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# First post-Miocene *Argonauta* from Japan, and its Palaeontological Significance

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A fossil of *Argonauta hians* Lightfoot, 1786, an epipelagic octopod species living now in tropical and subtropical oceans, was obtained from the upper Pliocene Dainichi Formation of the Kakegawa Group, central Japan. Its occurrence accompanied by abundant tropical and subtropical benthic molluscs indicates the influence of the warm ocean current in the mid-latitude of NW Pacific during the Late Pliocene warm episode (c. 2 Ma). This is the first record of argonautid species from a post-Miocene Japanese formation and marks the first appearance of a living *Argonauta* species in the NW Pacific. In the Middle Miocene, many argonautid species flourished around the Japanese Islands, but none are known from the post-Miocene as a result of the Late Miocene intensified Antarctic glaciation (Robin, 1988) and the terminal Miocene cooling event (Beu, 1990). The genus *Argonauta* is the only surviving genus known from the Pliocene to the present. The fossil occurrence of *Argonauta hians* from the Japanese Pliocene suggests that this surviving lineage expanded its distribution into the mid-latitude NW Pacific during the Pliocene warm climatic event.

KEY WORDS: Mollusca, *Argonauta*, Pliocene, Japan.

## Introduction

In August, 2000, a fossil *Argonauta* was found in the upper Pliocene Tenno silty sand Member, Dainichi Formation, Kakegawa Group, at Koichi, Kakegawa City, Shizuoka Prefecture, central Japan (Figure 1). The specimen is well preserved and allows us to identify the fossil as *Argonauta hians* Lightfoot, 1786, an epipelagic octopod species living now in tropical and subtropical oceans. Shiba *et al.* (2001) figured the specimen, but with no systematic description, and did not mention its palaeontological significance.

Many fossil argonauts have been reported all over the world in strata of the Oligocene to Lower Pliocene, and are important indicators of marine climate and palaeo-ocean currents (*e.g.*, Bellardi, 1872; Hilber, 1915; Martin, 1929; Fleming, 1945; Kobayashi, 1954a,b; Kaseno, 1955; Tomida, 1983; Noda *et al.*, 1986).

This paper is the first record of an argonautid fossil from a post-Miocene Japanese formation, and it marks the first appearance of a living *Argonauta* species in the NW Pacific. We provide a systematic description of *Argonauta hians* Lightfoot, 1786 on the basis of the fossil specimen, and discuss its palaeontological significance in relation to Neogene climatic events.

## Geologic setting

The Kakegawa Group is a Plio-Pleistocene fore-arc basin deposit of the Pacific side of SW Japan. The upper part of the Kakegawa Group is divided into three formations in ascending order: the Kamiuchida Formation (turbidite), the Dainichi Formation (shelf sand and silty sand), and the Hijikata Formation (slope silt) (Figure 2, 3) (Shiba *et al.*, 2000). Shiba *et al.* (2000) traced volcanic ash layers intercalated in the three formations and noted that the Kamiuchida, Dainichi, and Hijikata Formations correspond to the lowstand, transgressive, and highstand systems tract, respectively, from the viewpoint of sequence stratigraphy.

The Dainichi Formation unconformably covers Miocene basement rocks in the northwestern part (landward margin) of the basin, and the volcanic ash layers in the formation show coastal onlap patterns. The geologic age of the Dainichi Formation is determined to be latest Pliocene (c. 2.0 Ma) by several chronological techniques, *e.g.*, radiometric dating (Shibata *et al.*, 1984) and microbiostratigraphy (planktonic foraminifers: Ibaraki, 1986; calcareous nannofossils: Kameo, 1998).

