was counted for each age in each simulation.

As a result of the above simulation, a positive correlation between piled up diversity and time interval duration was generated when sampling probability was fixed through time. This result seems a natural consequence because the number of sampling for each bin depends on the duration of the time interval and the sample-size effect was not removed in the present analysis. The correlation was particularly remarkable when the mean turnover rate was high and/or probability of sampling was low. However, such a correlation was found also in some cases even when the sampling probability per time step was inversely proportional to the interval duration. In the latter case, the correlation was significant when the sampling probability was moderate.

キーワード: 古生物多様性, 地質年代単元長  
Keywords: paleobiodiversity, time interval duration

## 北西太平洋における上部漸新統・下部中新統の放射虫化石層序 Upper Oligocene to Lower Miocene radiolarian biostratigraphy in the Northwest Pacific

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Ocean Drilling Program Leg 145 Hole 884B core provides the most continuous Neogene sequence of pelagic sediments in the northwest Pacific. We examined radiolarians from the Upper Miocene to Lower Miocene sediment of the core to establish subdivided radiolarian biozones.

The Upper Oligocene sequence can be divided into three zones, *Actinomma* sp. A, *Hexacontium* sp. B and *Cyrtolagena laguncula* Zones, in ascending order. The Lower Miocene sequence can be divided into four zones, *Botryopyle* sp. B, *Pentactinosphaera hokurikuensis*, *Stichocorys subligata* and *Dendrospyrus sakaii* Zones, in ascending order. Each of *Botryopyle* sp. B Zone and *P. hokurikuensis* Zone has been subdivided into subzones a, b and c.

Some episodes of significant faunal changes of radiolarians are identified within the studied interval. They seem not to reflect global cooling events but to reflect some regional events.

キーワード: 放射虫, 化石帯, Site 884, 北太平洋  
Keywords: Radiolaria, biozone, Site 884, North Pacific

## その学名は適格か：白亜紀アンモナイト *Polyptychoceras* 属の命名法的検討 Available or unavailable? : nomenclatural examination of the Cretaceous ammonite genus *Polyptychoceras*

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生物の種類を表現する手段として学名が有効であることは、論を待たない。しかし命名規約に従って適切に学名を運用することは必ずしも容易ではなく、学名の混乱によって研究の客観性が損なわれてしまうことがある。

上部白亜系から産出する *Polyptychoceras* Yabe, 1927 は、クリップ状の殻形態が特徴的な異常巻きアンモナイトの 1 属である。本邦では *P. pseudogaultinum* (Yokoyama, 1890) 以来 12 種の産出が報告されている一方で、種分類を見直す必要性が指摘されている。しかし本属各種はそもそも、これまでに提唱されている学名に関して不明な点が多い。例えば、本属の 1 種 *P. yubarensis* は Yabe (1927) が最初に提唱したことから、多くの文献で本種の著者と公表の日付が Yabe, 1927 とされてきた。ところが Yabe (1927) は本種の学名を掲載しているにすぎないため、本種の本記載論文にはあたらない (規約条 12.1)。

そこで本研究では、最新の国際動物命名規約第 4 版 (動物命名法国際審議会, 2000) に基づいて、これら 12 種の学名を検討した。その結果、命名法上の適格性・著者・公表の日付・原記載論文が明らかになった。このことは、今後の分類学的研究に資するだけでなく、本属を扱った全ての研究の客観性を高めることにつながると考えられる。

なお、本予稿は動物命名法の目的のために発行するものではない (規約条 8.2 に基づく棄権宣言)。

### 引用文献

動物命名法国際審議会, 2000, 国際動物命名規約第 4 版日本語版. 日本動物分類学関連学会連合, 札幌, XVIII + 133 p.  
Yabe, H., 1927, *The science reports of the Tôhoku Imperial University, 2nd series (geology)*, **11**, 27-100.

キーワード: *Polyptychoceras*, 異常巻きアンモナイト, 学名, 国際動物命名規約, 白亜紀

Keywords: *Polyptychoceras*, heteromorph ammonite, scientific names, International Code of Zoological Nomenclature, Cretaceous

種毎の産出個体数に基づく多様性変動の評価：白亜系蝦夷層群産アンモノイドの例  
Assessment of local diversity in Cretaceous ammonoids from the Yezo Group using individual taxonomic abundance

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Exploring global diversity change across the Phanerozoic has been an important part of paleontology in the past quarter-century. It is widely known that the diversity estimates are seriously biased by variation in the volume of paleontological data and there have been many debates on how to remove the sampling intensity biases. The taxonomic richness has been standardized by sampling proxies such as collection-based occurrences and the amount of rock records. On the other hand, use of the number of individuals observed in each taxon is limited to the studies on sample level diversity at the outcrops because those data are not available at the global level. An intermediate approach between at the global and sample levels is commonly found in the tabulation of number of species for a particular taxonomic group through a restricted geologic time interval at the local level. However, such a local database compiled in a traditional manner does not record any information on abundance of each species in most cases.

Here, we studied chronological change in species diversity of Cretaceous ammonoids from the Yezo Group exposed in central Hokkaido, Japan, using the diversity indices that take into account the abundance of each species. This study was based on the fossil collections collected from Soya, Nakagawa, Haboro, Kotambetsu, Obira, Mikasa, Oyubari or Hobetsu areas and stored at Shizuoka University, National Museum of Nature and Science, Tokyo, Nakagawa Museum of Natural History, Mikasa City Museum and Hobetsu Museum. The number of individuals was counted for each species for each stratigraphic unit from the Cenomanian to Maastrichtian. A total of 9,834 individuals of 266 species was identified and counted.

The patterns of diversity change estimated in the present analysis were considerably different among collections even when the same diversity index was adopted. A plausible reason of this discrepancy is the difference in relative species abundance observed among collections. The only exception is the Shannon-Weiner function which exhibited a consistent pattern of diversity change independent of which collection was utilized. This result suggests that the Shannon-Weiner function is the most robust against variation in relative species abundance. The diversity estimates based on species richness tended to be correlated with the proportion of the rare species to the total number of species. This result suggests that these diversity estimates are readily distorted by the impact of rare species.

キーワード: 多様性変動, 白亜紀, アンモノイド, 蝦夷層群, 産出個体数

Keywords: paleobiodiversity, Cretaceous, ammonoids, Yezo Group, individual taxonomic abundance

## 古代タンパク質の復元に基づく生物進化初期の温度環境推定 Estimation of the environmental temperatures at the early evolutionary periods by resurrection of ancient proteins

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初期の生命がどのような環境下で進化したかを明らかにすることは、地球上の生命の起源と進化を理解する上で重要である。地球上の生命の初期進化に関する地質記録は極めて限られている。よって、現生生物に系譜が繋がる祖先生物が、地球上のどのような環境に生育したのかを推測することは容易ではない。

Woese et al. (1990, PNAS, 87: 4576-4579) が作製した 16S/18S rRNA に基づく系統樹は、異論はあるものの、広く「標準的」系統樹として利用されており、全生物が共通祖先を持ち、3つの生物群（古細菌 Archaea、真正細菌 Bacteria、真核生物 Eukarya）に分かれる事を示唆した。全生物の共通祖先が存在したとすると、その共通祖先がどのような生物であったかが、次の疑問となる。特に全生物の共通祖先の生育温度については、活発な議論がおこなわれて来た。「全生物の共通祖先が超好熱菌」であるという仮説が Pace (1991, Cell, 65: 531-533) によって提案されたが、その解釈に対する反論も多かった。しかしながら、これらの議論のほとんどは、分子系統解析により全生物の共通祖先の核酸の G+C 含量やアミノ酸組成を推定し、そこから生育温度を推論したものであり、実験的に検証されたものではない（例えば Galtier et al. (1999, Science, 283:220-221)）。しかし、近年、分子系統解析による祖先タンパク質のアミノ酸配列の推定と、その配列をコードする祖先型遺伝子の実験的な復元が、過去の生物の性質を理解するために行われるようになって来た（例えば Gaucher et al. (2003, Nature, 425: 285-288)）。

我々は、祖先生物の生育温度を推定するため、現存する古細菌および真正細菌由来ヌクレオシド二リン酸キナーゼ (NDK) のアミノ酸配列の多重アライメントを用いて最尤法に基づく進化系統樹を作製し、古細菌共通祖先生物と真正細菌共通祖先生物が持っていたと予想される NDK のアミノ酸配列を推定した。さらに、遺伝子工学的手法により復元した祖先型 NDK 遺伝子を大腸菌内で発現し、祖先型 NDK の精製と熱変性測定をおこなった。復元した古細菌共通祖先、真正細菌共通祖先 NDK は、どちらも変性中点温度が 100 °C を超える高い耐熱性を有していた。至適生育温度が異なる様々な微生物の NDK の変性温度が至適生育温度と強い相関を持つことから、これらの復元した NDK を持っていたと考えられる生物は超好熱菌であったと考えられる。さらに、祖先型アミノ酸配列推定の際の誤りや、祖先型配列推定の用いた系統樹の樹形が、復元した祖先型タンパク質の高い耐熱性には大きく影響しないことも明らかにした。また、古細菌共通祖先 NDK と真正細菌共通祖先 NDK の配列はよく似ており、全生物の最後の共通祖先生物 (Commonote: コモノート) の NDK も同様なアミノ酸配列を持っていたことが期待される。古細菌共通祖先 NDK と真正細菌共通祖先 NDK の配列から全生物の共通祖先 NDK の配列を作製すると、その変性温度は 90 °C 以上であり、この NDK を持った全生物の共通祖先は 75 °C 以上に生息する好熱菌であったと考えられる (Akanuma et al. 2013, PNAS, 110: 11067-11072)。以上の結果は、古細菌共通祖先生物、真正細菌共通祖先生物がともに (超) 好熱菌であり、Commonote が好熱菌であったことの実験的な証拠と言える。

キーワード: コモノート, タンパク質の祖先配列復元, ヌクレオシド 2 リン酸キナーゼ, 好熱菌

Keywords: Commonote, resurrection of proteins, nucleotide diphosphate kinase, thermophiles

## 地球環境の進化：堆積物記録中に残されたポルフィリンからの観点 Evolution of the Earth's environment: A view from sedimentary alkyl porphyrins

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Alkyl porphyrins are derivatives of chlorophylls that are formed in the surface of the Earth by photosynthesizers. Structural changes associated with the diagenetic processes have been intensively studied during the last half a century. Now we know that some alkyl porphyrins are derived only from specific chlorophylls that are originated from a specific type of photosynthesizers. Together with carbon and nitrogen isotopic compositions, such structural information provides a profound insight on the critical evaluation of the surface water environment in the geological past. In this presentation, I will review the diagenetic alteration of chlorophyll structures and review the current evidence.

