Miocene vesicomyid species (Bivalvia) from Wakayama in southern Honshu, Japan

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ABSTRACT

A fossil association of potentially chemosymbiotic bivalves is reported from the lower Miocene Shikiya Formation in Kii Oshima Island, Wakayama Prefecture, Japan. The association is dominated by the elongate vesicomyid species *Adulomya uchimuraensis* (Kuroda, 1931); a second vesicomyid of lower abundance is here described as *Archivesica sakoi* new species. It represents the oldest species of the genus *Archivesica* and has a similar hinge structure as *"Calyptogena" laubieri* (Okutani and Métivier, 1986). Additional faunal elements include chemosymbiotic bivalves, namely the solemyid *Acharax* cf. *yokosukensis* Kanie and Kuramochi, 1995, and the lucinids *Lucinoma*? sp. and *Poumea*? sp., as well as the naticid gastropod *Euspira meisensis* (Makiyama, 1926). This association of fossil bivalves all with well-known chemosymbiotic living relatives suggests that these specimens lived at an ancient cold seep, and their mode of occurrence as mostly articulated shells parallel to the bedding plane indicates that were transported a short distance and then quickly buried.

Additional keywords: Miocene, *Archivesica*, *Adulomya*

INTRODUCTION

Vesicomyidae is one of the six extant bivalve families with a chemosymbiotic mode of life, with have a fossil history ranging back to the middle Eocene some 47 Million years ago (Kiel, 2010a). The vesicomyid fossil record of the Northwestern Pacific region is increasingly well studied and revealed the successive appearance, dominance, and disappearance of several genera. *Hubertschenckia* Takeda, 1953 was the only genus present during the late Eocene and Oligocene and it disappeared afterward; the elongate *Adulomya* Kuroda, 1931 dominated during the early and middle Miocene; and in the late Miocene both *Archivesica* Dall, 1908 and *Calyptogena* Dall, 1891 appeared and are the dominant vesicomyid genera until the present day (Amano and Jenkins, 2011; Amano and Kiel; 2007; 2010; 2011; 2012; Sasaki et al. 2005). Among those two genera, *Archivesica* was, and still is, much more species rich than *Calyptogena*.

When Amano and Jenkins (2011) investigated the fossil record of extant vesicomyid species in Japan, they questioned an identification by Katto and Masuda (1978) of an early Miocene species from the lower Miocene Shikiya Formation in southern Honshu as *Akebiconcha* cf. *kawamurai* Kuroda, which is an older name for the extant *Archivesica kawamurai*. Amano and Jenkins (2011) suspected that the Shikiya species may belong to *Archivesica*, but was not *A. kawamurai*. Moreover, Katto and Masuda (1978) identified an elongate bivalve from the same locality as *Cultellus izumoensis* Yokoyama, although the lot documentation was poor. Based on observations on the original material of Katto and Masuda (1978) and new material collected at their locality, both species are here identified as members of the Vesicomyidae: the ovate specimens previously identified as *Akebiconcha* cf. *kawamurai* is named as a new species of the genus *Archivesica*, and the specimens assigned to *Cultellus izumoensis* are identified as *Adulomya uchimuraensis* Kuroda, 1931. Here we describe these species and discuss their evolutionary significance. We also describe the locality in more detail, including its paleoecology and the mode of occurrence of these fossils and additional taxa.

MATERIALS AND METHODS

The specimens were recovered from a large block (ca. 7 × 4 × 4 m) and several small blocks in its vicinity along the boulder beach near a cliff about 400 m north of Oshima fishing port in Kii Oshima Island, Wakayama Prefecture, Japan (Figure 1; Katto and Masuda, 1978, Loc. no. 10). These blocks are derived from the cliff and consist of sandy siltstone of the uppermost lower to lowermost middle Miocene Shikiya Formation of the Kumano Group (Hisatomi, 1981). All shell material is dissolved and rubber casts were made from the internal and external molds to document the internal and external morphology of the species, including the hinge structure. However, many small pyrite grains and the rough surface of weathered shells prevent us from making rubber casts without bubbles. All specimens reported here are deposited at the Wakayama Prefectural Museum of Natural History (WMNH).

MODE OF OCCURRENCE

The bivalves occur in shell beds consisting of mostly articulated specimens lying parallel to the bedding plane, although valves that are opened to various degrees were also found (Figures 2–5). The matrix of these shell beds does not differ from the surrounding sandy siltstone. This mode of occurrence indicates that shells are not preserved in life position but may instead have been transported for a short distance and then quickly buried. In addition to the two vesicomyid species described here, two specimens of the giant solemyid *Acharax* cf. *yokosukensis* Kanie and Kuramochi, 1995 (reaching about 30 cm in length), one specimen each of the lucinid bivalves *Lucinoma*? sp. and *Poumea*? sp., and of the naticid gastropod *Euspira meisensis* (Makiyama, 1926) were found (Figures 6–10).