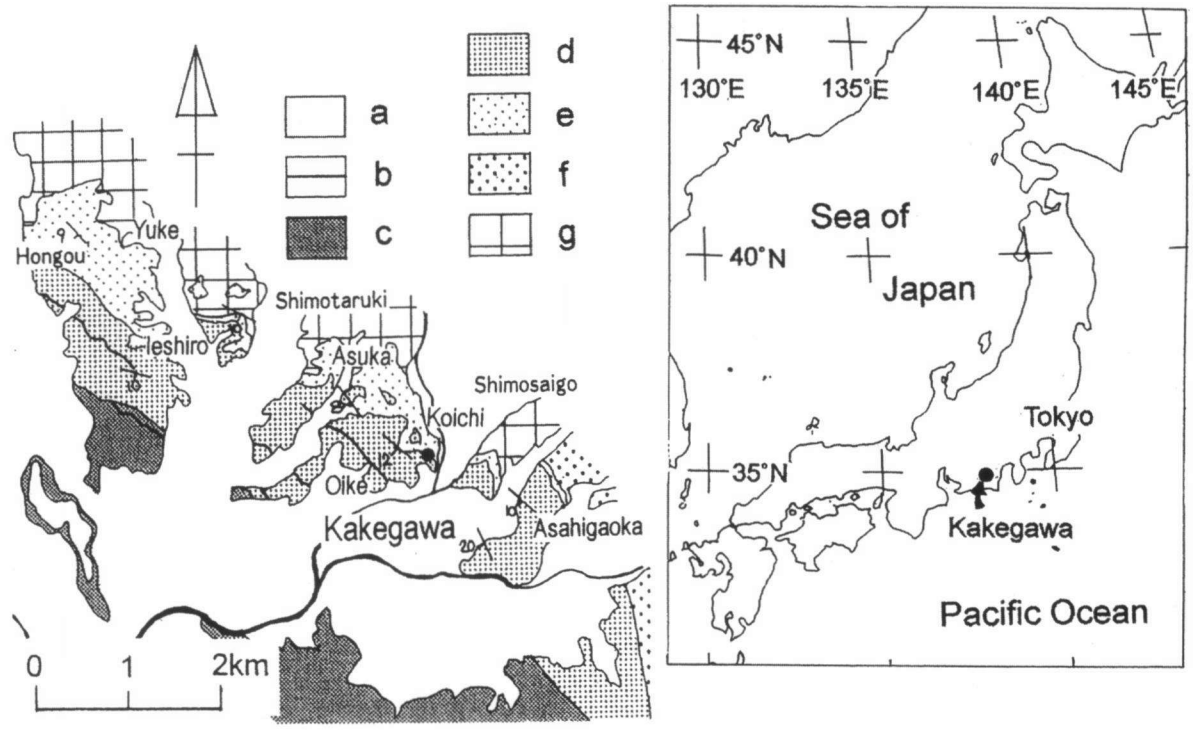


**Figure 1.** Index map and geological map of the northwestern part of Kakegawa City (after Shiba *et al.*, 2001). a: Holocene, b-f: Plio-Pleistocene Kakegawa Group (b: volcanic ash, c: Hijikata Formation, d: Tenno silty sand Member of the Dainichi Formation, e: Dainichi sand Member of the Dainichi Formation, f: Kamiuchida Formation), g: Miocene basement rocks. Black circle shows the fossil locality from which *Argonauta hians* was recovered.