キーワード: ポルフィリン, 堆積物, 地球表層環境

Keywords: Porphyrins, Sediment, Earth's surface environment



## 環境変動と後生動物進化の共進化：ゲノム重複と環境変動への急速な対応 The close correlation between environmental change and evolution of metazoans: Genome duplication and rapid adaptation

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The Neoproterozoic to Cambrian is one of the most exciting periods when Metazoa first appeared and quickly evolved. The origin and early evolution of Metazoa are very attractive firstly because the events suddenly happened after very long calmness, over 2000 m.y. since the emergence of eukaryotes, and proceeded very quickly, and secondly because appearance of new phylum was limited to this period (Cambrian explosion). Recent paleontology, biomarker study and molecular biology suggested early origin, especially of sponges and cnidarians, and cryptic evolution of the metazoans (e.g. Maloof et al., 2010; Love et al., 2010; Peterson et al., 2008; Sperling et al., 2010, Erwin et al., 2011). On the other hand, recent comprehensive study of multi-elemental and multi-isotopic chemostratigraphies of drill core samples in Three Gorges, Tianping and Beidoushan areas revealed that redox condition and bioessential element contents of seawater such as P, Ca,  $\text{NO}_3^-$ , Fe, Mn, Mo, and Sr drastically changed from the Neoproterozoic to the Early Cambrian. Sr isotope values display positive excursions at ca. 580, 570-550 and 540 Ma, indicating repeated high continental influxes at those times. P contents of carbonate minerals were very high until ca. 550 Ma, and then decreased, suggesting the seawater was enriched in phosphorus before 550 Ma and then depleted due to oxidation of seawater and deposition of phosphorite. High nitrogen isotope values of organic matter and high Ca isotope values of carbonate rocks indicate that seawater was depleted in  $\text{NO}_3^-$  and Ca contents until ca. 550 Ma, and then increased. Mo isotopes of black shale, and Fe and Mn contents and REE patterns of carbonate rocks indicate that seawater became more oxic since ca. 550 Ma. In addition, the Mo contents of black shale increased in the Late Ediacaran and Early Cambrian, indicating Mo content of seawater increased due to the oxidation of seawater. On the other hand, iron and manganese contents of carbonate rocks decreased, suggesting that iron and manganese contents of seawater decreased because of the oxidation of seawater.

Comparison of the geochemical evidence with biostratigraphy suggests that the emergence of Metazoan in the Early Ediacaran was caused under the relatively less oxic and P-rich condition, whereas their diversification occurred under oxic,  $\text{NO}_3^-$  and Ca-rich condition. Especially, the transition from phosphorus-rich to  $\text{NO}_3^-$ -rich seawater possibly increased Redfield ratio, and contributed to diversification of more actively mobile multicellular animals. In addition, the comparison of geochemical and paleontological evidence indicates that the biological evolution occurred just after the environmental changes, especially the timing of increase in nutrients, allowing a new insight of biological evolution of multicellular animals. The quick response of biological evolution to the environments suggests that the fundamental innovation for biological functions was already established long before the environmental changes. The quick adaptation implies that early metazoans or a common ancestor have genomes for the functions before they acquired the functions, indicating genome duplication plays important role on the early evolution of metazoans.

キーワード: 生命進化, 古環境解読, エディアカラ紀, 海洋栄養塩濃度変動, 後生動物進化とカンブリア爆発, ゲノム重複  
Keywords: Biological evolution, paleoenvironmental change, Ediacaran, Nutrients of seawater, Evolution of Metazoa and Cambrian explosion, Genome duplication

## 祖先的前口動物の形態形成遺伝子セットの復元 Reconstruction of the gene sets for the developmental signaling ligands in ancestral protostome animals

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Recently, a draft genome sequence of the pearl oyster *Pinctada fucata* was reported, enabling to infer a possible evolutionary scenario of the gene sets that are important for body plan formation in protostomes including both lophotrochozoans and ecdysozoans. We report the results of phylogenetic character mapping carried out for the gene families that encode developmental signaling ligands (Fgf, Hedgehog, PDGF/VEGF, TGF- $\beta$ , and Wnt families) to reconstruct possible copy numbers of signaling molecule-coding genes for hypothetical ancestral protostomes. Our reconstruction suggests that *P. fucata* retains the ancestral protostome gene complement, providing further justifications for the use of this taxon as a model organism for developmental genomics research.

キーワード: 古代ゲノム, 多細胞動物, 発生進化学, シグナル伝達遺伝子, カンブリア爆発, 冠輪動物

Keywords: paleogenomics, metazoan evolution, evo-devo, signaling ligand genes, Cambrian explosion, lophotrochozoans

## マイクロシンテニーに注目した後生動物古代ゲノム情報の復元 Reconstruction of paleo genomic information of metazoan based on a microsynteny analysis

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後生動物のゲノムが幅広く解読される事により、進化速度の比較的遅い動物同士を比較すれば、ゲノム上の遺伝子の並びが比較的よく保存されている事が分かってきた。たとえば 2007 年の Putnam らによる刺胞動物のゲノム配列と現生のヒトのゲノム配列の間に、わずかながら遺伝子配列の並びの保存性 (Macrosynteny) を見いだしている。これは 6 億年以上前にこの 2 種の生物が分岐した事を考えると驚くべき事である。さらにその後、Irimia らは、このように分岐後大きく隔たって保存されている遺伝子並びのうち、5' 側を共有して並んでいる遺伝子同士は、遺伝子発現の制御領域を共有する事により、互いの並びを変更しにくいような拘束をうけているという仮説をたて、証明しつつある。発表者はこれら最近の遺伝子のならびの保存性研究の進展に注目し、古代ゲノムの復元に応用するためのツールとする事を考えている。具体的には、発表者が現在進めているヒメギボシムシとウニやナメクジウオなどのゲノムを比較する事で、水腔動物群の共通祖先や、新口動物群の共通祖先について、それ以降に共通に維持されている発生メカニズムを示唆するデータが得られてきている。

キーワード: 後生動物, ゲノム, マイクロシンテニー, 再構築  
Keywords: metazoan, genome, microsynteny, reconstruction

顕生代におけるグローバル海洋環境変遷と海底鉱床生成の因果律  
A close relationship between global oceanic environmental changes and seafloor mineral  
deposition during the Phanerozoic

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Metal deposition on seafloor is strongly controlled by marine redox conditions. Fe-Mn and Mn oxide deposits are formed under oxygenated oceans. In striking contrast, Cu and Zn-bearing sulfide deposits are stable under anoxic oceans. Seafloor mineral deposits in turn are good indicators to redox conditions or redox changes of modern and ancient oceans.

There are numerous strata-bound ore deposits in the Japanese accretionary complexes. These deposits are mainly divided into three types; umber (Fe-Mn), Mn-rich, and volcanogenic massive sulfide (VMS; Besshi-type). The Mn-rich deposits are further divided into two subtypes that are associated with greenstone and NOT associated. Ages of these deposits provide us important constraints for a secular change of marine redox conditions over the past ~360 Myr. Depositional ages of umber and Mn deposits were previously determined by microfossils including radiolarians and conodonts. On the other hand, ages of the Besshi-type deposits are determined by Re-Os method (Nozaki et al., 2013). Oxide ore deposits such as umbers and Mn deposits were very likely precipitated in the modern-style oxygenated deep-sea. In contrast, Mn carbonate and VMS deposits were precipitated in the stagnant, O<sub>2</sub>-deficient deep-sea during the Triassic and Jurassic periods. Seafloor mineral deposition closely related to global oceanic environmental changes may give us a hint for exploring the causes of mass extinction, and further for elucidating the evolution of life.

Nozaki, T., Y. Kato, K. Suzuki (2013) Late Jurassic ocean anoxic event: evidence from voluminous sulphide deposition and preservation in the Panthalassa. *Scientific Reports*, 3: 1889; doi:10.1038/srep01889.

