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Two types of white clam communities in Sagami Bay, central Japan: geologic settings and the Tertiary records in the Miura and Boso Peninsulas

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相模湾の異なった湧水環境に生息するシロウリガイのコミュニティ：その地質学的条件と三浦半島・房総半島の第三紀における化石記録

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シロウリガイ属コミュニティは，プレートの境界部の特殊な地質環境に生息する底生生物群集といわれている。三浦半島と房総半島の南東沖合には相模トラフ（トロフ）が存在し，その地形変換をつくる急崖は，トラフを構成するフィリッピン海プレートが半島を構成する北米プレートの下に潜り込むところとされている。相模トラフのシロウリガイコミュニティの生息環境は，潜水船調査により明らかにされた。トラフ東側の沖ノ山堆列南西の急崖麓では多量のメタンを含む水温2～3°Cの底層水が存在する。トラフ西側の初島沖の急崖麓のメタンを含む海水は12°Cで，火山起源とされた。海水中のメタンと硫酸イオンは，メタン細菌によって硫化水素に還元され，シロウリガイの鰓に共生する硫黄細菌によってシロウリガイの体内にとりこまれていると推定される。

三浦半島では第三系の5層準からシロウリガイ属コミュニティが発見されている。16.2-14.4 Ma，葉山層群，石灰岩・粘土岩；13.0-10.8 Ma，三浦層群三崎層，石灰質凝灰岩；3.4-2.6 Ma，池子層，石灰質凝灰岩・凝灰岩；2.0Ma，上総層群浦郷層，凝灰岩；1.9-1.6 Ma，野島層，凝灰岩．房総半島では3地域の1.9-1.6Maの白間津層（野島崎）・黒滝層（粟又）・名洗層（銚子），凝灰岩。

現生コミュニティの生息環境と化石コミュニティの産状を比較検討すると，15Maの陸地・海洋プレートの境界付近は今の三浦・房総半島の沖合深海にあり，12 Ma以降は現在の伊豆諸島のような火山島から粗粒凝灰岩が供給される海域になったことを示唆している。コミュニティの生息環境は，メタンを含む湧水が供給され，石灰化されやすい底質の地質構造であったと考えられる．三浦半島と相模湾には15 Ma以降にシロウリガイ属のコミュニティが断続的に知られており，今後も発見される可能性が高い。従って，シロウリガイ属コミュニティによる地球科学的・生物的研究を進めるのに最も重要なフィールドのひとつといえる。地域開発が進行しているこのフィールドの保全も今後の重要な研究課題である。

Introduction

It was saying that ecology of giant white clam, genus *Calyptogena*, community depends on methane seepage from deepsea substrata, and the chemosynthetic community inhabits in characteristic geologic condition at plate boundaries. Southern offing of the Miura and Boso Peninsu-

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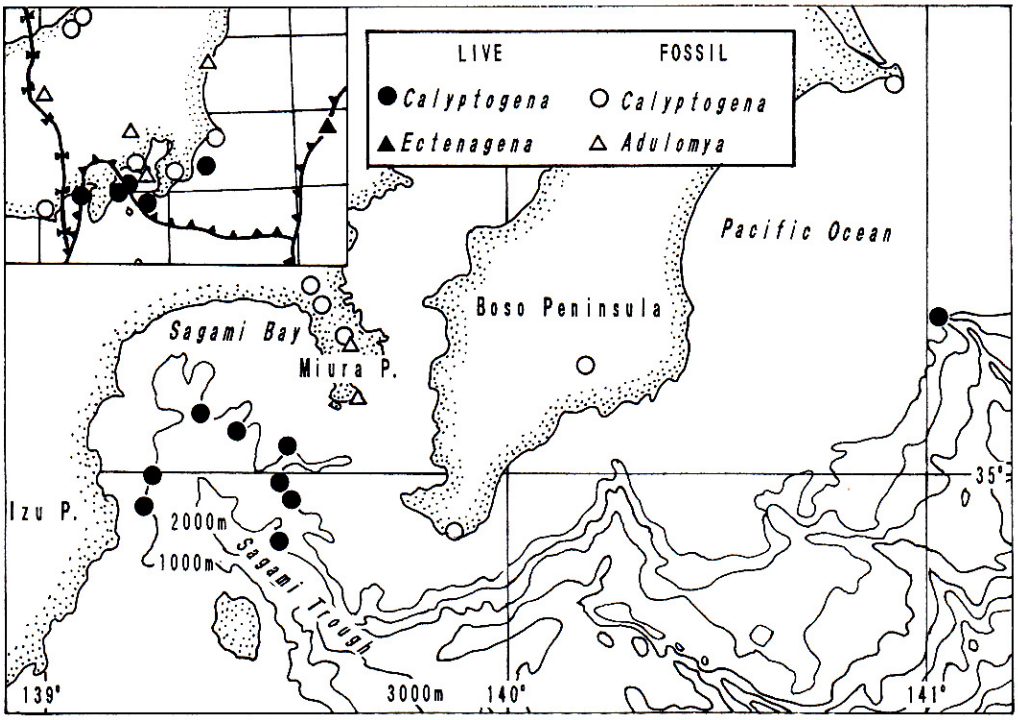