SYSTEMATICS

Family Vesicomyidae Dall and Simpson, 1901
Subfamily Pliocardiinae Woodring, 1925

Genus *Archivesica* Dall, 1908

Type Species: *Callocardia gigas* Dall, 1896, from the Gulf of California.

Archivesica sakoi new species
(Figures 11–17)

Akebiconcha cf. *kawamurai* Kuroda. Katto and Masuda, 1978: pl. 3, fig. 7.

Diagnosis: Medium-sized *Archivesica* with elongate ovate shell, no lunular incision, shallow and wide pallial sinus, and very shallow subumbonal pit; subumbonal cardinal tooth consisting of very small anterior (3a) and rather thick posterior (3b) teeth and thick cardinal tooth

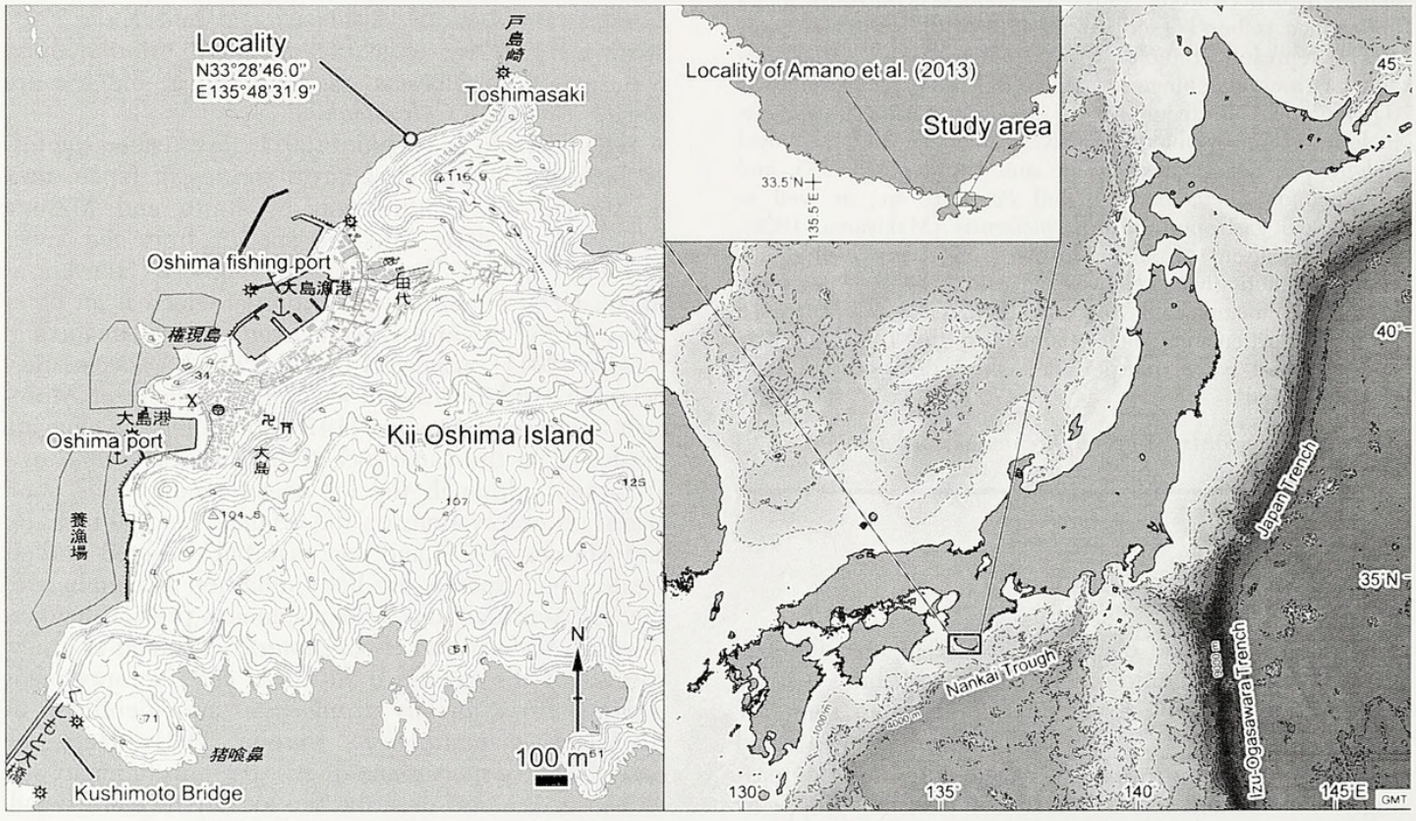


Figure 1. Locality of the vesicomyid fossils (left-side base map is from the "Kushimoto", scale 1:25,000 topographic map published by the Geospatial Information Authority of Japan).

