Chemosynthetic fossil molluscan faunas from the Neogene Taishu Group, distributed in Tsushima Islands, Nagasaki Prefecture, the southwest Japan

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Chemosynthetic fossil molluscan faunas from the Neogene Taishu Group, distributed in Tsushima Islands, Nagasaki Prefecture, the southwest Japan

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Abstract

The middle of the Neogene Taishu Group, distributed in Tsushima Islands, Nagasaki Prefecture, the southwest Japan, is considered to include the authigenic carbonates originated from cold-seep and the chemosynthetic molluscan faunas deposited in deep sea environment of greater than 500 m depth. In this study, the author examined classification of the bivalves occurred in the middle of the Taishu Group. Consequently, the molluscan faunas are assigned into the following ten species belonging to seven genera: *Bathymodiolus* sp., *Adipicola* sp., *Calyptogena* spp., *Acharax* spp., *Acila* sp., *Nuculana* sp., and *Yoldia* sp.

Keywords: the Neogene Taishu Group, deep sea environment, chemosynthetic molluscan faunas

1. Introduction

The formation of the Sea of Japan is thought to be the results of the following processes. (1) The east margin of the Eurasian Continent subsided in the late Cenozoic; (2) the spreading of the Sea of Japan reached the climax opening stage in the Early Miocene; and (3) the Japanese Archipelago was formed in the middle Miocene (Otofuji and Matsuda, 1983, 1985). The Taishu Group distributed in Tsushima Islands, which is located in the southwest part of the Sea of Japan, has been regarded as the conformable marine deposits and they can be compared with the Paleogene strata distributed in the northwest Kyushu (Nakajo and Funakawa, 1996; Nakajo et al., 2006). Therefore, Tsushima Islands are important area in reconstructing the formation history of the Sea of Japan and the Japanese Archipelago. However, our knowledge concerning the sedimentary environments of the Taishu Group was fragmental and there are many unsettled discussions about the formation age (Okada and Fujiyama, 1970; Nakajo and Maejima, 1998; Nakajo et al., 2006; Yamaguchi and Oho, 2007). Furthermore, the maga-fossils found in the Taishu Group are of mainly shallow marine fossil faunas. However, the maga-fossils are scarce and poorly preserved (Matsumoto, 1969; Masuda, 1970; Takahashi and Nishida, 1975). The author has been studying about the Taishu Group distributed in Tsushima Islands to understand the formation processes of the Sea of Japan and the depositional environments of the deep sea sediments in the southwestern Sea of Japan. Recently, small-scale carbonate and fossil assemblages are found successively in the middle of the Taishu Group (Aoki and Nishida, 1999; Ninomiya et al., 2008). In our study, it has been shown that they are authigenic carbonates originated from cold-seep and that the fossil molluscan faunas are chemosynthetically formed (Ninomiya et al., 2008). They state that the middle of the Taishu Group was deposited in deep-sea environments at greater than 500 m depth (Ninomiya et al., 2010). Therefore, cold-seep carbonates and chemosynthetic fossil assemblages from the Taishu Group are important in deciphering the paleoenvironments of the opening stage of the Sea of Japan. The author reports the classification of chemosynthetic bivalves occurred from the Taishu Group in this paper.

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2. Geological setting of Tsushima Islands

Tsushima Islands are located at 120 km off Kyushu in the southwestern Sea of Japan (Fig. 1). The Taishu Group is conformable marine formation with the thickness of greater than 5,400 m and it is classified into the Lower Formation, Middle Formation and Upper Formation based on lithology and distribution of T3 Tuff (MITI, 1973). The layer of T3 Tuff can be tracked in distance of greater than 40 km (Fig. 2). Anticlinorium and synclinorium structures with a northeast-southwest axis are observed in Tsushima Islands. In the south of Tsushima Islands, where granite as intrusive rock is observed the Taishu Group was affected by contact metamorphism. Also observed are rhyolite, quartz porphyry, plagiophyre and dolerite as intrusive rocks. The formation age of the Taishu Group has been regarded as the early Eocene-early Miocene (Ibaragi, 1994; Nakajo and Funakawa, 1996; Sakai and Yuasa, 1998). However, the author and his colleagues dated T3 Tuff and subaqueous pyroclastics of the Upper Formation. Consequently, we learned that the main part of the Taishu Group was deposited at approximately 16 Ma which was in the middle Miocene (Ninomiya et al., 2010). Furthermore, the lower most of the Taishu Group with the reported early Eocene radiolarians may be compared with the Paleogene strata distributed in the northwest Kyushu.