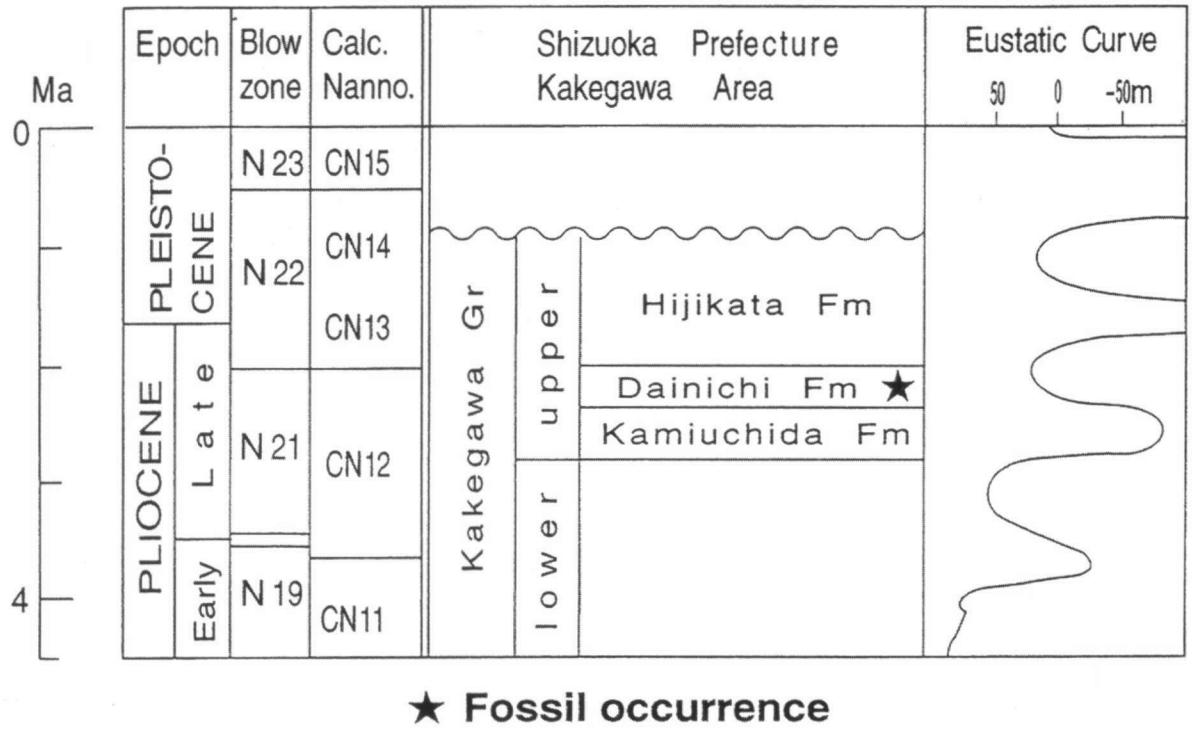


**Figure 2.** Upper Neogene sequence of the Kakegawa area, and stratigraphic position of the fossil locality of *Argonauta hians*. Sea level eustatic curve redrawn from Malmgren & Berggren (1987).

The transgression recognized in the Dainichi Formation corresponds to the global sea-level rise at 2.0 - 1.8 Ma shown by Haq *et al.* (1987) and Malmgren & Berggren (1987).

A columnar section for the fossil locality is shown in Figure 3. The Dainichi Formation is composed of the Dainichi sand Member (nearshore facies) and the Tenno silty sand Member (off shore facies), in ascending order. The fossil *Argonauta* occurs in a shell-rich sand lens intercalated in the Tenno silty sand Member. The sand lens is 40 cm in maximum thickness, but pinches out rapidly. The sand lens contains muddy rip-up clasts and covers the underlying silty sand with an erosional contact. Abundant warm-water benthic mollusks occur in the sand lens. Almost all of them are nearshore, sandy-bottom dwellers, such as *Suchium suchiense suchiense* (Yokoyama), *Turritella perterebra* Yokoyama, *Glossaulax hagenoshitensis* (Shuto), *Babylonia elata* (Yokoyama), *Scapharca castellata* (Yokoyama), *Glycymeris totomiensis* Makiyama, *Glycymeris albolineata* (Lischke), *Amussiopecten praesignis* (Yokoyama), *Chlamys satoi* (Yokoyama), *Bathytormus foveolatus* (Sowerby), *Megacardita panda* (Yokoyama), *Callista chinensis* (Holten) and *Paphia takanabensis* Shuto. In contrast, the silty sand beds just below and above the sand lens yield muddy-bottom dwellers of lower-shelf to slope depths, such as *Yoldia similis* Kuroda & Habe and *Fulgoraria* sp. The sand lens is interpreted as an infill of a small channel or a local scour on the lower shelf to slope.

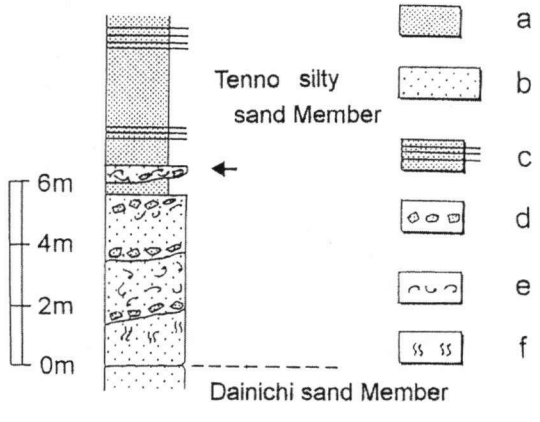


**Figure 3.** Columnar section for the fossil locality. Arrow indicates the horizon of the fossil locality. a: mud to silty sand, b: fine-grained sand, c: mud to silty sand intercalating fine-grained sand layers, d: muddy rip-up clasts, e: shell remains, f: burrows.