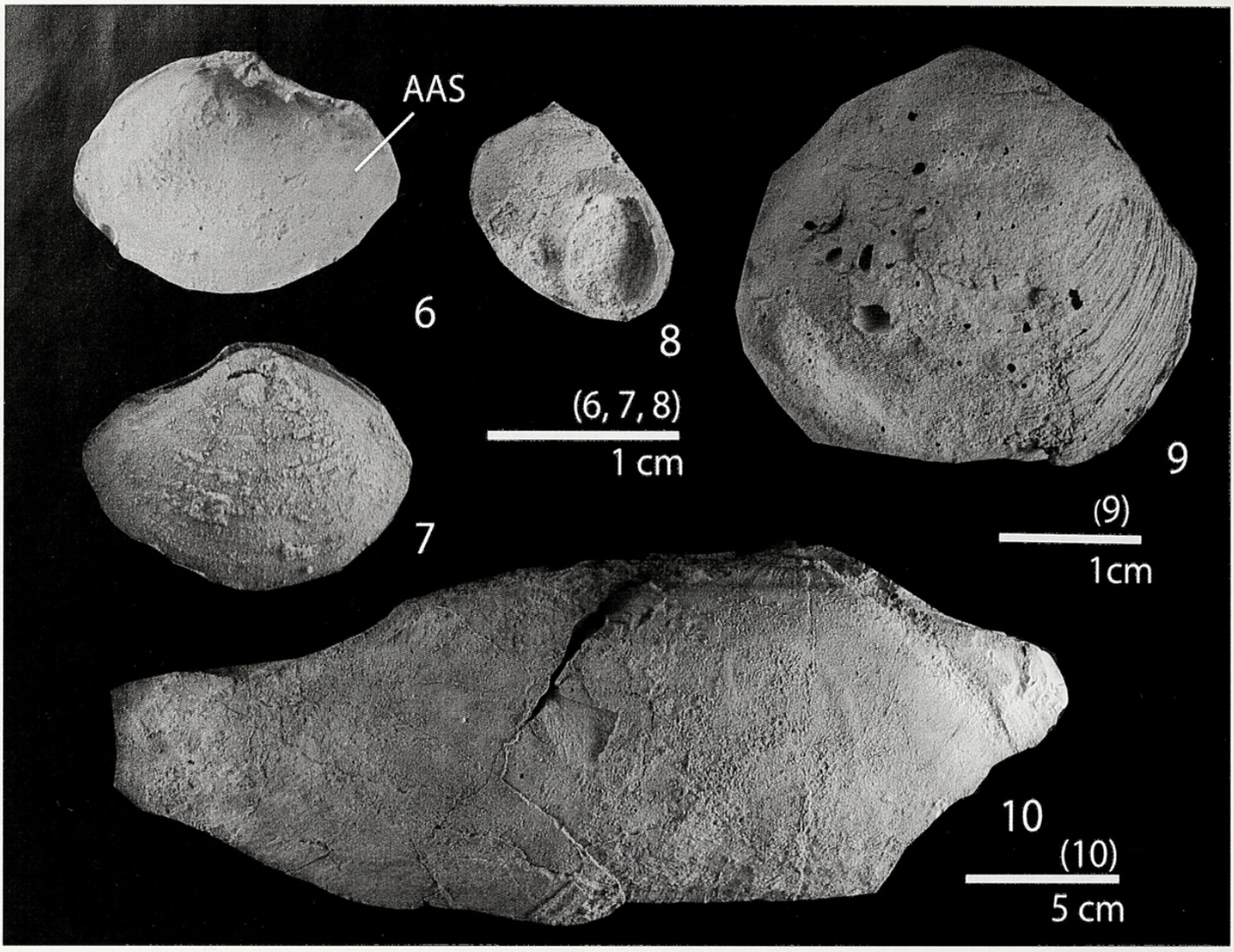
Figures 2–5. Field images of the outcrop. **2–4.** Large block yielding vesicomyid fossils, white arrow indicates a gregarious occurrence; enlargement of the southern side of the block (**3**), and close up of the gregarious occurrence (**4**). **5.** Cluster of *Adulomya uchimuraensis* Kuroda in a small block in the immediate vicinity of the large block.

(1) in right valve; subumbonal cardinal tooth consisting of thin anterior ramus (2a) and very thick triangular posterior tooth (2b) and posterior cardinal tooth (4b) very thin in left valve.