Keywords: oceanic environmental change, seafloor mineral deposit, Japanese accretionary complexes, marine redox condition, Phanerozoic

## 世界古地理と生命進化：その2 中生代 Global paleogeography and life evolution: 2. Mesozoic

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The Mesozoic witnessed the Pangean breakup. Since the Triassic, the southern half of Gondwana successively rifted/separated, kicking out numbers of continents northward to form Laurasia, i.e., the northern half of Pangea, ca. 200 Ma. Multiple collisions among the Russian platform, Kazakhstan, Siberia, N. China, S. China, Indochina, Tarim, and other minor continental blocks were completed mostly in the Triassic or in the Early Jurassic at the latest. Gondwana has started to be fragmented immediately after its birth at 540Ma, except the collision of Laurentia at 430 Ma. The apparent supercontinent Pangea formed when Laurasia came in shape by 200 Ma. Its disassembly began first by the opening of the central Atlantic domain induced by the eastward moving of Africa for ca. a few thousands of km. The birth of South Atlantic Ocean was delayed until ca. 120Ma, whereas the opening of Northern Atlantic already started. The separation of S. America from Africa occurred ca. 120Ma. There was a pulse period of Pacific superplume ca. 120-85Ma when the production rate of MORB was 150-300 % higher than the rest of the Mesozoic. Numbers of huge oceanic plateaus were formed in the Pacific domain, including the Caribbean plateau. The birth of Indian Ocean occurred at ca. 100-120Ma by the separation of India from Gondwana. It is composed of 4 distinct oceanic lithospheres (separated by NS-trending major transform faults) behaved uniquely. The sea-level was kept relatively high according to such Mesozoic global tectonics; warm period without global glaciation but with oceanic anoxia and remarkable production of oil, gas, and coal. The climate was generally dryer than the Cenozoic, with higher production of evaporites. The mammalian diversification was triggered by the ca. 120Ma separation of the final bridge among Africa, S. America, and Laurasia. The appearance of the fox monkey in Madagascar, and of new-world monkeies in S. America, was likely connected to Indian migration and narrow arc bridge to S. America.

キーワード: 古地理, 中生代, 超大陸, パンゲア, 大西洋, 生命進化  
Keywords: paleogeography, Mesozoic, supercontinent, Pangea, Atlantic Ocean, evolution

## 有孔虫の石灰化に関する最近の結果 Recent results of foraminiferal calcification

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Foraminifera, marine unicellular organism, have been thought as one of the major carbonate producer in ocean. Their calcareous tests are commonly utilized as paleo-environmental indicators in various studies of earth science because their tests have been archived as numerous fossil in sediment for long time and various environmental information are brought by population, morphology and geochemical fingerprints. The calcareous test itself is interested by many foraminifer scientists. The knowledge about the cytological process on carbonate precipitation has been described for couples of decade using by many legacy technology. Cellular regulations of ions uptake into calcareous tests from seawater are of great interest for broad fields of earth science. Our recent studies showed the potential to understanding the biomineralization of foraminifera by the application of fluorescent indicators. Recently, we visualize the spatial distributions of cytological calcium and pH in living cell at same time under several pH conditions (7.5-8.1). Observed results show that foraminifera controls very detailed timing of pH variation and concentration of calcium at any stage of chamber formation dynamically even ambient pH are varied. These observations results will help to consider how the geochemical compositions arranging on the foraminiferal test, sensitivity of pH proxy of boron and others.

## 単細胞真核生物・浮遊性有孔虫における左右二型 Left-right reversal in unicellular eukaryotes, planktonic foraminifera

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Aquatic unicellular organisms are little motile and passively disperse in general. Holoplankton, which spend their entire life-cycle floating in the water column, are likely carried by water flow and exposed to diverse conditions of environment. Their morphology may vary over wide distribution ranges by phenotypic plasticity or allelic variation. Among these organisms, planktonic foraminifera are an excellent system to examine diversity and evolution in cellular responses to the environment because of two reasons: (1) occurrence in every ocean and (2) visible asymmetry in coiled shell. Both left- and right-coiled forms are often found within single morphospecies. Their coiling direction has traditionally been thought to change phenotypically depending on environmental factors, especially water temperature, based on coil-morph distributions but without statistical evidence. Molecular phylogenetic studies have revealed that morphospecies often contain multiple cryptic species. The arguments on the role of temperature for coil reversal most probably confused cryptic species into single taxa. In the present study, we examined the dependence of morph frequency on temperature by focusing on populations that are dimorphic for coiling direction and occur across wide ranges of temperature. *Globorotalia truncatulinoides* includes five genetically isolated species, and each of them is dimorphic for coiling direction. The statistically meaningful regression analysis was possible in three species that are distributed in global ranges. The results showed that morph frequency does not depend on water temperature in warm or cold seasons or on the annual mean temperature. Moreover, the geographic patterns of frequency variation among water masses in these species suggest that gene flow affects morph frequency. The majority exhibits the same coiling direction among populations that inhabit water masses connected by ocean circulation system. In contrast, morph frequency greatly varies between unconnected water masses regardless of climatic conditions. The present results, therefore, reject temperature-dependence of coiling direction and suggest the presence of genetic basis for coiling direction in planktonic foraminifera. Our study provides a base to explore the evolution on left-right asymmetry in unicellular eukaryotes.

キーワード: 左右非対称, 巻き方向, 隠蔽種, 単細胞真核生物

Keywords: left-right asymmetry, coiling direction, cryptic species, unicellular eukaryote

## 最終氷期の日本海に生息した海洋小型プランクトンは地理的に分断されていたか？ Were marine microplankton in the Japan Sea geographically isolated during the Last Glacial Maximum?

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The Japan Sea is connected by three straights (the Soya, Tsugaru, and Tsushima Straights) to the Sea of Okhotsk and Pacific Ocean with the shallow sill depth (140 m). During the last glacial maximum (LGM: 23-19 kilo years before present), the sea-level was decreased at least 120 m lower than today and the Japan Sea was almost isolated from surrounding seas. It is possible that such geographic isolation reduced and/or impeded gene flow of marine organisms between the Japan Sea and surrounding seas. Previous phylogeographic studies of coastal vertebrates (only whose larval stage is planktonic) have actually suggested that the Japan Sea was closed during the LGM. However, there is no phylogeographic study with marine microplankton, which inhabit the water column throughout their entire life cycle.

Radiolaria, the major marine planktonic protists, are passively transported in the pelagic ocean. Their geographic distribution would be easily affected by geographic changes through geological time. Moreover, their siliceous shells have been preserved in marine sediments and form a good fossil record. The sensitivity to geographic changes and well-preserved fossil record of Radiolaria could allow us to elucidate a past geographic isolation of marine microplankton. *Larcopyle buetschlii*, a morphospecies of radiolarians analyzed in the present study, is found in the surface waters in the Pacific Ocean, whereas it has a characteristic distribution vertically ranged from the surface to deep layers in the Japan Sea. In addition, its fossil specimens are continuously observed in the Japan Sea before the LGM. Therefore, *L. buetschlii* could be a good model to study a link between geographic isolation during the LGM and reproductive isolation of marine microplankton.

Heterogeneity of internal transcribed spacer regions of ribosomal DNA (ITS1 and ITS2) is observed in many eukaryotes (e.g., vertebrates, dinoflagellates, and diatoms). The ITS1 and ITS2 regions are spliced out during the maturing process of ribosome, causing a nucleotide substitution rate higher than ribosomal DNA coding regions. Nevertheless, the ITS1 and ITS2 sequences are functionally important for their splicing, because the premature transcript composed of 18S, 28S, 5.8S rRNA, ITS1, and ITS 2 is folded into a secondary structure followed by the self-splicing of ITS1 and ITS2. Based on the secondary structures of ITS1 and ITS2 sequences, compensatory base changes (CBCs: base changes occurring on both sides of a double-stranded portion) and hemi-CBCs (HCBCs: base changes occurring on one side of a double-stranded portion) are often observed among closely related species. The correlation between CBCs and HCBCs in the ITS2 sequences likely reflects sexual compatibility among individuals of a closely related species. Thus, the CBCs/HCBCs correlation is a useful marker to infer whether geographically isolated populations are reproducible.

We demonstrated that there is heterogeneity of the ITS2 sequences within an individual of *L. buetschlii* and that all individuals of *L. buetschlii* collected from the surface to deep layers in the Japan Sea do not have a significant difference in the CBCs/HCBCs of the ITS-2 sequences. Furthermore, the CBCs/HCBCs of the ITS-2 sequences do not show a significant difference between individuals of the Japan Sea and Pacific Ocean. These findings suggest that *L. buetschlii* in the Japan Sea and Pacific Ocean likely forms a reproducible single population. Thus, the geological isolation during the LGM is unlikely effective for the reproductive isolation of this radiolarian species.

Keywords: Japan Sea, *Larcopyle buetschlii*, Radiolaria, secondary deep-sea plankton



## 哺乳類 4 目それぞれで独自に進化的に保存された非コード領域の解析 Non-coding sequences conserved independently in four different mammalian orders

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脊椎動物において進化的に保存された非コード配列 (CNS) は、タンパク質コード遺伝子の発現調節領域と密接に関連していると考えられている。われわれは、哺乳類の 4 目 (霊長目、齧歯目、食肉目、鯨偶蹄目) について、CNS の個数とそれらのゲノム上の位置を調べた。CNS の定義にはタンパク質コード領域の保存についての 2 種類の閾値を用いた; すべてのコード領域塩基配列を用いる場合と、コドンの 1 番目と 2 番目だけを用いた場合。CNS の個数は系統によって異なっており、霊長類がもっとも多く、齧歯類がもっとも少なかった。これらの CNS は哺乳類ゲノム全体の 1.3~5.5% であり、より祖先的なもののほうがより最近に生じたものよりも保存度が高かった。CNS は、齧歯類と霊長類では、食肉目と鯨偶蹄目の場合よりもイントロンにより多く存在していた。ヒトゲノムとイヌゲノムでは、順系相同な CNS の 19% はゲノム上の異なった位置にあった。これら哺乳類の 4 目間の CNS の差は目独自の表現型を生じる原因になっている可能性がある。齧歯類で CNS の数が少ないのは、齧歯類内の多様性により遺伝子発現調節に関する進化的保存が少ないことを示唆する。霊長類の CNS は神経系に関与する遺伝子の近傍にクラスターすることが多くみられたので、霊長類の神経系の高度な複雑性に関与しているのかもしれない。この研究はすでに *Genome Biology and Evolution* (Babarinde and Saitou, 2013; vol. 5:2330-2343) に発表した。