## Systematic palaeontology

Class Cephalopoda Cuvier, 1797
Superorder Dibranchiata Owen, 1836
Order Octopoda Leach, 1818
Family Argonautidae Cantraine, 1841
Subfamily Argonautinae Berry, 1912
Genus *Argonauta* Linnaeus, 1758

*Type-species* — *Argonauta argo* Linnaeus, 1758

***Argonauta hians*** Lightfoot, 1786
Figures 5a-d

Selective synonymy:

1786 *Argonauta hians* Lightfoot, p. 44
1920 *Argonauta hians* sensu Bülow-Trummer, p. 269. (listed only)
1984 *Argonauta hians* sensu Bandel & Dullo, p. 37, figs 14, 15. (figured only)
1993 *Argonauta hians* sensu Trego, p. 299, figs 1-J, K. (figured only)
2001 *Argonauta hians* sensu Shiba *et al.*, p. 86, fig. 14. (figured only)

*Material examined* — An almost complete female egg case (Natural History Museum, Tokai University: Reg. no. NHMT-KM0023) is laterally compressed and lacking the horn-like rostrum on one side, collected from the upper Pliocene Dainichi Formation at Koichi, Kakegawa City, Shizuoka Prefecture, Japan (34°46'57" N, 138°0'48" E).

*Description* — An egg case calcareous, rather small, thin, and single-chambered with no septae. Spire coiling very involutely and rapidly expanding. Umbilicus shallow and closed. Whorl section slightly inflated, somewhat higher than wide, and broadly subtrapezoidal. Outer side flattened, becoming gradually wider toward the aperture, and bicarinate; widely-spaced double keels formed by two rows of rather large, obtuse, distally narrow and elongate spinose nodules; spinose nodules in one row arranged alternately relative to those in the other; the area between nodule rows is smooth. Lateral sides ornamented with numerous, coarse, smooth, prorsiradiate, and weakly sinuous radial ribs; radial ribs, 35+ in number on the last whorl, bifurcating into main and intercalatory ones and terminating at spinose nodules on the keels. Aperture widely subtrapezoidal in section; a horn-like projection on apertural margin near the umbilicus.

*Measurements* — Maximum diameter 58.9 mm, max. width of one half 23.8 mm, aperture height c. 44 mm.

*Comparison* — The living and extinct *Argonauta* species can be classified into three groups on the basis of egg case morphology: the first represented by *A. hians* Lightfoot, 1786 with widely spaced keels and smooth radial ribs, the second represented by *A. argo* Linnaeus, 1758 with narrowly spaced keels and smooth radial ribs, and the third represented by *A. nodosa* Lightfoot, 1786 with widely spaced keels and nodulose radial ribs.
*Argonauta hians* resembles the following extinct species of the first group: *Argonauta sismondai* Bellardi, 1872 from the Lower Pliocene of San Stefano, Roero, Torino, Italy; *Argonauta oweri* Fleming, 1945 from the Lower Pliocene of New Zealand; *Kapal batavus* Martin, 1929 from the Middle Miocene of Palembang, Sumatra.

