

アラスカ州のマストリヒチアン階（上部白亜系）から産出したメタン湧水性化学合成群集 Early Maastrichtian (Late Cretaceous) methane seeps and their associated fauna from southern Alaska

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We investigated early Maastrichtian (Late Cretaceous) methane seep deposits hosted by the upper Matanuska Formation in the Talkeetna Mountains, southern Alaska. During two field seasons (2006 and 2007), we encountered numerous carbonate concretions embedded in the mudstone-dominated formation that is exposed along the Alfred Creek. These carbonates can be classified into several morphotypes, i.e. rounded, irregularly rounded, doughnuts, pipe, and burrow types. At one outcrop, we studied the distribution pattern of the carbonate types. At outcrop, the pipe and doughnuts type carbonates were distributed in the lower horizon, whereas, the rounded type carbonates and the irregularly rounded and burrow type carbonates were found in the middle and upper horizons, respectively. Carbon and oxygen isotopic compositions of the carbonates range from -41.5 to -6.1 per mil (vs VPDB) and from -10.7 to -0.4 per mil (vs VPDB), respectively. Among the investigated carbonates, the burrow, irregularly rounded, and rounded carbonates have more negative values of carbon isotopes indicating that these carbonates were formed under the influence of anaerobic oxidation of methane. Dozens of crustaceans and solemyid bivalves, with lucinid bivalves as a minor component, were found from the upper part of the outcrop. The recent counterparts of solemyid and lucinid bivalves are known to host chemosymbiotic bacteria in their gills. The bivalves have been commonly found around ancient and Recent methane-seeps.

It is worth to note that this is the first record of the methane-seep dependent chemosynthesis-based ecosystems from the Maastrichtian worldwide. The fauna at the Early Maastrichtian seep of Alfred Creek is dominated by infaunal dwellers: crustaceans, solemyid and lucinid bivalves. This finding supports previously reported macroevolutionary pattern in chemosymbiotic bivalves, i.e. after the decline of modiomorphid Caspiconcha at the end of the Early Cretaceous and its last occurrence in the Campanian, the ecological niche of epifaunal to semi-infaunal seep endemic bivalves was largely vacant and not reoccupied until the Eocene with the appearance of the vesicomylid and bathymodiolin bivalves.

キーワード: メタン湧水, 後期白亜紀, キヌタレガイ, ツキガイ, 炭素同位体比, 自生炭酸塩

Keywords: methane seep, Late Cretaceous, solemyid, lucinid, stable carbon isotope, authigenic carbonate

北海道の上部中新統望来層より産するシロウリガイ類化石群集の生息場復元 Reconstruction of seepage site with *Calyptogena* colonies in the Upper Miocene Morai Formation, Hokkaido, Japan

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The Upper Miocene Morai Formation, Hokkaido, Japan, consists of alternating beds of semi-consolidated and hard mudstone, and intercalates calcareous concretions associated with abundant fossils of *Calyptogena pacifica*. This study reconstructs habitat conditions of *Calyptogena pacifica* on the basis of field observation of a 20-m-high sea-cliff outcrop.

The calcareous concretion blocks bearing *Calyptogena pacifica* fossils are restricted in several horizons in the upper part of the sea cliff. We surveyed the shape, size and distribution of the concretions and observed the carbonate lithology and modes of fossil occurrence, hanging from the cliff with a rope. The concretion blocks are lenticular in shape, attaining over 10 m in horizontal length and less than 2 m in thickness, and laterally changed into hard mudstone beds which also yield abundant *Calyptogena* shells. The concretion blocks have nearly flat roof and base, but its sides sometimes interfinger with neighboring mudstone.