Fig. 1 Live (solid) and fossil (open) communities in South Kanto and Fossa Magna regions. Circles: subgenera *Calyptogena* and *Akebiconcha* are elongate quadrate shells, triangles: *Ectenagena* and *Adulomya* are elongate blade shells.

las, there exists the Sagami Trough on inside with Okinoyama Bank Chain extending northwest to southeast at the central part of Sagami Bay (Fig. 1). The bank chain forms steep cliffs which are regarded as the places where the Phillippine Sea Plate (trough) subducts under the North American Plate (peninsulas). The ecology of *C. soyoae* has been surveyed by submersibles Reserch Vehicles (manned and unmanned submersible) of the Japan Marine Science and Technology Center at Yokosuka since 1984. *Calyptogena* communities and methane seepages were found in the eastern and western margins of the trough. *Calyptogena* fossil communities were discovered from five geologic horizones of the Tertiary system in the Miura Peninsula (KANIE, 1992a, 1992b)

The purpose of this paper is to document the modern and extinct *Calyptogena* communities of Sagami Bay and the Fossa Magna region. Then, we propose ecological model of *Calyptogena* colony and discuss geologic setting of the communities.

Calyptogena-communities in Sagami Bay

Calyptogena-community is conisist of genera *Calyptogena, Solemya (Acharax), Conchocele, Lucinoma and Neptunea* (Fig. 2), along with tube-worms, some kinds of miobenthos and bacteria.

Genus *Calyptogena* comprises at least two subgenera *(Calyptogena=Akebiconcha* ?) ELONGATE QUADRATE form and (*Adulomya=Ectenagena* ?) ELONGATE BLADE form.

In Sagami Bay, two types of *Calyptogena*-communities have been recognized as the off Hatsushima community (western margin of the Sagami Trough in the western part of Sagami Bay) and the Okinoyama Bank Chain communities (eastern margin of the trough in the eastern part of the Bay) (Fig. 1). *Calyptogena soyoae* is a major constitution of the community in both sites,

but the constitution of both communities resembles.

Okinoyama Bank Chain communities: Communities have been recognized at the foot of the Okinoyama, water depth 750-1300 m (HATTORI, 1989), and at the foot of the Sagami Knoll, water depth 1455 m (HATTORI *et al.*, 1992). Cold, subduction related bottom water seepages of 2–3°C temperature contain much methane were obseved at the foot of the Okinoyama Bank Chain. Some tube-worms (Vestimentifera) were observed on the rock surface that outcrops at the foot of the banks.

Off Hatsushima community: Community of *C. soyoae* occurs at the water depth 1000–1100 m in the western part of Sagami Bay. Pore water of bottom surface sediments contains much methane and sulphides. The temperature 12°C is probably due to from volcanogenetic activities (NAKA *et al.*, 1991). MASUZAWA and HANDA (1989) showed biochemical model that methane and hydrosulphide ion in bottom seawater are reduced by methane bacteria.

Fig. 2 Shell silhouette of *Calyptogena*-community.

Genus *Calyptogena* is composed of at least two subgenera (*Calyptogena*=*Akebiconcha* ?) ELONGATE QUADRATE and (*Adulomya*=*Ectenagena* ?) ELONGATE BLADE forms. *Solemya (Acharax), Conchocele, Lucinoma* and *Neptunea* genera, along with tube-worms and some kinds of bacterias are communities.

Discussion Based above data, it is suggested that sulphate ion was reduced to hydrogen sulphides by methane. Thereafter chemoautotrophic bacteria that are rich in clam's gill fuels hydrogen sulphide for microbial chemosynthesis. Ecological model of *C. soyoae* in the eastern part of Sagami Bay is proposed in figure 3.

Calyptogena-communities in the Tertiary beds of the Fossa Magna region

Extinct *Calyptogena*-communities in South Kanto and Fossa Magna regions are shown in figure 1. Two types of *Calyptogena* bivalve shells were known (Fig. 2). The former subgenera *Calyptogena* and *Akebiconcha* are elongate quadrate shells, and the latter subgenus *Adulomya* is elongate blade shell.