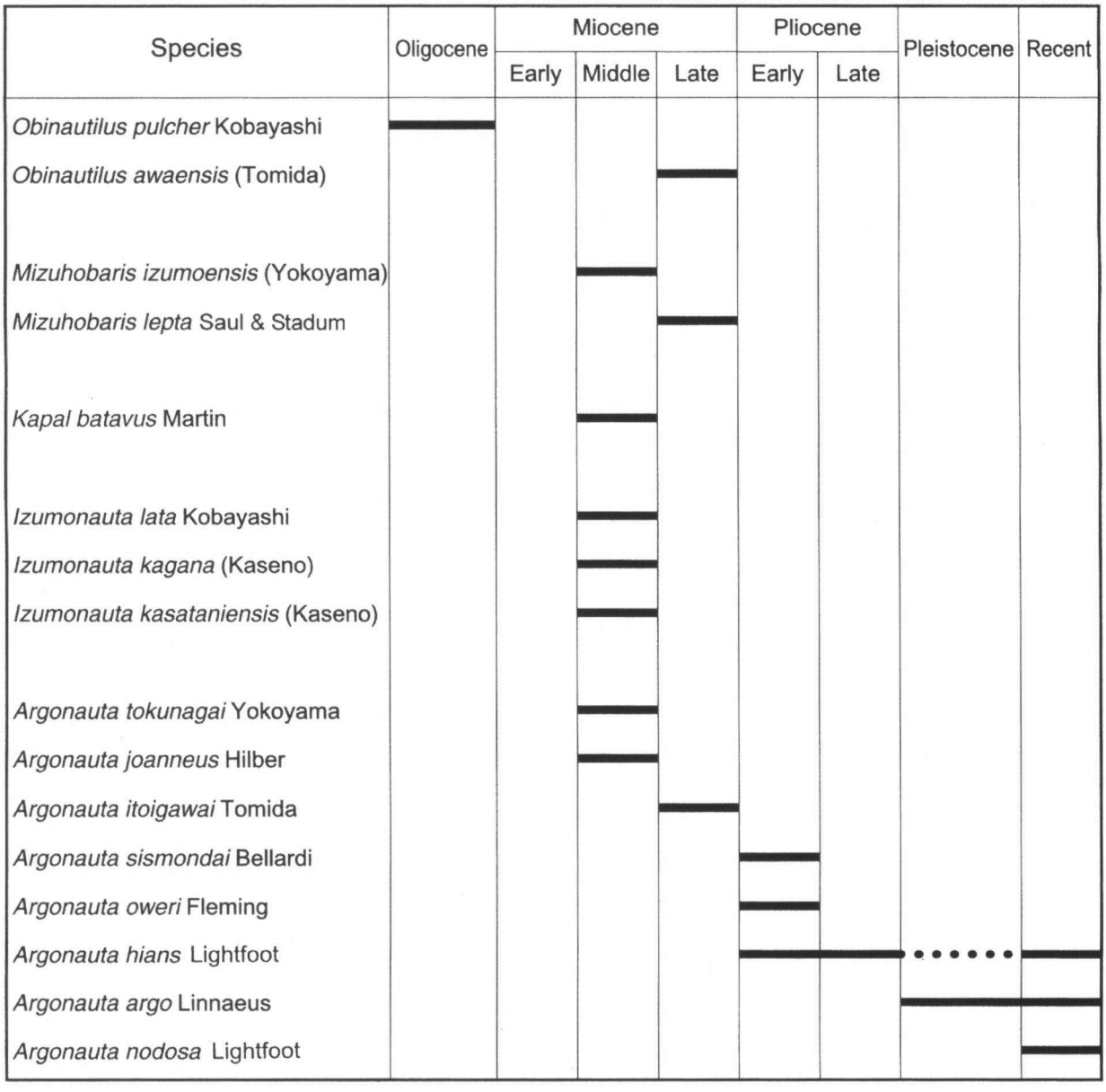


**Figure 4.** Geological range of fossil and living argonautids.

*Argonauta hians* most closely resembles *A. sismondai* among them, but is distinguished from it by having a somewhat larger egg case with thinner and finer radial ribs. Moreover, spinose nodules of *A. hians* are fine, distally narrow and elongate, whereas those of *A. sismondai* are gibbous. *Argonauta hians* differs from *A. oweri* by having a smaller shell with coarser radial ribs and coarser spinose nodules. *Argonauta hians* is distinguished from *Kapal batavus* by having an involute spire and less spaced keels.