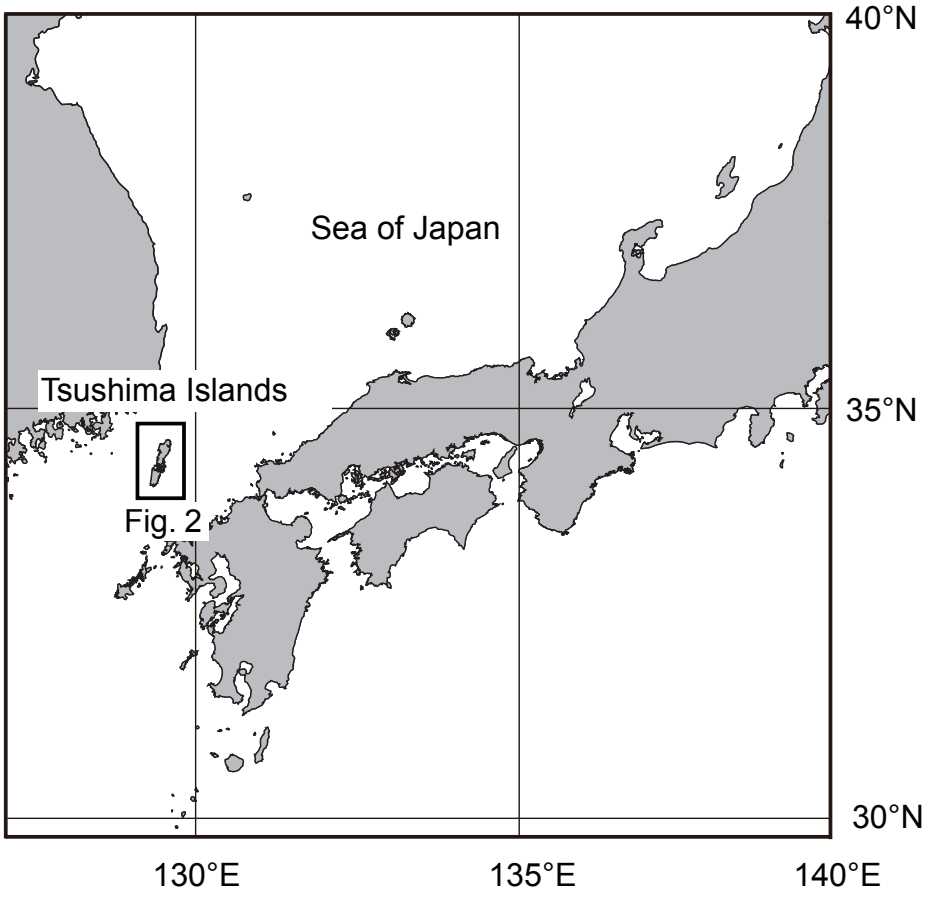

Fig. 1. Location of Tsushima Islands.