キーワード: ゲノム, 哺乳類, 霊長目, 齧歯目, 偶蹄目, 食肉目  
Keywords: genome, mammals, Primates, Rodents, Artiodactyla, Carnivores

## 古代ゲノム研究に向けたハイフネーティッド化学分析技術の開発 Development for new hyphenated analytical technologies for paleogenomics research

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Cytometry is the analytical technique, basically applied for quantitative analysis of cells and cell systems. In general, cytometry measures optical properties of cells, and most often uses fluorescence to measure specific antigen molecules, intracellular ions and DNA/RNA. Cells may be live or fixed, depending on the application, and individual cells can often be physically sorted. Other optical signals can be measured, including light scatter. The cytometry has blossomed to become the key technique to evaluate the nutritional status or to understand the elemental metabolism for animals. Several advantages can be derived by the cytometry, such as analysis speed, detection sensitivity, the ability to measure many parameters simultaneously, and the ability to sort individual cells (i.e., single cell spectroscopy). Recently, new generation cytometry utilizing the sensitive mass spectrometers (i.e., mass cytometry) was described. With the mass cytometry, further sensitive detection of ions or proteins and higher capability for the multiparameter analysis of individual adherent cells (e.g., Benfall et al., *Science*, 2011; Bodenmiller et al., *Nature Biotechnology*, 2012). With the extensive number of information collected from cells or samples through the cytometry, reliable and objective evaluation for the changes in biochemical functions could be achieved. This approach can also be applied to understand the solar system evolution based on the numerous number of age data. In recent ten years, we have demonstrated the unique study approach using the distribution pattern of sample ages based on the series of precise age data collected from large number of samples (i.e., age-cytometry) (e.g., Rino et al., *PEPI*, 2008; Iizuka et al., *Geology*, 2008; Iizuka et al., *Chem. Geol.*, 2009; Iizuka et al., *GCA*, 2010). The mass cytometry will become a powerful tool to promote the big-data science for various research fields such as metallomics, medical sciences or the geochemistry. For elemental or isotopic analysis of trace- or ultratrace-elements, plasma ion source mass spectrometry (ICP-MS) has been widely employed because of its high analytical capabilities such as high-elemental sensitivities, minimal sample preparation procedures, high-analysis throughput or user-friendly operations (Bandura et al., *Anal. Chem.*, 2009). With the laser ablation sample introduction technique, distribution of both the elemental and isotopic data for trace- or ultratrace-elements can be successfully derived directly from large-sized solid samples (>10cm). Despite the obvious success in obtaining elemental and isotopic data (age data), it should be noted that stable isotope ratio data for light elements (e.g., C and O) could not be derived by the present LA-ICPMS technique because of serious contribution mass spectrometric interferences on C and O isotopes, which provides key information concerning the physico-chemical conditions for the sample formation. To overcome this, we would like to develop a new analytical technique to measure the C isotopes, at a same time with elemental analysis using the LA-ICPMS technique. Newly developed spectroscopy technique combined to the LA-ICPMS technique can become a major analytical tool to expand the analytical capability for mass cytometry for biochemical samples and geochemical samples through precise, reliable and uniform quality data. The analytical technique develop here will promote the big-data science for various research fields including geochemistry and biochemistry.

Keywords: mass spectrometry, laser ablation, paleogenomics, hyphenated technology, analytical chemistry, geochemistry

## 海洋有光層ユーキシニアの発生条件:海洋生物化学循環モデルからの制約 Conditions for photic zone euxinia deduced from ocean biogeochemical cycle model

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顕生代においては、大気中の酸素濃度は基本的に現在とほぼ同様のレベルに維持されてきたと考えられている。しかし、海洋においては、しばしば一時的 (<10<sup>6</sup> 年) に酸素の欠乏が起きたことが知られており、「海洋無酸素イベント (Oceanic Anoxic Events; OAEs)」と呼ばれている。

酸素の欠乏した水塊においては、硫酸還元が起き、硫化水素が発生する。したがって、貧酸素水塊は、無酸素かつ硫化水素に満ちた条件になることがあり、「ユーキシニア」と呼ばれる。

ペルム紀/三畳紀境界や白亜紀の OAE2 などにおいては、緑色硫黄細菌のバイオマーカーが検出されており、大気とよく混合されているはずの有光層 (~100m) が硫化水素に満ちていたことが示唆される。

このような、「有光層ユーキシニア」という非常に特殊な海洋環境は、どのような条件で発生するのかといった、その詳細はよく分かっていない。

そこで本研究では、海洋無酸素イベントに伴う有光層ユーキシニアの発生条件を明らかにするために、Ozaki and Tajika(2013) で開発された海洋生物化学循環モデル CANOPS を用いてその再現を試みた。

さらに、海洋表層を高空間解像度化することによって、有光層ユーキシニアにおける物質の鉛直分布とその時間変化を定量的に評価し、海洋無酸素イベントに伴う海洋一次生産者の変遷等についての理論的推定を試みる。

キーワード: 海洋無酸素イベント, 生物地球化学循環, リン循環, アノキシア/ユーキシニア, 有光層ユーキシニア  
Keywords: oceanic anoxic events, biogeochemical cycles, phosphorus cycle, anoxia/euxinia, photic zone euxinia

## 原生代前期全球凍結時の大気二酸化炭素分圧 Partial pressure of atmospheric CO<sub>2</sub> during the Paleoproterozoic global glaciation

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The Paleoproterozoic Makganyene Glaciation is a particular enigmatic geologic event in that ice covered the oceans even at low latitude (Snowball Earth). This event might have drastically curtailed biological productivity but melting of the oceanic ice presumably induced a cyanobacterial bloom, leading to an acceleration of global oxygenation. It has been predicted that this event occurred as a result of the drawdown of greenhouse gases in the atmosphere. However, atmospheric CO<sub>2</sub> levels at that time are still under debate. Here, we constrained the CO<sub>2</sub> concentration in seawater based on fluid inclusions in subseafloor hydrothermal quartz deposits from the 2.2 billion years (Gyr) old Ongeluk volcanics, South Africa, in which the ancient water and carbon dioxide are preserved. The quantitative analysis of the concentration and stable carbon isotopes of CO<sub>2</sub> in the fluid inclusions revealed that the CO<sub>2</sub> concentration in the seawater was limited to be less than 7 mmol/kg. Because the Ongeluk seawater was locally open to the atmosphere, atmospheric CO<sub>2</sub> level was also estimated to be lower than 33 times the present atmospheric level (PAL) ( $<1.3 \times 10^2$  bar) assuming equilibrium between the Ongeluk seawater and atmosphere. This CO<sub>2</sub> level was not enough to compensate the faint young sun and keep the ocean temperature sufficiently above freezing point by itself. Although the behavior of other greenhouse gases is still unknown, our results demonstrate that the deficient atmospheric CO<sub>2</sub> level was a significant contributing factor to the 2.2 Gyr global glaciation.

## 天体衝突が引き起こす海洋酸性化と K/Pg 事件の絶滅機構 Impact-driven ocean acidification as a mechanism of Cretaceous?Palaeogene mass extinctions

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The Cretaceous?Paleogene (K?Pg) mass extinction event at 65.5 Ma triggered by a meteorite impact is one of the most drastic events in the history of life on the Earth. Many hypotheses have been proposed as killing mechanisms induced by the impact, including global darkness due to high concentrations of atmospheric silicate dust particles, global wildfires, greenhouse warming due to CO<sub>2</sub> release, and global acid rain. However, the actual mechanism of extinction remains highly controversial. One of the most important clues for understanding the extinction mechanism is the marine plankton record, which indicates that plankton foraminifera, living in the near-surface ocean, suffered very severe extinction in contrast to the high survival ratio of benthic foraminifera. No proposed extinction mechanism can account for this globally observed marine extinction pattern. Here, we show that SO<sub>3</sub>-rich impact vapor was released in the K-Pg impact and resulted in the occurrence of global acid rain and sudden severe ocean acidification at the end of the Cretaceous, based on the new results of impact experiments at velocities much higher than previous works (>10 km/s) and theoretical calculations on aerosol coagulation processes. Sudden severe ocean acidification can account for many of the features of various geologic records at the K?Pg boundary, including severe extinction of plankton foraminifera. This extinction mechanism requires impact degassing of SO<sub>3</sub>-rich vapor, which is not necessarily found at impact sites other than Chicxulub, suggesting that the degree of mass extinction was controlled greatly by target lithology.

キーワード: K/Pg 生物大量絶滅, 天体衝突, 室内実験, 酸性雨, 海洋酸性化, 質量分析

Keywords: K/Pg mass extinction, impact, laboratory experiment, acid rain, ocean acidification, mass spectroscopy

## トリアス紀・ジュラ紀深海堆積物中に保存された白金族元素濃度異常 Platinum group element anomalies in the Triassic-Jurassic deep-sea sediments

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One of the biggest mass extinctions in the Phanerozoic occurred at the Triassic-Jurassic (T-J) boundary. The large magmatic activity associated with the breakup of Pangaea (CAMP event) or a bolide impact attract interests as causes of the mass extinction at the T-J boundary. However, the cause of the mass extinction is still controversial because of insufficient geological evidences. PGE abundances and radiogenic Os isotope ratios are powerful tracers that potentially distinguish ancient basaltic magmatism from the effect from extraterrestrial.