Description: Shell medium-sized for genus (up to 80.4 mm in length), moderately inflated, elongate-ovate (height/length = 0.48–0.56), equivalve and inequilateral. Antero-dorsal margin concave and continuing to rounded anterior margin; postero-dorsal margin nearly straight, posterior margin subtruncated; ventral margin broadly arcuate. Beak prominent, prosogyrate and located at anterior one-fifth to one-third of shell length (U%=22–34). Lunule absent. Surface ornamented with irregular commarginal lines. Right valve hinge wide for size, with three cardinal teeth and very shallow subumbonal pit. Anterior tooth (3a) in right valve very short and thin, connected with posterior tooth (3b). Posterior tooth (3b) rather thick, oblique posteriorly; middle cardinal tooth (1) moderately thick, oblique anteriorly. Left valve hinge wide, with three cardinal teeth. In left valve, anterior tooth (2a) thin, connected with middle tooth (2b); middle tooth (2b) triangular and very thick; posterior cardinal tooth (4b) very thin. Anterior adductor scar semicircular and deeply excavated; anterior pedal adductor scar narrow, quadrate and deeply excavated, distinct from adductor muscle scar; posterior adductor scar indistinct, ovate, situated directly above a weak ridge running from umbo to postero-ventral corner; pallial sinus shallow and wide.

Type Material: Holotype: Right valve, length, 63.2 mm, height, 31.3 mm, WMNH-Ge-5. Paratypes: Left valve, length, 48.7 mm+, height, 26.0 mm, WMNH-Ge-6; left valve, length, 59.5 mm, height, 30.5 mm+, WMNH-Ge-7; left valve, length, 80.4 mm, height, 39.2 mm, WMNH-Ge-8.

Type Locality: The coastal near cliff about 400 m north to Oshima fishing port in Kii Oshima Island, Kushimoto-cho, Wakayama Prefecture, Japan.