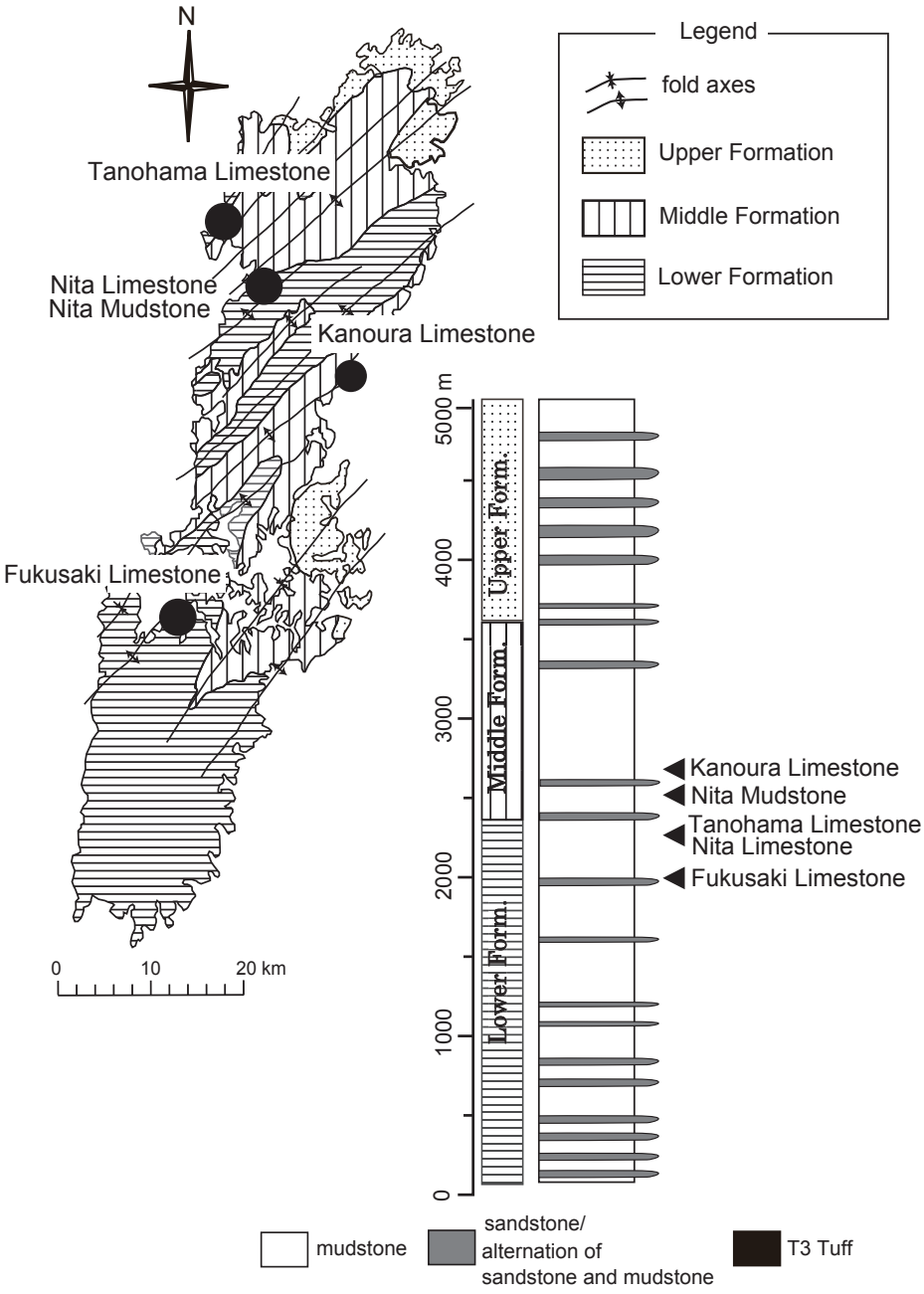

Fig. 2. Geologic map of Tsushima Islands and lithological column of the Taishu Group based on MITI (1972, 1973, 1974). Circles show the locality of limestone and chemosynthetic fossil assemblages.

3. Chemosynthetic bivalves from the Taishu Group

MITI (1972) reported *Adulomya* cf. *uchimuraensis, Calyptogena akanudaensis* from the limestone boulder at Tanohama, where the upper part of the Lower Formation is located. Aoki and Nishida (1999) found a lenticular limestone including small *Adulomya* sp. from the same horizon. Moreover, fossil molluscan faunas are dominated by *Acharax* spp. with occurrences of *Sacella*, *Yoldia* and *Portlandia*. These fossil molluscan faunas are quite dense in population and they are regarded as chemosynthetic fossil assemblages.

Ninomiya et al. (2010) reported that fossil assemblages of the authigenic cold-seep carbonates and mudstone are chemosynthetic bivalves which are mytilids, vesicomyids and solemyids. As Aoki and Nishida (1999) indicated, the calcareous shells are absent in mudstones but are preserved in carbonates. Based on these conditions, the middle part of the Taishu Group is considered to be deposited at deep-sea floor greater than 500 m depth (Ninomiya et al., 2010).

4. Description of molluscan fossils

Class Bivalvia Linnaeus, 1758
Family Solemyidae Gray, 1840
Genus *Acharax* Dall, 1908
Type species: *Solemya johnsoni* Dall, 1891; Recent, Northeast Pacific.

***Acharax* sp. A**
Plate 1, fig. 1

Acharax sp. A, Aoki and Nishida, 1999.

Locality: Nita (Basal part of the Middle Formation; Aoki and Nishida, 1999)

Measurements (in mm) :

Sumple No.	valve	Length	La	Height	Height/ Length	La/L	Rib number	Plate
Aok-001	right balve	49.7	14.2	23.7	0.48	0.29	20	Plate 1, fig. 1

La: Length of anterior margin.