We conducted detailed geological survey at the Inuyama area, where Triassic to Jurassic deep-sea sediments well crop out. We developed detailed a geological map of the study area and reconstructed ocean plate stratigraphy. We collected ca. 70 siliceous shale samples bed-by-bed were also collected to measure PGEs concentration and Os isotopes with a high spatial resolution. The rock powder was spiked with <sup>190</sup>Os, <sup>185</sup>Re, <sup>191</sup>Ir, <sup>99</sup>Ru, <sup>194</sup>Rt, and <sup>105</sup>Pd and digested by 2:1 mixture of HNO<sub>3</sub> and HCl in a sealed Carious tube at 240oC for 48 hours. After chemical separation using an anion exchange resin, the isotope ratios of PGE were measured by a quadrupole type ICP-MS at Tokyo Tech. The Os isotope ratios were determined by N-TIMS (Triton plus) at Tokyo Tech.

PGEs concentrations and Os isotope composition are determined from 28 siliceous shale samples across the T-J boundary. Re and Os contents varies from 14.7 to 128.6 pg/g and from 4.9 to 99.2 pg/g, respectively. <sup>187</sup>Os/<sup>188</sup>Os decreases from 0.77 to 0.34 before the T-J boundary. The <sup>187</sup>Os/<sup>188</sup>Os values in the Jurassic siliceous shales fluctuated around ca. 0.5. The highest Os concentration and negative Os isotope anomaly corresponds to the first occurrence of Jurassic type radiolarian. Also, Ir/Pt vs Pd/Pt cross plot and C1 chondrite-normalized PGE patterns of siliceous shales across the T-J boundary show similar trend to CAMP and upper continental crust (UCC). This indicates that the origin of PGEs detected from siliceous shales are the mixture of CAMP and UCC, and that extraterrestrial influence at the T-J boundary was minor.

Keywords: T-J boundary mass extinction, deep-sea sediments, platinum group element

## 三疊紀後期ノーリアンにおける放散虫群集変化と隕石衝突イベント Impact event and radiolarian faunal turnover across the middle-upper Norian transition at Sakahogi section in Japan

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Anomalously high platinum group element (PGE) concentrations have been reported for Upper Triassic (middle Norian) deep-sea claystone layer in the Sakahogi section, central Japan, which have been interpreted to be derived from an extraterrestrial impact event that formed the 90 km Manicouagan crater in Canada. Here we report middle to upper Norian radiolarian biostratigraphy from the Sakahogi section across the impact ejecta layer. Based on the radiolarian biostratigraphy from the Sakahogi section, three radiolarian zones are recognized in ascending order as follows: Capnodocce?Trialatus zone, Trialatus robustus?Lysemelas olbia zone, and Lysemelas olbia zone. Detailed high-resolution sampling and biostratigraphical data allowed us to date precisely the ejecta layer, which occur in the base of the radiolarian Trialatus robustus?Lysemelas olbia zone. Our biostratigraphic analysis suggests that there was no mass extinction of radiolarians across the impact event horizon. Only one species became extinct at the ejecta horizon and the extinction rate of radiolarians (extinct species divided by total species at the same level) is estimated to be about 5% at the horizon. Major turnovers of radiolarians occur above the ejecta horizon within the Trialatus robustus?Lysemelas olbia zone. Biostratigraphic analysis shows that 20 radiolarian species became extinct in this zone and the extinction rate is estimated to be 83%. This turnover is associated with a deposition of spicular chert, suggesting temporal changes in marine ecosystems after the impact event. Given that the average sedimentation rate of the middle to upper Norian chert succession is 2.7 mm per thousand years, this turnover occurred 400 kyr after the impact event. Thus the meteorite impact did not directly cause of radiolarian extinction event.

キーワード: 三疊紀, 隕石衝突, 放散虫

Keywords: Triassic, Meteorite Impact, Radiolaria

## 前期三畳紀極端温暖化直後の全球的海洋酸化イベント A global ocean oxidation event immediately after the Early Triassic thermal maximum

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Biotic recovery after the largest mass extinction at the end of the Permian (252.3 million years ago, Ma) became evident in early Spathian (250.1 Ma), Early Triassic, and was eventually completed in middle-late Anisian (ca. 244 Ma), early Middle Triassic. Recent studies showed that this much delayed recovery was impacted by several biocrises and associated environmental and climatic stresses during the Early Triassic. For instance, the end-Smithian extinction and associated thermal maximum and Smithian oceanic anoxia may have prevented biotic recovery initiated in early Smithian (251 Ma). Our new study not only confirmed the oceanic anoxia in late Smithian but also found an oxygenation event just after the Smithian thermal maxima (STM) using sulfur isotope fractionation between sulfate and sulfide. Newly obtained sulfur isotope ratios of carbonate-associated sulfate (d34SCAS) in the surface water and sulfide (d34Ssulfide) in the Panthalassic deep water during the late Permian to the Early Triassic compiled with published data show a significant increase in fractionation between the d34SCAS and d34Ssulfide during the early Spathian (41-51 permil to 62 permil). The latter indicates an increase in global oceanic dissolved oxygen levels, which also coincided with a climatic cooling and may have facilitated biotic recovery in late Early Triassic.

キーワード: 前期三畳紀, 海洋溶存酸素, 硫黄同位体

Keywords: Early Triassic, ocean dissolved oxygen, sulfur isotope



## 前期三畳紀におけるシアノバクテリアの繁栄 Cyanobacterial proliferation during the Early Triassic

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Recent studies have shown that microbes bloomed in the aftermath of several major Phanerozoic biocrises. Microbial proliferation, as indicated by widespread microbialites, characterized marine ecosystems after the end-Permian mass extinction, which constituted the most severe biocrisis for life on Earth. The microbialite builders, including cyanobacteria and other unknown microalgae or bacteria, acted as primary producers in the trophic structure of the earliest Triassic marine ecosystem. However, the stratigraphic distributions of cyanobacteria and eukaryotic algae during the Permian-Triassic transition remain unknown. Thus, we conducted studies for the interval from the latest Permian to the Middle Triassic using the monomethyl heptadecane ratio (MHR) and 2-methyl hopane index (2-MHI) as cyanobacterial proxies, and the n-alkyl-cyclobenzene ratio (ACBR) as a biomarker for eukaryotic algae. We detected a proliferation of eukaryotic algae during the latest Permian and early Middle Triassic, whereas cyanobacteria flourished during most of the Early Triassic. The new findings are consistent with previously determined stratigraphic distributions of microbialites and the species richness of eukaryotic algae. The erosion intensity and temperature fluctuated in conjunction with changes in the populations of cyanobacteria and eukaryotic algae. Therefore, we postulate that these population changes were primarily the result of enhanced water turbidity from elevated bedrock erosion and lethally hot temperatures.

キーワード: バイオマーカー, 前期三畳紀, 絶滅, シアノバクテリア

Keywords: biomarker, Early Triassic, extinction, cyanobacteria

## ペルム紀末大量絶滅後の海水モリブデン濃度の減少 Mo depleted ocean after the end Permian mass extinction referred from Mo and U behaviors in pelagic deep-sea sedimentary

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The end-Permian mass extinction was the largest biotic catastrophe of the Phanerozoic, and evidence of global oceanic anoxia during this event has been reported (e.g. Wignall and Twitchett, 1996). Such anoxic/euxinic conditions have also been revealed by enrichments of redox-sensitive elements (Fio et al., 2010; Grasby et al., 2009, 2011; Algeo et al., 2012). Among redox-sensitive elements, uranium increased in sediments and finally result uranium drawdown, suggested by a decrease in sedimentary uranium isotope ratio (238/235U) and a increase in Th/U ratio from the shallow marine carbonates (Brennecke et al., 2011). In this presentation, we will show the possible evidence of Mo drawdown after the mass extinction event from the continuous deep-sea Permian-Triassic boundary section which located in the low latitude pelagic Panthalassa (Akkamori section-2; Takahashi et al., 2009).

High resolution ICP-MS analysis using sedimentary rock samples from the study section (Takahashi et al., in review) indicates vertical distribution of UEF and MoEF (Enrichment factor of U and Mo), the Mo/U ratio. MoEF and UEF show a synchronous increase from the Upper Permian bedded chert to the overlying siliceous claystone, while the Mo/U ratio increases from 3.9 to 47.3 showing continuous elevation from the  $1.0 \times$  modern seawater Mo/U ratio ( $1.0 \times$  SW) to  $9.0 \times$  the modern ratio ( $9.0 \times$  SW). Accepting the previous study's criteria (Algeo and Tribovillard, 2009), increased Mo/U ratios that clearly exceed 9 ( $3 \times$  times the value of modern seawater [ $3.0 \times$  SW]) suggest the presence sulphidic bottom water at that time. Considering possibility of U drawdown suggested by Brennecke et al. (2011), decrease in seawater U concentration (possibly up to 1/7) would also help the rise of Mo/U ratio. Further elevations of MoEF and the Mo/U ratio reach values of more than 1000, and MoEF reaches values of several thousands from Upper Permian siliceous claystone to the basal 20cm end-Permian black claystone, indicating that sulphidic bottom water was increasingly developed and that Mo transportation by the particulate shuttle was activated. The particulate shuttle, proposed by Algeo and Tribovillard (2009), is a process by which Mn oxyhydroxides absorb molybdate oxyanions above the oxic/anoxic chemocline in the water column and then sink and finally dissolve on at or just below the sediment-water interface, releasing Mo to the sediments. Additionally, in such a developed sulphidic water column, syngenetic pyrite formation in the euxinic water column could possibly have contributed to Mo transportation to the sediment (Algeo and Maynard, 2004). Above the 20 cm horizon of the black claystone, MoEF decreases to values lower than 100 and the Mo/U ratio takes values of more than 3 but less than 20. These values could be interpreted to indicate that sulphidic bottom water was still present but that the particle shuttle had subsided to some extent after the time of the mass extinction. Low Mo/U values occur in earliest Triassic siliceous claystone bed, despite high MoEF and UEF values. Because MoEF and UEF are high, reducing bottom water conditions still existed. Thus, the decrease in Mo/U does not indicate a return to oxic conditions, but rather a Mo drawdown in the earliest Triassic seawater. The study examples of such trace-metal drawdown in geologic past have been reported by Algeo (2004) and Hetzel et al. (2009). In fact, the trend of low Mo/U values with high MoEF and UEF is consistent with that of the Mo-depleted seawater condition identified in the modern Black Sea (Algeo and Tribovillard, 2009), suggesting a drawdown of seawater Mo in the pelagic ocean.