*Distribution* — Pliocene: Piemont, Italy (Bülow-Trummer, 1920), Ponte near Rimini, Italy (Bandel & Dullo, 1984). Upper Pliocene: Dainichi Formation in Shizuoka Prefecture, central Japan (Shiba *et al.*, 2001; present study). Living: Warm Pacific and Atlantic oceanic seas (Abbott & Dance, 1998): *e.g.*, W. Pacific and Sea of E. Indian Archipelago (Nesis, 1977), the Mediterranean and Red Sea (Mienis, 1978), off Papua-New Guinea (Knight, 1989), and off South Africa (Norman, 2000).

## Discussion

Modern argonauts live and reproduce primarily in tropical to subtropical seas at epipelagic depths, but they are frequently drifted into neighbouring temperate seas by winds and currents (Stadum & Saul, 2000). Unlike empty *Nautilus* shells, argonautid egg cases are fragile and without septae and camerae, that is lacking in the buoyancy, and are unlikely to be transported far after death (Stadum & Saul, 2000).

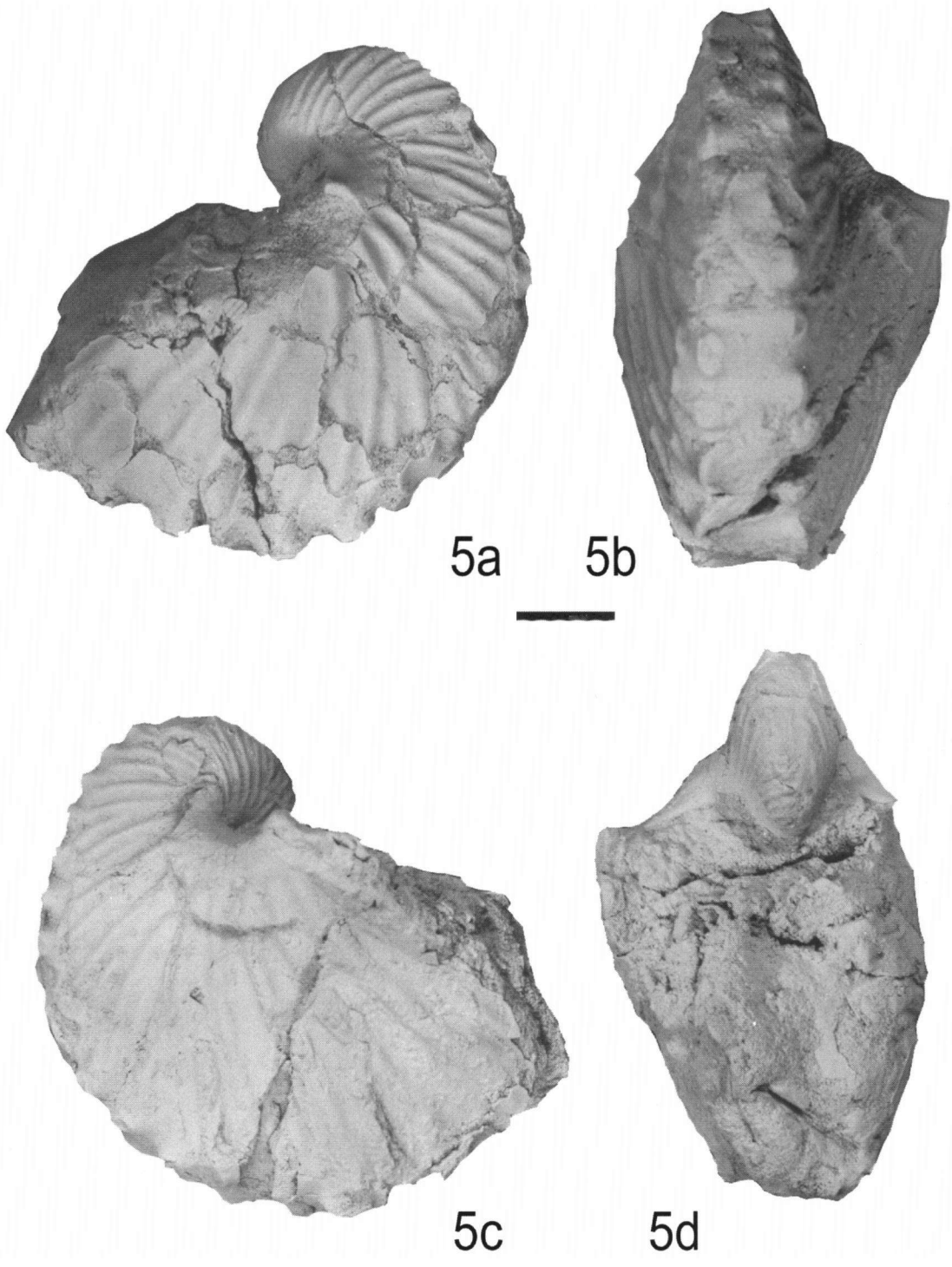


**Figure 5.** NHMT-KM0023. *Argonauta hians* Lightfoot, 1786 from the upper Pliocene Dainichi Formation, Koichi, Kakegawa City, Shizuoka Prefecture, Japan; 5a - left lateral side, 5b - ventral side, 5c - right lateral side, 5d - anterior side. All figures x1.5 and with whitening; Scale bar 10 mm).

Therefore, the fossil occurrence of a well-preserved egg case from the Dainichi Formation suggests that *Argonauta hians* were living in the epipelagic sea off central Japan in the Late Pliocene, and indicate the strong influence of warm palaeo-Kuroshio current.

The palaeoclimatic view is consistent with that the Dainichi

Formation yields many tropical to subtropical benthic mollusks represented by the following species, *Turbo (Lunatica) marmoratus* Linnaeus, *Thiara scabra* (Müller), *Gyrineum cuspidatum* (Reeve), *Bathytormus foveolatus* (Sowerby) and other species (Tomida & Ozawa, 1996; Ozawa *et al.*, 1998). The northern limits of their distribution are now off Taiwan or Ryukyu Islands, but were expanded to central Japan during the peak of the climatic optimum around 2 Ma (Ozawa *et al.*, 1995).