Description: Shell is of middle size. Ligament external. Dorsal margin straight, antero-postero margin rounded. Ventral margin nearly straight. Umbo located at anterior one and third of valve of shell length. Radial ribs count 18-20, and marginal portion degitated beyond shell margin. The ribs are strong at anterior-posterior end, but weak and obscure at center of valve.

Remarks: According to Aoki and Nishida (1999), this species resembles *Acharax tokunagai*. As Sasaki et al. (2005) indicated, *Solemya* (*Acharax*) *agasizii, Solemya tokunagai, Solemya* (*Acharax*) *tibai,* and *Solemya tokunagai elongata* are synonymyzed with *Solemya johnsoni* (Coan et al., 2000). This species resembles *Acharax johnsoni* in many points. However, umbo of *Acharax johnsoni* situates posteriorly, 78%. Therefore, this species may be distinguished from *Acharax johnsoni*.

***Acharax* sp. B**
Plate 1, figs. 2-6

Acharax sp. B, Aoki and Nishida, 1999.

Locality: Nita (Basal part of the Middle Formation; Aoki and Nishida, 1999)

Measurements (in mm) :

Sumple No.	valve	Length	La	Height	Height/ Length	La/L	Rib number	Plate
Aok-002	right balve	38.3	8.8	13.8	0.36	0.23	17	Plate 1, fig. 2
GK-L12000	left valve	29.4	8.2	10.4	0.35	0.28	17	Plate 1, fig. 3
Aok-003	right balve	44.2	10.6	13.3	0.30	0.24	15+	Plate 1, fig. 4
GK-L12001	right balve	59.5+	16.1	—	—	—	18	Plate 1, fig. 5, 6

Description: Shell is small to middle size and elongated. Ligament external. Dorsal margin straight, antero-postero margin rounded. Ventral margin nearly straight. Umbo located at anterior about three of quarter of valve length. Radial ribs count 17, and marginal portion digitated beyond shell margin. The ribs are strong at anterior-posterior end, but weak and obscure at center of valve.

Remarks: Bivalves of geneus *Acharax* is reported at least in eight species (Baba, 1990; Hatai and Koike1956; Kamada, 1962; Kanehara, 1937; Kanno, 1960; Kanie and Kuramochi, 1995; Kanie et al, 1995; Kanie et al., 1999; Natori, 1964). This species resembles *Acharax yessoensis, Acharax dalli, Acharax muroensis*, and *Acharax gigas*. However, radial rib numbers of *A. yessoensis* are 18-20. Shell length of *A. dalli* is smaller than that of this species and radial rib numbers are 10-11. Shell length of *A. muroensis* is less than that of this species. *Acharax bosoana* is larger than *Acharax* sp. B and has 10-11 ribs. Shell size of *Acharax gigas* is much larger than those of *A. yessoensis, A. dalli, A. muroensis* and *Acharax* sp. B. Therefore, *Acharax* sp. B can clearly be distinguished from other species. It appears necessary in the future to discuss about the possibility of erecting this taxon as a new species.

***Acharax* sp. C**
Plate 2, figs. 1-2

Locality: Kanoura (Lower part of the Middle Formation)

Description: Shell size and outline unknown. Ligament is external. Radial ribs marginal portion digitated beyond shell margin. Frequently, this species is observed in mudstones around Kanoura Limestone. However, shells are imperfect, shell outline is unknown. This species may be identified as *Acharax* sp. A or *Acharax* sp. B. In this paper, the author assigns this taxon as *Acharax* sp. C.

Class Bivalvia Linnaeus, 1758
Family Nuculidae Adams and Adams, 1858
Genus *Acila* Adams and Adams, 1858
Type species: Nucula divaricata Hinds, 1843; Recent, China

***Acila* sp.**
Plate 2, fig. 3

Locality: mudstone around Fukusaki Limestone (Upper part of the Lower Formation)

Measurements (in mm):

Sample No.	valve	Length	Height	Plate
GK-L12004	left valve	26+	34.7+	Plate 2, fig. 3

Description: Shell length greater than 26 mm and height reaching about 35 mm. Shell subovate, inequilateral, not so inflated well-defined rostral portion. Posterior side is very short. Umbo located at nearly posterior margin. Anterior dorsal margin gently sloping, but anterior end is absent. Ventral margin regularly arched. Posterior margin form and lunula cannot be observed. Sculpture consisting of divaricating oblique threads, the line of main devarication is slightly posterior to the middle.