キーワード: モリブデン, 大量絶滅, ペルム紀, 三畳紀, 遠洋域深海相, パンサラッサ  
Keywords: molybdenum, mass extinction, Permian, Triassic, deep-sea, Panthalassa

南中国朝天セクションのP-T境界層におけるN同位体層序  
Nitrogen isotope chemostratigraphy across the Permian-Triassic boundary at Chaotian,  
Sichuan, South China.

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Nitrogen isotopic compositions of upper Permian to lowermost Triassic rocks were analyzed at Chaotian in northern Sichuan, South China, in order to clarify changes in the oceanic nitrogen cycle during the Changhsingian (Late Late Permian) prior to the end-Permian extinction. The analyzed interval across the Permian-Triassic boundary (P-TB) at Chaotian consists of three stratigraphic units: the upper Wujiaping Formation, the Dalong Formation, and the lowermost Feixianguan Formation, in ascending order. The upper Wujiaping Formation is mainly composed of dark gray limestone with diverse shallow-marine fossils deposited on the shallow shelf. In contrast, the overlying Dalong Formation is mainly composed of thinly bedded laminated black mudstone and black siliceous mudstone containing abundant radiolarians, deposited on the relatively deep slope/basin under anoxic condition. The lowermost Feixianguan Formation is composed of thinly bedded gray marl and micritic limestone with minor fossils deposited on the shallow shelf.  $\delta^{15}\text{N}$  values are in positive values in the upper Wujiaping Formation implying denitrification and/or anammox in the ocean.  $\delta^{15}\text{N}$  values gradually decrease in the lower Dalong Formation and are consistently low in the middle Dalong to lowermost Feixianguan Formation. In particular, no clear  $\delta^{15}\text{N}$  shift is recognized across the extinction horizon. The consistently low  $\delta^{15}\text{N}$  values at Chaotian suggest the enhanced nitrogen fixation in the ocean during the entire Changhsingian to early Induan (Early Early Triassic), accompanied with the emergence of anoxic condition. The  $\delta^{15}\text{N}$  trend at Chaotian was possibly a regional isotopic signature in northwestern South China and not a global one, because the composite  $\delta^{15}\text{N}$  profiles document that no  $\delta^{15}\text{N}$  trend similar to that at Chaotian is observed in other P-TB sections around the world. Nonetheless, the protracted oceanic nitrogen depletion during the Changhsingian suggested by the present results at Chaotian may have acted as a stress to shallow-marine biota.

ペルム紀中期末におきた顕著な海水準低下とグローバル寒冷化：超海洋中央部海山起源石灰岩の記録  
A remarkable sea-level drop and global cooling in the late Middle Permian: record from the mid-superoceanic limestone

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For clarifying the global environmental changes relevant to the Guadalupian-Lopingian boundary (G-LB) extinction, i.e. the first major biodiversity drop during the Permian, litho-, bio-, and chemo- stratigraphy of  $\delta^{13}\text{C}_{carb}$  and  $^{87}\text{Sr}/^{86}\text{Sr}$  were analyzed in the Middle-Upper Permian paleo-atoll limestone at Akasaka in central Japan, which was derived from a paleo-atoll complex deposited primarily in the low latitude in the mid-Panthalassa. Between the Capitanian (upper Middle Permian) black limestone (the *Yabeina* fusuline Zone) and the Wuchiapingian (lower Upper Permian) light gray limestone (the *Codonofusiella-Reichelina* Zone), a unique black-white striped limestone is intercalated, of which top marks the G-LB horizon.

The major extinction occurred in the uppermost black limestone, large-tested fusuline and large bivalve that were adapted to low-latitude extremely warm conditions sharply became extinct. Most parts of the Akasaka Limestone consist of shallow marine wackestone/packstone deposited in low-energy settings of the subtidal zone likely within a lagoon on the top of a seamount.

We newly identified 1) a remarkable hiatus with erosional features at the top of the striped limestone, 2) large-scale cross-beddings in the striped limestone immediately below the hiatus, and 3) the dominance of grainstone in the basal light gray limestone immediately above the hiatus. These lines of evidence altogether suggest that a remarkable sea-level drop has occurred around the G-LB in the mid-oceanic paleo-atoll complex, and that a cool climate has appeared in the Capitanian. The isotope stratigraphy for the Capitanian interval with extremely high  $\delta^{13}\text{C}_{carb}$  values over +5 ‰ and the extremely low  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios below 0.7070 indicate the high productivity in the superocean and the suppressed continental weathering on Pangea, respectively. Both isotope signatures can be concordantly explained by the appearance of a putative global cooling in the Capitanian. After all, the litho-, bio-, and chemostratigraphical records from the Permian mid-superocean positively suggest a possible link between the Capitanian global cooling and the end-Capitanian extinction.

キーワード: G-L 境界, 超海洋起源石灰岩, 海水準低下, 寒冷化, 炭素同位体, Sr 同位体

Keywords: G-L boundary, mid-superoceanic limestone, sea-level drop, cooling, carbon isotope, strontium isotope

## 中・後期ペルム紀の海水 Sr 同位体比変動および氷床増減との関連 Middle to Late Permian seawater Sr isotope variation linked to the glaciation/deglaciation

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We report the detailed secular change of the Middle to Late Permian seawater  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio for the Akasaka and Iwato limestone in SW Japan. The studied two sections were originally deposited as paleo-atoll complexes on the low-latitude, mid-Panthalassa seamounts. We also analyzed coeval sections at Sizipo and Liangshan deposited on the shallow marine shelf of South China. Commonly in the four studied sections, extremely low values ( $<0.7069$ ; the lowest values of the Phanerozoic) continued from upper Wordian (middle Middle Permian) to the topmost Capitanian (upper Middle Permian) immediately below the Middle-Late Permian boundary. The  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios increased to 0.7072 in the early Late Permian. This increase recorded the most rapid in the entire Phanerozoic. The ca. 5 m.y.-long minimum interval and the following rapid increase in Sr isotope ratio can be explained by the remarkable changes in continental erosion/weathering rate; in particular, by the onset of glaciation and the following deglaciation, that is supported by global sea level change, in addition to the initial doming/rifting of Pangea. After the Capitanian cooling, the long-term climatic regime shifted to a warmer one during which covering ice was removed from continents to expose crustal silicates for to erosion/weathering. The continental rifting with new drainage systems likely increased decisively the highly radiogenic continental flux to the superocean.

Keywords: Permian, Sr isotope, seawater, limestone

南部北上帯ペルム系岩井崎石灰岩産の特異な低緯度型軟体動物群集とその意義  
A unique low-latitude-type molluscan assemblage from the Permian Iwaizaki limestone  
in the S. Kitakami belt, NE Japan

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東北日本南部北上帯の中部ペルム系上部岩井崎石灰岩から初めて巨大巻貝”*Pleurotomaria*” *yokoyami*が産出した。小型の平旋回巻貝*Porcellia* sp. が随伴する。これらの巻貝化石の産出は極めて稀で、これまで西南日本の赤坂石灰岩からの産出報告があるのみである。赤坂石灰岩は超海洋パンサラサ中央の低緯度域で堆積した海山上の礁石灰岩がであるのに対し、岩井崎石灰岩は碎屑岩優勢の陸棚浅海で形成されたパッチ礁石灰岩からなる。岩井崎石灰岩から、赤坂と共通のユニークな巻貝群集、さらに巨大二枚貝や大型フズリナの産出が確認されたことから、同様に低緯度域で堆積したこと、さらには南部北上帯が南中国縁辺、すなわちその東北延長部をなしていたことが推定される。

キーワード: ペルム紀, 二枚貝, 巻貝, 南部北上帯, 南中国

Keywords: Permian, bivalve, gastropod, South Kitakami belt, South China

## 古生代の大気海洋系酸化還元状態の安定化メカニズム Mechanisms regulating the redox state of an atmosphere-ocean system during the Paleozoic

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There is now a great interest in understanding paleoredox conditions of an atmosphere-ocean system because it is essential for investigating links between oxygenation of biosphere and major biological innovation/extinction. Therefore, understanding the regulating mechanism(s) of secular (over millions of years) changes of redox state of Earth's surface environments is one of the fundamental topics. Early Paleozoic is marked by the prominent biological evolution/diversification events (i.e., Cambrian explosion, Great Ordovician Biodiversification Event, and advent of land plants). On the other hand, multiple lines of geological and geochemical evidence (such as black shale deposition, low C/S ratio of buried sediments, low molybdenum isotopic value, and iron speciation data) suggest that oxygen-depleted waters were generally more common and widespread in the ocean interior than they are today until the Devonian. Among these, recent finding of an increase in molybdenum isotopic value from ~1.4 ‰ to ~2.0 ‰ between ~440 Ma and ~390 Ma (Dahl et al., 2010 PNAS) attracts the attention because it implies the oceanic redox transition to a well-oxygenated condition. However, the ultimate cause of this transition remains uncertain.

Considering the fact that the ocean oxygenation event correlates with the diversification of land plants since the Late Ordovician, causal linkage between them are intriguing; an enhanced chemical weathering on the continent by land plants could lead to an increase in the burial rate of terrigenous organic matter, giving rise to an oxygenation of an ocean-atmosphere system. However, it remains unclear whether the radiation of land plants is necessary to cause such redox transition.