Miura and Boso Peninsula

Fossil communities are found in the early Middle Miocene (CN4 nannoflora zone) 16.2–14.4 Ma Hayama Group in the central part of the Miura Peninsula (KANIE *et al.*, 1992). *Calyptogena (Calyptogena)* sp. and *Calyptogena (Adulomya)* sp. of 12 cm shell length were rarely found. Paleodepth by benthic foraminiferas is assigned to the lower bathyal or abyssal zone. According to KANIE *et al.* (1992), *Solemya (Acharax) tokunagai*

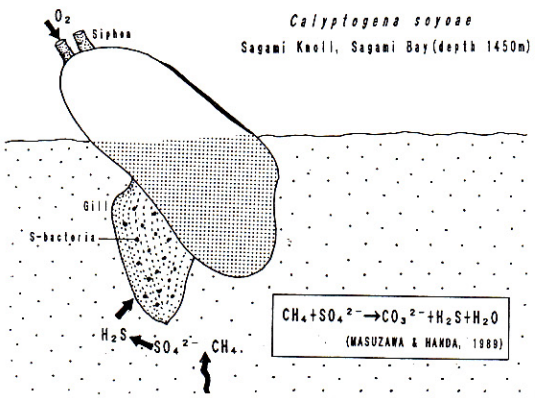

Fig. 3 Ecological model of *Calyptogena soyoae* in the eastern part of Sagami Bay.

Sulfur bacterias exists in the clam's large gills. Meshed part of the shell is black colored probably due to reduced mud.

were most abundant in the Hayama Group. Ultra-large shells of 30 cm in length were collected. Fossil community occurred in the fault zone of the Hayama Group. Therefore, almost all fossils were fractured and tipped. In the field, abundant *Solemya* existed in bottom claystone, possively tube-worms (mean diameter is 5 mm) in the limestone surface, and *Calyptogena* in the above the limestone.

In the southern end of the Miura Peninsula, a school of juvenile shells (ca. 10 mm in length) of *Calyptogena (Adulomya)* sp. and *Solemya (Acharax)* sp. were found from the late Middle Miocene (CN5b nannofossil subzone, 13.0–10.8 Ma) Misaki Formation of the Miura Group. The shells were embedded in lenticular tuffaceous limestone. Paleobathymetry by benthic foraminiferas assigned to lower-middle bathyal zone (KANIE, ARIMA *et al.*, 1991).

In the northern part of the Miura Peninsula, *C. (Calyptogena)* cf. *nipponica* community is reported in the Pliocene (CN12a nannofossil subzone, 3.4–2.6 Ma) Ikego Formation of the Miura Group (KANIE, OKADA *et al.*, 1991). Community was discovered in the tuff beds. The sorrounding breccias are composed of hemiperagic siltstone from nearest beds. Benthic foraminiferal bathymetry of the siltstone suggests middle to upper bathyal zone (AKIMOTO, 1990).

Fossa Magna region

Calyptogena (Calyptogena) sp. is found from CN12a-c nannofossil zone (KANIE and OKADA's unpublished data, 3.4–1.8 Ma of Pliocene) Tamari Formation of the Sagara Group in South Fossa Magna region. Most fossils were preserved in siltstones, but rarely in limestones. One meter columnar section comprises siltstones at the bottom, calcareous siltstones without fossil at the central bottom, lenticular shelly limestones at the central top, and siltstone without fossil at the top. Probably calcification by methane seepage existed at the central bottom calcareous siltstone and central top limestone.

C. (Adulomya) uchimuraensis is found from the Middle Miocene (CN5a ? nannofossil zone of 14.4–13.0 Ma by OKADA and KANIE's unpublished data; Middle to Late Miocene radioralians by NISHIMURA and KANIE's unpublished data) Akanuda Limestone of the Bessho Formation in North Fossa Magna region. Limestone body contacts with claystone in the field observation. *C. (Adulomya) uchimuraensis* makes a school, and rare occurrences of *C. (Calyptogena) akanudaensis*. Genus *Adulomya* was included in *Calyptogena* (s.l.) by KANNO (1991).