The concretion blocks consist of monotonous muddy dolomicrite, associated with small calcitic nodules, several centimeters in diameter, just below the blocks. The dolomitic concretions sometimes show auto-brecciation, which shows break of mudstone into angular pieces to form jigsaw-puzzle fabric. The space between breccia was filled with dolosparitic cement. It is noted that the brecciated fabric is restricted to interior of the concretion blocks and does not continue to the surrounding mudstones, which does not show any fracturing. These suggest that the auto-brecciation was not due to hydrofracturing by pore-fluid pressure, but was maybe caused by contraction during dolomitization.

Calyptogena fossils form shell concentrated beds associated with *Conchocele bisecta*, *Acharax johnsoni*, and *Lucinoma* sp. The shell beds continue laterally more than 20 m. The thickness attains more than 50 cm in the concretion blocks, but becomes thinner (ca. 15 cm) in the surroundings. It is noted that all the bivalve species show high ratio of conjoined valves (ca. 60 % in case of *Calyptogena pacifica*). In particular, almost all of *Conchocele bisecta* fossils preserved their life position. Most of *Calyptogena* conjoined valves show life position or reclining orientation with their commissural plane horizontal, but some show an inverted orientation from life position, maybe fossilized on the way to escape from rapid burial. These suggest that the *Calyptogena* shell concentrations were not due to transportation, but preserved the original colony condition due to rapid burial maybe by muddy turbidity current.

Localized distribution of carbonate concretions and *Calyptogena* shell beds indicate that the *Calyptogena* colony was not formed by reducing mud due to oxygen-depleted water-mass, but was supported by methane seepage. The outcrop observation suggests that the seepage was not channelized but diffusive. The seepage influence expanded the bottom surface area over 20m in diameter, but was repeatedly interrupted by rapid burial of muddy turbidite.

キーワード: 化学合成群集, 冷湧水, 中新世, 望来層, 北海道, シロウリガイ類

Keywords: chemosynthetic community, cold-seepage, Miocene, Morai Formation, Hokkaido, *Calyptogena*

相模湾初島沖のシロウリガイ類遺骸殻に残された捕食痕

Predation marks on *Calyptogena* dead shells off Hatsushima Island, Sagami Bay, central Japan

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Predation pressure is one of the important factors controlling community structure and evolution, but only few attempts have so far been made to quantitatively estimate predation pressure in chemosynthetic communities.

We analyzed breaking pattern of *Calyptogena* dead shells in a living colony at a cold-seepage site off Hatsushima Island, Sagami Bay, central Japan. The sampling site is located at 856 m in bathymetrical depth, on slope of western side of Sagami Bay. The dead shells were collected by submersible *KAIKO 7000II* (Dive #546, KR12-05 cruise) using a Kumade-sampler with 15 cm x 18 cm mouth, 13 cm depth, and 7.6 to 7.8 mm sieve openings.

The dead shell assemblage consists of a mixture of various conditions from complete conjoined valves to abraded shell fragments. Among them, we paid attention to open valves with umbo intact, some of which are not abraded, preserved sharp and fresh break edge, and show remarkable contrast in preservation between the right and left valve. Almost all part of one valve (right or left) is missing except for the strong hinge and dorsal margin connected with ligament, whereas the other valve is nearly complete with notch-like injury in ventral margin. This breaking pattern is difficult to be explained only by non-biological factors. We judge the shell breaking pattern to be a predation mark, and estimate the predator as decapod crab *Paralomis multispina*, which were frequently observed to gregariously habit around the sampling site. *P. multispina* was reported to catch and eat *Calyptogena* by Fujikura et al. (2008), who attached the photograph showing that *P. multispina* inserted its right crusher chelae into the ventral margin of a *Calyptogena* shell and tried wrenching open it.

In order to quantitatively estimate the contribution of predation to all death causes, we calculate the ratio of numbers of predation-mark specimens to all attached valves in each shell size class. We exclude detached or fragment specimens in the calculation because it is difficult to judge whether the specimens are results of predation crush or physical break.