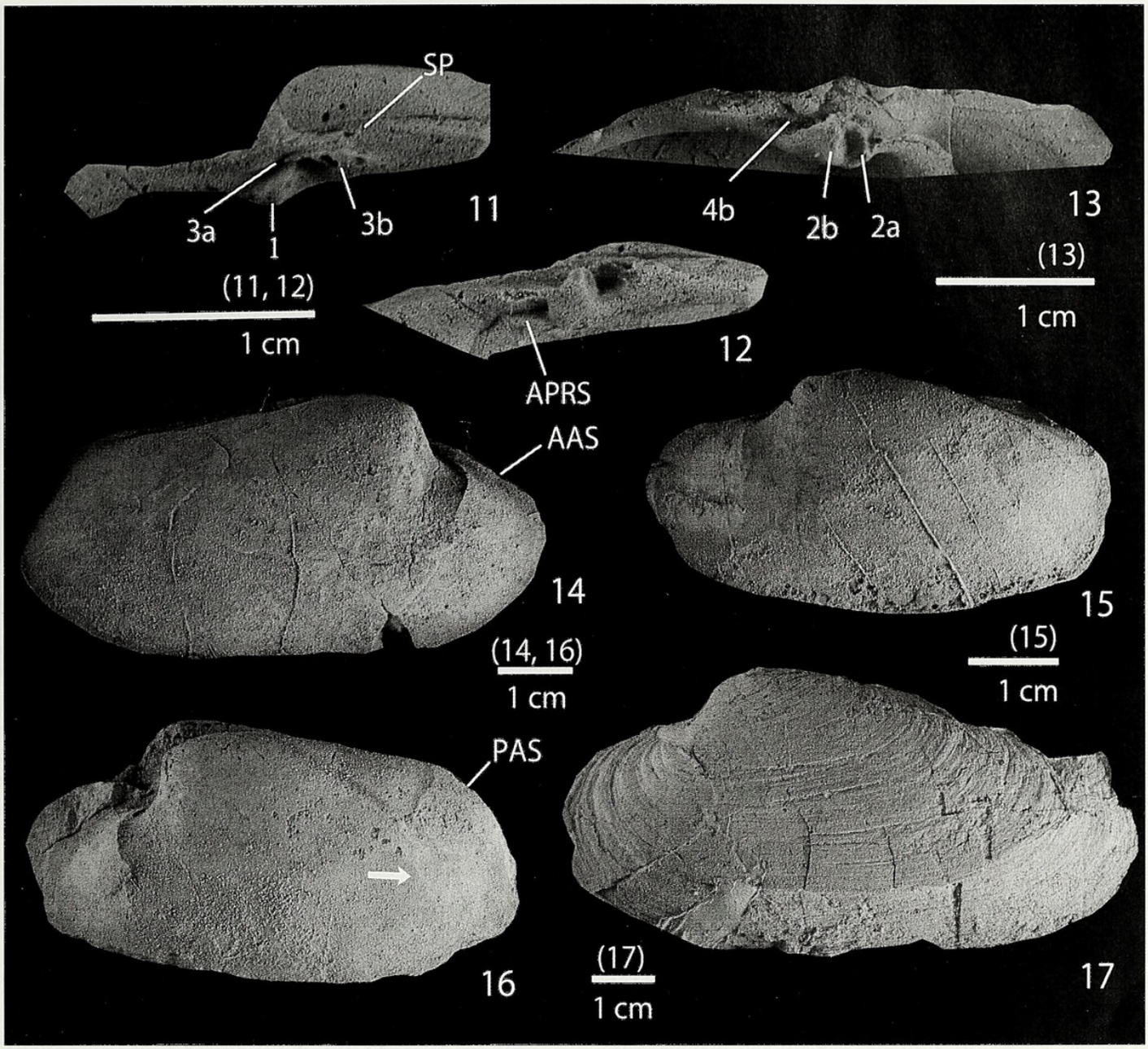


Figures 6–10. Mollusks associated with the vesicomyid bivalves described here. **6, 7.** The lucinid bivalve *Poumea*? sp. (WMNH-Ge-1120210284); **6**, rubber cast of the inner surface of a left valve showing elongate anterior adductor scar (AAS); **7**, internal mold. **8.** The naticid gastropod *Euspira meisensis* (Makiyama) (WMNH-Ge-1120210285), rubber cast. **9.** The lucinid bivalve *Lucinoma*? sp. (WMNH-Ge-1120210287), rubber cast of the external surface of a right valve. **10.** The solemyid bivalve *Acharax* cf. *yokosukensis* Kanie and Kuramochi (WMNH-Ge-1120210291), internal mold of a left valve.

Material Examined: Twelve specimens from the type locality.

Remarks: *Archivesica sakoi* new species was previously reported as *Akebiconcha* cf. *kawamurai* Kuroda, 1943 by Katto and Masuda (1978), but their illustration did not show the hinge structure. The outline of *Archivesica kawamurai* is indeed somewhat similar to that of *A. sakoi* except for being higher and larger. However, the subumbonal cardinal tooth of right valve enables us to easily separate both species. The right valve of the present new species has a small anterior tooth (3a) and posteriorly oblique posterior tooth (3b), while that of *A. kawamurai* has a larger anterior tooth and a posterior tooth that is slightly inclined anteriorly (Kuroda, 1943; Sasaki et al., 2005).

Comparisons: The right valve hinge of *Archivesica sakoi* is most similar to that of the Recent "*Calyptogena*" *laubieri* Okutani and Métivier, 1986 in having a small 3a tooth and a shallow subumbonal pit (Figure 18). A recent molecular phylogenetic analysis (Audzijonyte et al., 2012) indicates that this species is phylogenetically close to the type species of *Archivesica*, *A. gigas* (Dall, 1895). However, "*C.*" *laubieri* can be separated from the present new species by having a distinct blunt ridge running from beak to posterior end, a tapering posterior end, a very narrow hinge plate, a less stout middle tooth of left valve, and many distinct irregular growth lines on the outer surface (Figures 19, 22). The extant *Archivesica ochotica* Scarlato, 1981 also resembles this new species in a having broadly rounded ventral margin, a shallow pallial sinus, a rather small 3a tooth, a shallow subumbonal pit in the right valve, and a stout 2b tooth in the left valve (Figures 20, 21, 23). However, *A. ochotica* has a larger (105.0 mm long) and higher shell (H/L = 0.58), an overhanging posterior tooth above anterior and middle cardinal teeth of left valve, and



Figures 11–17. *Archivesica sakoi* new species. **11, 12, 15.** Paratype (WMNH-Ge- 1120210286); **11**, a rubber cast showing details of the hinge of a right valve; SP=subumbonal pit; **12**, ventral view showing the anterior pedal retractor scar (APRS); **15**, internal mold of left valve. **13, 16.** Paratype (WMNH-Ge-1120210288); **13**, rubber cast showing details of the hinge area of a left valve; **16**, view on the left valve of an internal mold, white arrow indicates the very shallow pallial sinus; PAS=posterior adductor scar. **14.** Holotype (WMNH-Ge-1120210283); view on the right valve of an internal mold; AAS=anterior adductor scar. **17.** Paratype (WMNH-Ge-1120210289), rubber cast showing the outer surface of a left valve.

a more roundly curved postero-dorsal margin than *Archivesica sakoi* new species.