Discussion Shell morphology of the *Calyptogena (Adulomya)* from 15 Ma Hayama Group is similar to *C. (Ectenagena) phaseformis* reported by MÉTIVIER *et al.* (1986) from Japan Trench, water depth up to 6400 m. Huge shells of *S. (Acharax) tokunagai* from the Hayama Group were abundant in claystone. Modern *S. (Acharax) tibai* is collected from off-shore clays of abyssal and bathyal zones. Fossil occurrences are harmonious with those of modern species. The shell morphology of *C. (Calyptogena)* cf. *nipponica* from 3 Ma coarse tuff is quite similar to that of living *C. (Calyptogena) soyoae* in corse-grained sediments of Sagami Bay. The shell morphology of *Calyptogena (Calyptogena)* sp. from 3.4–1.8 Ma of silty Tamari Formation is similar to that of living *C. (Akebiconcha) kawamurai* off the Boso Peninsula. In each fossil locality, lenticular calcareous layers are often found.

Geologic settings of the *Calyptogena*-communities

Major fossil localities of *Calyptogena*-communities in the northern Pacific regions are shown in figure 4. The communities have been known in late Eocene to modern seawaters.

On the communities of the Miura Peninsula, *C. (Adulomya)* was observed in ca. 15 Ma claystones and ca. 12 Ma tuffaceous siltstone facies. Contrarily *C. (Calyptogena)* was in ca. 4 Ma to recent corse-grained tuff facies. The systematics of the present two subgenera are still uncertain.

In evely modern and extinct *Calyptogena* localities, the main constituents are *Calyptogena* and *Lucinoma*, followed abundance by *Conchocele* and

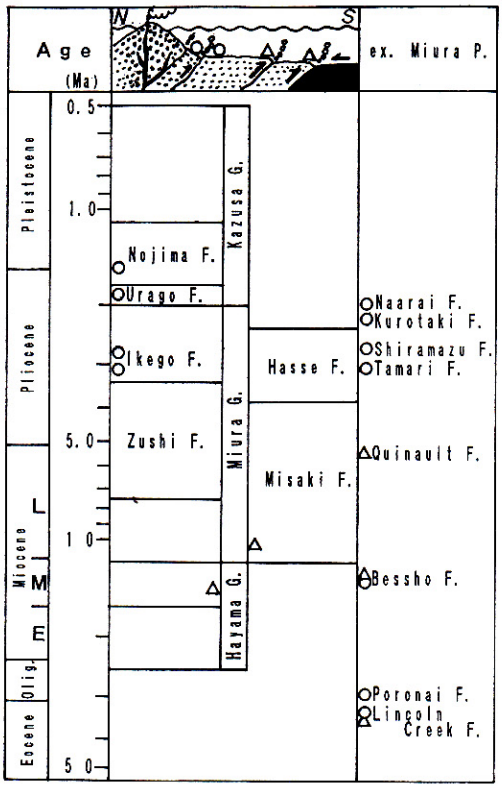

Fig. 4 Major fossil localities of *Calyptogena*-communities in the Miura Peninsula and northern Pacific regions.

On the communities of the Miura Peninsula, *C. (Adulomya)* (△) were observed in 15 Ma claystones and 12 Ma tuffaceous siltstone facies. Contrally *C. (Calyptogena)* (○) were in 4 Ma to recent tuff facies. The geologic age of the formations in the Miura Peninsula based on KANIE, OKADA *et al.* (1991). Urago and Nojima Formations (NIITSUMA *et al.*, 1987); Naarai Formation (OZAKI, 1954); Kurotaki Formation (ASAGA *et al.*, 1991); Shiramazu Formation (MAJIMA *et al.*, 1992); Quinault Formation (CAMPBELL, 1992); Poronai Formation (TAKEDA, 1954); Lincoln Creek Formation (SQUIRES and GOEDERT, 1991).

Neptunea, then *Solemya* and crabs.

It was revealed that two types of the habitat environment of *Calyptogena*-communities exist in the Sagami Trough. In the eastern margin of the trough, there is bottom cold waters containing much methane which relates to plate subduction. In the western part, southwards off Hatsushima Island, seawater contains much methane and shows rather high temperature probably originated from volcanogenetic activitiy at the foot of the Izu Peninsula.

Comparative studies of modern and fossil *Calyptogena*-communities, it is suggested that the Miura and Boso Peninsulas were located at the boundary between the continental and ocean plate at ca. 15 Ma, and that since ca. 12 Ma they were located along the continental border where tuff was transported from tholeitic volcanoes as the modern bathyal Sagami Bay.

Fossil communities around limestone or calcareous tuff were probably related to chemosynthenic community that were formed by methane seepages by the model as shown in figure 3.

The study of white clam chemosynthetic communities are most progressive in this region by means of comparative observation between oceanography and geology of peninsulas. The Sagami Trough is active "trench" in abyssal to bathyal zone since 12 Ma. Therefore, we should keep the living fossils intact in the Sagami Trough and the Miura Peninsula.

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