Besides the palaeoclimatological significance, even more important is that this fossil occurrence is the first record of argonautids from a post-Miocene Japanese formation and marks the earliest appearance of a living *Argonauta* species in the NW Pacific.

In contrast with the Pliocene fossil records, a considerable number of argonautid fossil specimens were reported from the Middle Miocene (*e.g.*, Hilber, 1915; Martin, 1929; Kobayashi, 1954b; Kaseno, 1955; Noda *et al.*, 1986). The diversity of argonautid genera also peaked during the Middle Miocene and seven species of four genera flourished: *Argonauta tokunagai* Yokoyama, 1913, *A. joanneus* Hilber, 1915, *Kapal batavus* Martin, 1929, *Izumonauta lata* Kobayashi, 1954b, *I. kagana* (Kaseno, 1955), *I. kasataniensis* (Kaseno, 1955) and *Mizuhobaris izumoensis* (Yokoyama, 1913). All the species disappeared prior to the Late Miocene, and only three species of three genera, *Argonauta itoigawai* Tomida, 1983, *Obinautilus awaensis* (Tomida, 1983) and *Mizuhobaris lepta* Saul & Stadum, 2005, were reported from the upper Miocene (Tomida, 1989, 1996; Yanagisawa, 1990; Saul & Stadum, 2005). Finally, the genus *Argonauta* is the only survivor through the Pliocene to the present (Figure 4). This declining trend of argonautid abundance and diversity is similar to that of the nautiloid *Aturia*. Most of the Neogene *Aturia* species became extinct at the mid-upper Miocene boundary, and only two species, *A. coxi* Miller and *A. cubaensis* (Lea), survive to the end of the Miocene (Beu, 1973; Ozawa & Tomida, 1996), when *Aturia* went extinct. This decline of the Neogene cephalopods was probably caused by the remarkable regressions and climatic cooling in relation to the intensified Antarctic glaciation at 10 Ma (Robin, 1988) and the terminal Miocene event of cooling (*e.g.*, Beu, 1990). For example, in New Zealand 23 percent of the molluscan genera included *Aturia* was extinct at the end of Miocene. The fossil occurrence of *Argonauta hians* from the Japanese Pliocene suggests that the surviving lineage of the genus *Argonauta* expanded its distribution into the mid-latitude NW Pacific during the Pliocene warm climatic event.

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