The evolution of atmospheric oxygen concentration has been studied intensively, but reconstructed atmospheric oxygen evolution varies widely between models, demonstrating that further understanding on the mechanisms controlling atmospheric oxygen level is still required. Because oxygen is most likely regulated by a combination of several feedbacks in the Earth system, it is essential to evaluate the impact of plant diversification on the oxygenation state of an ocean-atmosphere system with the aid of a biogeochemical cycle model. In this study, a model is designed to explore the roles of several feedback mechanisms regulating the redox state of the atmosphere and oceans during the early Paleozoic, and to reconstruct the paleoredox history of an ocean-atmosphere system during the early Paleozoic. The results of systematic sensitivity experiment demonstrate that (1) oceans before the advent of land plant had been kept in suboxic-anoxic condition, that (2) the diversification of land plant since Late Ordovician could cause an increase in atmospheric oxygen level to >16% by the Devonian and ocean could be oxygenated by the Middle Devonian, and that (3) a redox dependent burial efficiency of phosphorus at sediment-water interface and degradability of particulate organic matter (POM) play substantial roles in atmospheric oxygen level before the advent of land plant. The modeling results confirm the causal linkage between plant diversification and the oxidation of Earth's surface environments. Our result also highlights the need for more quantitative and process-based knowledge of the decomposition process of POM in order to reveal the redox evolution of atmosphere-ocean system during the Paleozoic.

キーワード: 古生代, 大気酸素濃度, 生物地球化学, 陸上植物進化, 物質循環モデル

Keywords: Paleozoic, atmospheric oxygen level, biogeochemistry, land plant evolution, biogeochemical cycle model

## カンブリア紀前期における生物ポンプの強化：南中国三峡地域のエディアカラ系-下部カンブリア系の分子種別炭素同位体比測定 Compound-specific carbon isotope ratios from the Ediacaran-lower Cambrian in the Three Gorges area, South China

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動物の爆発的多様化事件当時の海洋における有機炭素循環を探るために、南中国三峡地域で掘削されたエディアカラ紀からカンブリア紀前期の陸棚堆積物試料について、光合成生物由来の有機物相の変化を記録する脂肪族炭化水素の分子種別炭素同位体比を初めて得た。短鎖 n-アルカンとプリスタンの炭素同位体比間の差 ( $\Delta ap$ ) はエディアカラ紀では比較的高い値 (約-3~4 ‰) を示すのに対し、Terreneuvian (カンブリア紀最初期 541-521 Ma) 前期に約-6 ‰まで減少した後、約 6 ‰まで上昇し、Epoch 2 (カンブリア紀前期 521-509 Ma) で約-4 ‰まで減少する。一方、プリスタンとフィタンの炭素同位体比間の差 ( $\Delta pp$ ) は、エディアカラ紀に約 0 ‰を示し、Terreneuvian に約-5 ‰まで減少し、Epoch 2 に約 6 ‰まで上昇する。また、軽い同位体比 (-45 ‰) を持つ  $\beta$  カロタンが Epoch 2 の黒色頁岩からのみ見つかった。

$\Delta pp$  の変化は、エディアカラ紀の海中には単一の光合成生物コミュニティが存在したのに対し、カンブリア紀前期には複数存在したことを示唆する。 $\Delta ap$  の減少は、真核光合成生物由来の脂質の埋没が増えたことを示し、Terreneuvian 前期に動物の糞粒が出現し、海洋での生物ポンプが非常に強まってそれまで広大に存在していた溶存有機炭素リザーバーを縮小させたと考えられる。軽い同位体比を持つ  $\beta$  カロタンと負の  $\Delta pp$  は、嫌気的光合成生物が有機物の分解生成物由来の  $CO_2$  を用いたことと、その  $CO_2$  が底棲生物の出現によってもたらされたことを示唆する。

以上より、カンブリア紀前期の陸棚海域に初めて好気的光合成生物 (表層) と嫌気的光合成生物 (深海) の 2 つの光合成生物コミュニティが共存するようになったと考えられる。カンブリア紀最初期には、嫌気的水塊は陸棚の有光層にまで到達し、その状態は Epoch 2 まで継続したらしい。また、好気的光合成生物由来の脂質の埋没量が増えたことは、微小殻動物群 (SSFs) の多様化が起きた Terreneuvian 前期に生物ポンプが強化されたことと調和的である。

キーワード: エディアカラ紀, カンブリア紀, 酸素濃度, 分子化石, 南中国  
Keywords: Ediacaran, Cambrian, oxygen level, molecular fossil, South China



## エディアカラ紀からカンブリア紀の古海洋環境 Ancient ocean environment in the Ediacaran to Cambrian.

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The Ediacaran to Cambrian period is one of the most important intervals for the evolution of life. However, the scarcity of well-preserved outcrops of Ediacaran and Cambrian rocks still leaves ambiguity in deciphering ambient surface environmental changes and biological evolution.

Recent paleontologists, mainly Chinese scientists, revealed that life on the Earth have evolved through multiple stages. Some of the metazoan fossils were discovered from Ediacaran sedimentary rocks. This suggests that so-called Cambrian Explosion already started from the Ediacaran, not from the Cambrian. Therefore, unraveling surface environmental changes during the Ediacaran attract interests.

The Ediacaran to Cambrian strata in South China are almost continuously exposed and contain many fossils, which is suitable for study of environmental and biological changes in the Ediacaran and Cambrian. We (Tokyo Institute of Technology and The University of Tokyo) conducted on-land drilling through the Nantuo, Doushantuo, Dengying, Yanjiahe, Shuijintuo, Shipai and Tianheban Fms at six sites in the Three Gorges area to obtain continuous samples. We systematically analyzed some kinds of isotope ratios (carbon isotope ratios of carbonate and organic carbon, oxygen isotope ratios, nitrogen isotope ratios of organic matter, radiogenic strontium isotope ratios, calcium isotope ratios, molybdenum isotope ratios and iron isotope ratios of pyrite) and elemental concentrations (cerium, phosphorus, manganese and iron concentration in carbonate), using these core samples. The combination of these detailed chemostratigraphies enables us to decipher the surface environmental changes in the Ediacaran and Cambrian. The most important discovery is that surface environment also had evolved through multiple stages during the Ediacaran and the Cambrian.

I will talk about summary of our comprehensive work in the speech.

## ウェールズ北西部・アングレシー島とスリン半島に露出する後期原生代の付加体 Neoproterozoic accretionary complex exposed in the Anglesey island and Lleyn peninsula, northwestern Wales

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Accretionary complex is formed by subduction of oceanic plate, and records a history of the subduction. Subduction-related Precambrian rocks crop out in central England to Wales. The subduction with eastward polarity is considered to have continued from the Neoproterozoic to the Ordovician. Those are supported by three evidences: existences of (1) 680-480 Ma calc-alkaline volcano-plutonic complexes, (2) a high-P/T metamorphic belt formed by regional metamorphism, which has barroisite  $40\text{Ar}/39\text{Ar}$  ages of 560-550 Ma (peak ages), (3) pelagic to hemipelagic-sedimentary rocks and mafic to ultramafic rock in Monian Supergroup. Based on these evidences, previous studies suggested that the region from the central England to the Wales had been formed by subduction-related orogeny. However, there have been a few constraints on a depositional age in the Monian Supergroup. The age constraint is necessary to reveal tectonic history of the central England to the Wales.

The Monian Supergroup is exposed in the Anglesey island and Lleyn peninsula, northwestern Wales. This complex is divided into three groups; South Stack Group (Gp), New Harbour Gp and Gwna Gp. This study focuses on Gwna Gp because sedimentary rocks consist of lower to middle Cambrian acritarchs. The Gwna Gp has been described as melange since 1919 and is located at structural top than the other two groups. The Gwna melanges include pillow basalts, bedded or jaspery cherts, carbonates, mudstones, sandstones and quartzites, and these rocks are typical rocks of an ocean plate stratigraphy (OPS). At eight areas in the Lleyn peninsula, we conducted geological survey to reconstruct OPSs. In addition, we determined U-Pb ages of zircons from tuffs, mudstones, claystones or sandstones with LA-ICP-MS at the University of Kyoto.

Twenty-six OPSs are reconstructed, and then repetitions of the OPSs by layer-parallel thrusts are confirmed. We separated zircons from three tuffs, two mudstones, four claystones and three sandstones of each OPS. The U-Pb ages of the zircons range from  $637 \pm 13$  Ma (the oldest) to  $541 \pm 16$  Ma (the youngest). We constrained arrival time of each OPS to a trench by the youngest age of detrital zircons.

Although the Gwna Gp has been treated as a single unit, this group can be divided into three types based on the arrival times. The arrival times of Type1, Type2 and Type3 are 630-610 Ma, 610-570 Ma and younger than 560 Ma, respectively. This result indicates the structural upper sequence is older than the lower. This structurally downward growth is the characteristic of typical accretionary complex, and was formed by the eastward subduction. This trend is also supported by the spatial and temporal relation of both volcano-plutonic complexes and regional metamorphic belt. From these evidences, we concluded that the Gwna Gp is the accretionary complex formed by a series of the subduction-related orogeny.