Distribution: Lower Miocene Shikiya Formation at the type locality.

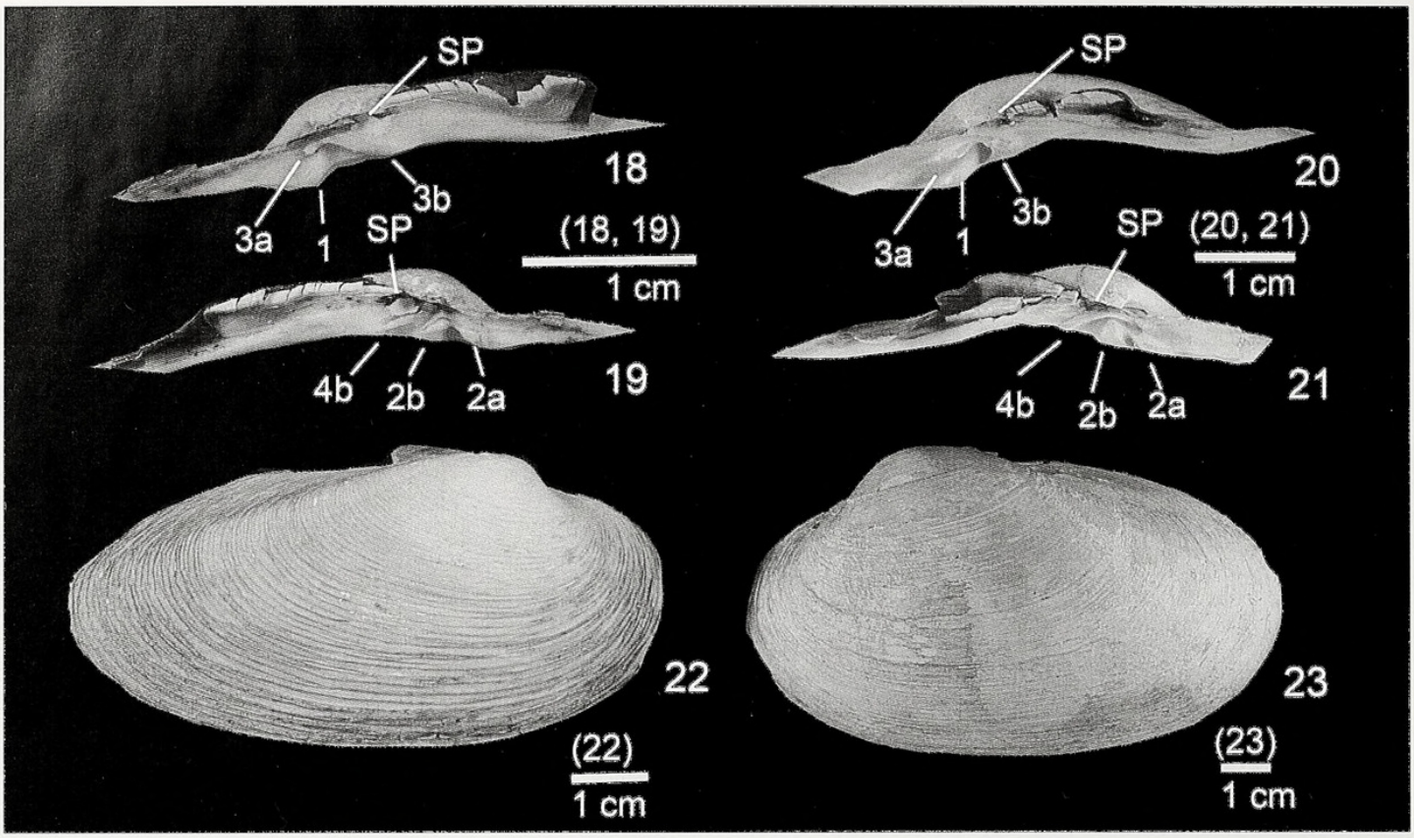
Etymology: Named after Mr. Yukio Sako who collected the type specimens and kindly offered them to the authors for study.

Genus *Adulomya* Kuroda, 1931

Type Species: *Adulomya uchimuraensis* Kuroda, 1931, from the middle Miocene Bessho Formation, central Honshu, Japan.

***Adulomya uchimuraensis* Kuroda, 1931**
(Figures 24–29)

Adulomya uchimuraensis Kuroda, 1931: 27–28, pl. 13, figs. 111–114; Tanaka, 1959: 117–118, pl. 1, fig. 1–10; Tanaka, 1960: 24–26, pl. 32, figs. 1–7; Amano and Kiel, 2011: 77–80, fig. 2.