Total 75 attached valves are examined. The predation marks are recognized from young to gerontic *Calyptogena* clams, shell length of which varies from about 2 cm to over 12 cm. The ratio of predation-mark specimens in each shell size class varies from 17 to 83%, and its average is 40%. This data shows no size-selective feeding behavior, and that the predators have crushing force enough to break the stout shells of gerontic *Calyptogena* clams. The predator, maybe *Paralomis multispina*, contributes 40% to all death cause of *Calyptogena* clams.

These suggest that *Calyptogena* colonies off Hatsushima Island have been maybe under high predation pressure in spite of the deep-sea condition. Methane-seep sites are deep-sea oases not only for chemosynthetic animals but also for the predators.

キーワード: 化学合成群集, 冷湧水, シロウリガイ類, 捕食圧

Keywords: chemosynthetic community, cold-seepage, *Calyptogena*, predation pressure

沖縄トラフ深海熱水噴出域生物群集の種多様性と環境の関連

Biodiversity of deep-sea hydrothermal vent fauna and its relationships to environments in Okinawa Trough

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Flourish assemblages of deep-sea hydrothermal vent fauna associated with steep environmental gradient formed by high temperature venting fluid containing high concentration of metals and the other kinds of chemicals. The Okinawa Trough, is a backarc basin which has started rifting from the southern part 2My ago, and at least nine hydrothermal vent fields has been discovered along the NE-SW spreading axis. Multi-disciplinary investigation was carried out in five of nine vent fields to find out the relationships between biodiversity and environments in the Okinawa Trough.

In the five hydrothermal vent fields, quantitative faunal sampling and simultaneous environmental measurements using sensors including a newly developed D-Pote (a Deep-sea Potentiostat) were carried out at more than two points in each vent field, during the NT11-20 cruise of R/V Natsushima / ROV Hyper-Dolphin. Biodiversity was evaluated based on the collected faunal samples and the relationships between faunal composition and environmental factors such as temperature, depth, salinity, and concentrations of oxygen and sulphide compounds were examined statistically.

Biodiversity of the vent fauna was relatively low in the northern part of the Okinawa Trough, where vent fields are located in relatively shallow area (< 1000 m depth). On the other hand, in the southern, relatively deep (> 1000 m depth) and older part, vent communities of relatively high biodiversity corresponding with great variation of concentration of sulphide compounds were observed. The present results suggested that the correspondence of the biodiversity, environmental diversity, and geological history of hydrothermal vent fields in the Okinawa Trough.

キーワード: 熱水噴出孔, 生物多様性, 類似度, 化学合成生物群集

Keywords: hydrothermal vent, biodiversity, similarity, chemosynthetic community

沖縄トラフ・シンカイヒバリガイの脂質バイオマーカーの多様性

Variation of lipid biomarker composition in *Bathymodiolus* sp. at hydrothermal vents in Okinawa Trough

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【はじめに】

海底熱水活動域に生息するシンカイヒバリガイ類は、メタンや硫化水素を酸化して有機物を作り出す化学合成細菌を鰓上皮細胞内に共生させている。しかし、共生細菌を親から子へ受け渡している実証例はなく、幼生時はプランクトン捕食をしていた二枚貝がどのようにして化学合成細菌を体内に取り込むのか、未だに議論されている。長期的・断続的な観測や十分な試料採集が困難であるため、深海性二枚貝の成長・代謝と共生細菌との関係における研究例は極めて少ない。本研究では、シンカイヒバリガイの容量を成熟度とし、成長段階と共生細菌との関係を、鰓組織の脂質バイオマーカーと同位体組成を用いて解明することを目的とした。

【試料・実験方法】

海洋調査船「なつしま」の「ハイパードルフィン」によって、2009年7月沖縄トラフ鳩間海丘の熱水噴出孔付近で採集したシンカイヒバリガイ3個体(容量:49.1~89.8cm³)と同年9月伊平屋海凹北部海丘で採集した同4個体(容量:14.2~44.2cm³)を試料として用いた。試料は-20℃で保管し、凍結乾燥後、鰓組織約10mgから脂質化合物を抽出し、ガスクロマトグラフ(GC)質量分析計にて定性定量後、GC燃焼同位体比質量分析計で炭素同位体比を測定した。鰓組織全体の炭素・窒素・イオウ同位体比も測定した。