Keywords: Wales, Neoproterozoic, U-Pb age of detrital zircon, Accretionary complex, Subduction-related orogeny

## マリノアン全球凍結時の深海無酸素事件 Deep-sea anoxia during the Marinoan Snowball Earth

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The oxidation of the deep ocean in the Earth's history is regarded to have occurred in the Neoproterozoic, coincident with the metazoan diversification; however, the geological record of the Neoproterozoic environment has been restricted only to shallow-sea sediments. Here we present the discovery of the Neoproterozoic deep-sea sediments in the accretionary complex in Llyn Peninsula, Wales, UK. In the studied section, the oceanic plate stratigraphy consists of mid-ocean ridge basalts, bedded dolostones, ca. 10 m-thick black mudstones, hemipelagic siliceous mudstones and turbidite sandstone, in ascending order. The detrital zircons separated from sandstone give the youngest age of 637±13 Ma. Within ca. 10 m-thick black mudstones, lithological changes are observed; (1) alternating black mudstone and dolomitic carbonate layers, (2) black mudstone with less developed lamination, (3) pyrite-enriched black mudstone, and (4) rhythmically bedded black mudstone, and gradually turns into bedded greenish gray chert sequence. The overlying greenish gray cherts show red color in some place. We analyzed these mudstones and cherts by <sup>57</sup>Fe Mossbauer spectroscopy, and identified six iron species, i.e., hematite, pyrite, two paramagnetic Fe<sup>3+</sup>, and two paramagnetic Fe<sup>2+</sup> with different quadrupole splittings. About a quarter of iron content in the black mudstones consist of pyrite, and other component belong to paramagnetic Fe<sup>2+</sup> or occasionally paramagnetic Fe<sup>3+</sup>. The overlying red cherts contain hematite as the main iron mineral. In the analyzed samples, hematite and pyrite never co-existed. The occurrence of hematite in deep-sea chert essentially indicates a primary oxidizing depositional condition, and that of pyrite a reducing one, respectively. The present results confirmed that a reducing condition persisted in the Neoproterozoic deep-sea through the interval of the black mudstone deposition. The overlying partly-red hematite-bearing cherts give evidence of recover from reducing to oxidizing condition before the arrival to the trench. Here we propose that the black mudstone in Llyn Peninsula shows the global-scale oceanic anoxic event during the Marinoan Snowball Earth, and name this event the 'Marinoan Superanoxia'. During the black mudstone deposition, the whole ocean may have turned into anoxic like the Permo-Triassic boundary Superanoxia; although further discussions for the depositional model based on other geochemical proxies are needed.

## Paleogeography of the Earth; Neoproterozoic Paleogeography of the Earth; Neoproterozoic

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Neoproterozoic Earth was a transient state to bridge Precambrian mono-cellular world to Phanerozoic Earth of metazoans and plants. The snowball Earth from 770Ma to the onset of Cambrian time, was another environmental pressure to force the life evolution.

### (1) Continent configuration

Supercontinent Rodinia was consolidated ca. 1.0Ga around the equatorial region, and began to be rifted in Neoproterozoic. After ca.600Ma, it became fragmented by rising superplume in the center to give a birth of Pacific Ocean. Immediately after the fragmentation, continents were removed to the South Pole to assemble again to make a semi-supercontinent Gondwana by 540Ma.

### (2) Environmental change

Owing to the leaking Earth (Maruyama and Liou, 2005; Maruyama et al., 2014), the rapid emergence of huge landmass caused the rapid diversification of surface environment and birth of metazoans, as well as algae evolution. Preceding to the Cambrian explosive evolution of life, the snowball Earth event which was a warm-cold fluctuation, GCR-triggered cloud cover, rapid sea-level change, nutrients supply, and probably wet and dry climate change, forced the rapid evolution of life. The first appearance of sponge was between Sturtian and Marinoan snowball Earth event, but the most explosive diversification of metazoans occurred between 540 and 520Ma.

Chemostratigraphy more than 10 were completed for the drilled cores in S. China and the detailed environmental changes were analyzed (Special issue in GR, 2014). Weakened paleomagnetic intensity caused severe radiation for the evolving life on the surface of the Earth.

### (3) Life-evolution and mass extinction

By this reason, and presumably the rift volcanism related to atomic bomb magma caused local mass extinction to promote mutation-induced quick evolution to diversify life.

### (4) Biomass, Ecosystem, mass extinction

Sr isotopic change recorded in platform carbonate clearly indicate the huge amount of nutrients supply for continents and sea-level drop caused the birth of paradise of metazoans on the continental visible platform with enough nutrients supply. A new diversified ecosystem was appeared.

The most extensive mass extinction occurred during the Ediacaran to Cambrian time, more than 10 times in this restricted period, from 635Ma to 488Ma.

### (5) Role of Universe

This could be due to the starburst in our Milky Way Galaxy, and promoted volcanic eruption of atomic bomb magma along the continental rifts on the Rodinia and Gondwana.

## スロバキア Kardolina セクションの三畳紀末 (レーチアン) 石灰岩から発見されたスフェルール層の特徴 Spherules layer of the uppermost Triassic (Rhaetian) limestone sequence in the Kardolina section, Slovakia

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Triassic/jurassic (T/J) boundary of approximately 201 million years ago is known as a stratigraphic boundary recorded one of the big five Phanerozoic mass extinctions. Catastrophic processes such as widespread eruption of the Central Atlantic Magmatic Province (CAMP) flood basalts and extraterrestrial impacts have been proposed to account for the mass extinction event. Here we show the results of our analysis of enigmatic spherules in the Upper Rhaetian of the Kardolina section, Slovakia. The Kardolina section is situated on a steep western slope of the Mt Palenica in the Belianske Tatry Mts as the most continuous section of the uppermost Triassic (Rhaetian) Fatra Formation. The Fatra Formation is shallow marine carbonate sequence and is overlain with a sharp contact by marine shale of the lowermost Jurassic (Hettangian) Kopieniec Formation. The Kopieniec Formation consists of a sequence of brown claystone with sandstone and limestone intercalations. The position of the T/J boundary is constrained by foraminiferal assemblages.

The limestone sequence containing the spherules exists in the upper part of Fatra Formation. A negative  $\delta^{13}\text{C}$  excursion and a positive  $\delta^{18}\text{O}$  peak have been known from spherules layers. Analysis of the foraminiferal assemblages showed the diversity of foraminifera have decreased in spherules layers. Spherules are found in at least six sedimentary layers in the Fatra limestone. The size of spherules is approximately 200-300  $\mu\text{m}$ . Spherules are contained ~10 % in the layers and the other component grains consist of lithoclasts, bivalves, and crinoids. These grains were relatively rounded and have reworked fabrics. The results of SEM-EDS analysis indicated that spherules were composed mainly of Si, Al and Mg, and contain small sulfide particles with Fe, Zn, and Cu. Such a geochemical composition was clearly different from ooids and peloids in Fatra Formation, though the origin of spherules in Kardolina section remains uncertain.

キーワード: 三畳紀/ジュラ紀境界, レーチアン, 石灰岩, スフェルール, 絶滅  
Keywords: Triassic/Jurassic boundary, Rhaetian, limestone, spherule, extinction

## 世界古地理と生命進化：その1 新生代 Global paleogeography and life evolution: 1. Cenozoic

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Continental configuration in the Phanerozoic were synthesized, by the integration of not only continents and oceans, but also, plates, ridge-transform system, ocean current, desert, glacier, major rivers, plume-driven bulge, rifts, mountain belts, lakes, vegetation, and the location of first fossils appeared on the Earth. Methods employed here are as follows; plate reconstruction after Scotese (1996, 2002, 2008), for the oceans by Engebretson et al. (1985; 1992), Cogné and Humler (2006), and Seton et al. (2012), and OIB by Utsunomiya et al. (2008).

The Earth system has been changed drastically at 20 Ma under the strong influence by the internal phenomena of solid-Earth, in particular, by the generation of 410 km-depth swarm of hydrous plumes immediately above the "2nd continents". The Cenozoic is clearly divided into the two periods at ca. 20 Ma on the basis of the secular change in seawater Sr isotopic composition (Veizer et al., 1999). This sharp change reflects the increased material flux from continental crusts to ocean by the plume-driven topographic elevations and collision orogeny along the Himalayan-Tethyan domain all the way from Europe to Papua New Guinea. It should be emphasized that the former is nearly 10 times greater in magnitude than the latter. The uplifted regions include Tibet-East Asia, Rocky Mtn./Colorado plateau/Basin-and-Range/Rio Grande Rift in North America, and Middle America. The A-subduction of the main S. America block caused the uplift of the Andean Mtn. The separation

of S. America from Antarctica was critical to have isolated Antarctica around the South Pole to have triggered the glaciation by virtue of cold-water circulation around the Antarctica.

The rapid glaciation both in Arctic and Antarctica started the Quaternary Period at 1.8 Ma, although the Cenozoic glaciation had already started on Antarctica back to 20 Ma. The ultimate cause of the Quaternary glaciation can be blamed to the encounter of our galaxy with a small "dark cloud" since 20 Ma, and to that with nearby supernovae since 1.8 Ma. The low-temperature on the planet surface and the resultant glaciation was triggered likely by the increased galactic cosmic radiation (GCR) through the extensive development of cloud.

The appearance of the cold weather initiated two independent but critical driving forces for nutrient supply in ocean; i.e., cold-water formation in high-latitudes coupled with accelerated upwelling, and intensified the Hadley atmospheric circulation induced by the plume-driven development of topographic highs on-land closer to the altitude of basal stratosphere, as monitored by the secular curve of seawater Sr isotope ratio. As to the changes in ecosystem after the end-Cretaceous extinction, the promoted nutrients supply caused the increased volume of biomass and various biological innovations; e.g., replacement of radiolarians by diatom, the appearance of C4 plants etc. The collision of India against Asia, caused the species mixing between two continents. On the other hand, the resultant Tibetan uplift and birth of Asian Monsoon brought contrasting climate within Eurasia. The birth of human being along the Rift Valley in E. Africa ca. occurred 5-7Ma was caused likely by the episodic eruption of "atomic bomb" magma along the prominent rift zone. In addition to the local mass extinction by radiations, this led the episodic human escapes from Africa into Eurasia in multiple times after 1.2 Ma.

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