Figures 18, 19, 22. *"Calyptogena" laubieri* Okutani and Métivier, 1986, Holotype (NSMT Mo 64158); **18**, hinge dentition of a right valve; SP=subumbonal pit; **19**, hinge dentition of a left valve; **22**, right side view of the holotype. **Figures 20, 21, 23.** *Archivesica ochotica* Scarlato, 1981, Holotype (ZIN AN SSSR no. 9912); **20**, hinge dentition of a right valve; **21**, hinge dentition of a left valve; **23**, left side view of the holotype.

Calyptogena (*Adulomya*) *uchimuraensis* Kuroda.—Kanno and Tanaka in Kanno et al., 1998: 20–22, figs. 7–8.
Calyptogena (*Adulomya*) *uchimuraensis kurodai* Kanno and Tanaka in Kanno et al., 1998: 22–25, figs. 9–10.
Akebiconcha chitanii (Kanehara).—Kanno and Ogawa, 1964: pl.1, figs. 17–18.
~ *Adulomya uchimuraensis* Kuroda.—Hayashi and Miura, 1973: pl. 1, fig. 15.
Cultellus izumoensis Yokoyama.—Katto and Masuda, 1978: pl. 3, figs. 8–9.
non Akebiconcha uchimuraensis Kuroda.—Matsumoto and Hirata, 1972: 755–757, pl. 1, figs. 1–8, pl. 2, figs. 1–2.

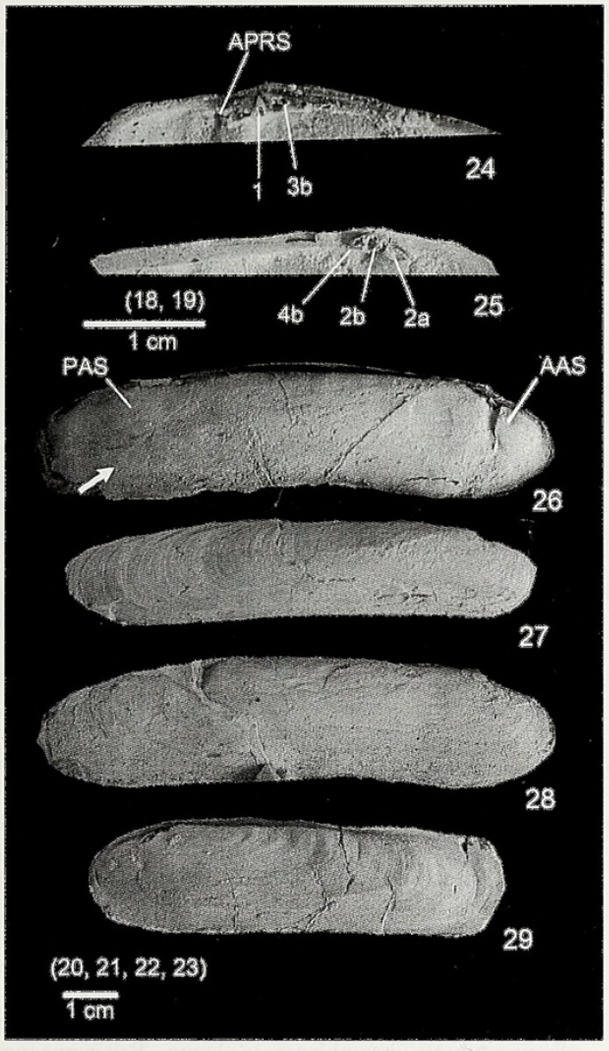
Material Examined: Fifty-three specimens were examined.

Remarks: Katto and Masuda (1978) illustrated two elongate specimens as *Cultellus izumoensis*. Our examination of the hinge of their illustrated specimen (Katto and Masuda, 1978: pl. 3, fig.9; Figures 15, 19 herein) indicates that they belong to *Adulomya uchimuraensis* for the following reasons: the left valve has an anterior (2a) and a middle cardinal (2b) tooth and a low posterior tooth (4b), and the right valve has only two teeth (cardinals 1, 3b); the anterior retractor scar is very deep, and some examined specimens show that the pallial line is entire (Figure 16). Such characteristics are never seen in any cultellid species. Cultellid species have only two protruded cardinal teeth in each valve and pallial sinus present.

Comparison: As discussed by Amano and Kiel (2011), *Adulomya uchimuraensis* can be separated from the early to middle Miocene *Adulomya chitanii* Kanehara, 1937 by its larger size and the lack of a pallial sinus. Although the maximum size of *Adulomya uchimuraensis* at Kii Oshima (94.1 mm long) is smaller than the maximum size of the specimens of *A. uchimuraensis* at its type locality in the Bessho Formation (180 mm; Amano and Kiel, 2011), it is still larger than *A. chitanii*, which reaches only up to 70.4 mm in length (Amano and Kiel, 2011).