【結果と考察】

鳩間・伊平屋北試料共にC₁₅からC₂₂にわたる飽和および不飽和脂肪酸が検出され、各個体間で組成に違いが見られた。全脂肪酸に占める割合(%)で最も大きく異なったのはC_{18:1(n-7)}脂肪酸であり(鳩間:4.9~23.7%、伊平屋北:2.8~6.1%)、共生細菌種の違いを示していると考えられる。鳩間海丘では伊平屋北海丘に比べてアンモニウムイオン濃度が高く、二枚貝は窒素固定を行うType Iのメタン酸化細菌をより多く共生させていると考えられる。

鰓組織のバルクとC₁₆、C₁₈の飽和および一価不飽和脂肪酸の炭素同位体組成を、二枚貝の容量と比較した結果、伊平屋北の試料では容量が大きくなるにつれてC16以外の同位体組成は-2.5~-3.7%軽くなった。一方、鳩間で採れた二枚貝は容量が大きくなるにつれて+0.7~5.3%重くなった。伊平屋北の二枚貝の結果は、幼生時に表層から落ちてくるプランクトンを捕食して炭素同位体組成は重かったが、成長するに連れて化学合成細菌を取り込み、熱水中に含まれるメタン(CH₄中の¹³C=-54.0‰)を栄養源として使うことで徐々に炭素同位体組成が軽くなったと考えられる。鳩間海丘の二枚貝は、個体差間が小さかったために有意な差が見られなかった可能性がある。

キーワード: シンカイヒバリガイ, 脂質バイオマーカー, メタン酸化細菌, 沖縄トラフ, 脂肪酸組成, 炭素同位体組成

Keywords: *Bathymodiolus* sp., Lipid biomarkers, Methanotrough, Okinawa Trough, Fatty acid composition, Carbon isotopic composition

化学合成生態系の進化：進化発生学的視点から Evolution of Chemosynthetic Community: From an Evo-Devo perspective

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化学合成生態系の進化に関する研究は、古生物学・系統学・系統地理学を中心に進んできた。これらの研究を通して、いつ、どこに、どのような生物が生息していて、そして生息域を拡大させてきたのが明らかとなってきた。そしてこれらの生物がどのような近縁種から進化してきたのかも明らかとなった。すなわち、進化の歴史に関する情報は蓄積してきている。一方で進化のメカニズムについてはほとんど未知と言っていい。どのような遺伝情報の変更や表現型可塑性が、その極限環境への適応を可能にしたのか？その特殊な形態・生理・行動を司る分子メカニズムはどのようなもので、それは近縁の系統からどのように進化してきたのか？これまで盛んに行われてきた進化のパターンに関する研究に加え、進化のメカニズムが明らかになることによって、初めて我々は化学合成生態系を構成する生物の進化を理解したと言えるだろう。

進化発生学 (EvoDevo, evolutionary and developmental biology) は、進化のメカニズムの解明を目的とした研究領域である。形態・生理・行動などの形質が発現する遺伝基盤を明らかとし、その結果を近縁種と比較することで、形質の進化を明らかとする。このような研究を行うためには、その形質の発生過程や、行動や環境への応答を正確にとらえなければならない。すなわち多くの場合に実験室内での長期飼育や発生過程の観察などの実験系が確立されていない。化学合成生態系は、その多くが深海の熱水噴出孔や湧水域に生息し、その特殊な環境が故に、採集や飼育が困難である。我々はこの状況を克服するために、様々な化学合成生態系の構成種において、飼育や実験室内での発生系の立ち上げを行ってきた。本講演では、その中でヒゲムシ科多毛類をもちいた研究例を紹介する。