Measurements: Left valve, length, 83.2 mm, height, 21.4 mm, WMNH-Ge-9; right valve, length, 89.7 mm, height, 17.8 mm, WMNH-Ge-10; right valve, length, 94.1 mm, height, 23.9 mm, WMNH-Ge-11.

Distribution: Lower Miocene Shikiya Formation in Wakayama Prefecture, lowest middle Miocene Takinoue Formation in Hokkaido and middle Miocene Bessho Formation in Nagano Prefecture.



Figures 24–29. *Adulomya uchimuraensis* (Kuroda), **24, 26, 28.** Right valve (WMNH-Ge-1120210293); **24**, rubber cast showing the hinge dentition and the anterior pedal retractor scar (APRS) of a right valve; **26**, rubber cast showing the anterior (AAS) and posterior adductor scars (PAS) in a right valve, white arrow indicates the posteriormost portion of the entire pallial line; **28**, rubber cast showing the outer surface of this shell. **25, 29.** The specimen illustrated by Katto and Masuda (1978, pl. 3, fig. 9)(WMNH-Ge-1120210292); **25**, rubber cast showing details of the hinge area; **29**, left valve. **27.** Rubber cast of the outer surface of a right valve (WMNH-Ge-1120210290).

DISCUSSION

Recent studies on presumed Paleogene members of *Archivesica* from western North America (Amano and Kiel, 2007; Kiel and Amano, 2010) indicate that these species may not belong to *Archivesica* but instead to the genus *Pliocardia* or a related new genus (Amano and Kiel, 2012). Thus, the early Miocene *Archivesica sakoi* new species described here from southern Japan represents the oldest species of the genus *Archivesica*. However, this does not change our earlier observation that *Adulomya* was the dominant vesicomyid taxon during the early and middle Miocene in Japan because *Adulomya uchimuraensis* is far more common at the Kii Oshima site than *Archivesica sakoi*.

The association reported here from Kii Oshima consists almost exclusively of potentially chemosymbiotic bivalves (e.g., Taylor and Glover, 2010): dominant are the vesicomyids *Adulomya uchimuraensis* and *Archivesica sakoi* with a minor number of lucinids (*Lucinoma*? sp. and *Poumea*? sp.) and a solemyid (*Acharax* cf. *yokosukensis*). Such an association dominated by vesicomyid bivalves is typical for extant cold seep communities (Paull et al. 1985; Levin 2005; Majima et al. 2005; Campbell, 2006) and suggests that the Kii Oshima fauna might have lived at an ancient cold seep. Predatory gastropods such as the naticid *Euspira meisensis* found along with the chemosymbiotic bivalves are common in soft sediments in many marine environments, but they are also frequently found at ancient cold-seep communities, especially in the North Pacific realm (Amano et al. 2010; Kiel, 2010b). Due to the transported nature of the association and the lack of carbonate, the usual approach to identify an ancient cold-seep deposit by stable carbon isotope analysis (cf. Peckmann and Thiel, 2004) is not possible. This is so far the only record of a vesicomyid-dominated faunule from the Shikiya Formation and from southern Honshu (cf., Majima et al. 2005).

Only about 4 km west of the Kii-Oshima locality, a hydrocarbon-seep fauna has been recently been reported by the present authors from the upper Eocene to lower Oligocene(?) Tanamigawa Formation at Tanosaki (Amano et al., 2013). That Paleogene community differs from the early Miocene fauna from Kii Oshima reported here by consisting of a different vesicomyid genus (*Hubertschenckia*), the bathymodiolin mussel *Bathymodiolus*, the thyasirid bivalve *Conchocele* and the absence of lucinids. As already pointed out by Amano et al. (2013), Paleogene seep communities in Japan generally lack lucinid bivalves, while lucinids are generally present at Miocene seep communities as in the the Kii Oshima fauna reported here.

ACKNOWLEDGMENTS

We thank Yukio Sako (Kushimoto-cho), Yukito Kurihara (Mie University) and Hiroshi Saito (National Science Museum) for their help in examining some fossil or recent specimens; Elena Krylova (P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences) for discussions on vesicomyid systematics, for her helpful review of the manuscript, and for allowing us to use her images of *A. ochotica*. An anonymous reviewer is thanked for suggestions that helped improve on the manuscript. This study was partly supported by a Grant-in-aid for Scientific Research from the Japan Society for Promotion of Science (C, 23540456, 2011-2013) to KA, Grant-in-Aid for JSPS Fellows to RGJ, and by the Deutsche Forschungsgemeinschaft through grant Ki802/6-1 to SK.

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