Remarks: This species resembles *Acila submirabilis* and is common in the Neogene of Japan. However, umbo, linule and posterior margin forms are unknown. Therefore, the author tentatively assigns this taxon as *Acila* sp. until well-preserved specimens with visible structures are studied.

Family Nuculanidae Adams and Adams, 1858
Genus *Nuculana* Link, 1807
Type species: *Arca rostrata* Bruguière, 1791= *Mya pernula* Müller, 1779; Recent, North Atlantic.

***Nuculana* sp.**
Plate 2, fig. 4

Locality: Nita (Basal part of the Middle Formation; Aoki and Nishida, 1999).

Measurements (in mm):

Sample No.	valve	Length	La	Plate
Aok-004	left valve	8.7	3.2	Plate 2, fig. 4

Description: Shell small, long-ovate, inflated, nearly veneriform. Escutcheon is obscure. Umbo located at nearly anterior margin. Strong concentric regular growth line presents on surface. Hinge structure unknown.

Remarks: Shell form and only growth line are observed on surface. However, hinge structure is unknown. Therefore, the author assigns this taxon as *Nuculana* sp. until well-preserved specimens are studied.

Genus *Yoldia* Möller, 1842
Type species: *Yoldia hyperbore* Torell, 1859= *Nucula hyperborea* Gould, 1841; Recent, North Atlantic.

***Yoldia* sp.**
Plate 2, figs. 5-6
Locality: Nita (Basal part of the Middle Formation; Aoki and Nishida, 1999).

Measurements (in mm):

Sample No.	valve	Length	La	Height	Height/ Length	Plate
Aok-005	right valve	13.7	3.2	10.1	0.74	Plate 2, fig. 5
Aok-006	left valve	14.9	5.0	8.2	0.55	Plate 2, fig. 6

Description: Shell small, long-ovate, anterior margin rounded, anterior side slightly shorter than posterior side. Postero-dorsal corner pointed. Postero-dorsal border concaved. Strong concentric regular growth line is observed on surface. Hinge structure and escutcheon are unknown.

Remarks: Shells are deformed, umbo area structures cannot be observed. Therefore, the author assigns this taxon as *Yoldia* sp.

Unidentified species
Plate 2, fig. 6

Locality: Nita (Basal part of the Middle Formation; Aoki and Nishida, 1999).

Measurements (in mm):

Sample No.	valve	Length	La	Plate
GK-L12005	left valve	42.1+	13.2	Plate 2, fig. 6

Description: Shell moderate, elongated, anterior margin rounded, ventral margin slightly arcuated. Posterior dorsal margin is straight. Strong concentric regular growth line presents on surface. Hinge structure is unknown. Therefore, it will be necessary to describe more details in the future based on well-preserved specimens whose structures can be observed.

Class Bivalvia Linnaeus, 1758
Order Mytiloida Férussac, 1822
Family Mytilidae Rafinesque, 1815
Subfamily Bathymodiolinae Kenk and Wilson, 1985
Genus *Bathymodiolus* Kenk and Wilson, 1985
Type species: *Bathymodiolus thermophilis* Kenk and Wilson, 1985; Recent, Galapagos Rift zone.

***Bathymodiolus* sp.**
Plate 3, figs. 1-6

Locality: Fukusaki Limestone (Upper part of the Lower Formation).

Measurements (in mm):

Sample No.	valve	Length	La	Height	Plate
GK-L12006	right valve	36	1.3	−	Plate 3, fig. 1
GK-L12007	right valve	38.1+	4.6	21.8	Plate 3, fig. 2
GK-L12008	right valve	41.5	−	−	Plate 3, fig. 3
GK-L12009	left valve	29.5+	−	17.7	Plate 3, fig. 4
GK-L12010	right valve	46.7+	−	−	Plate 3, fig. 5
GK-L12011	left valve	33.0+	−	17.5	Plate 3, fig. 6

Description: The largest one reaches about 47 mm in length, although the present specimen is broken at anterior, posterior, and dorsal sides. All the specimens are imperfect and height/length ratio and width/length ratio unknown. Shell rather thick and solid, modioliform, inflated, elliptical equivalve. Umbo subterminal, prosogyrated at nearly anterior margin. Anterior margin is located slightly forward than umbo. Anterior margin rounded, dorsal margin convex, postero-dorsal corner rounded, posterior margin broadly rounded, ventral margin straight. Feeble radial threads present in mid-portion. Inner structures are unknown.

Remarks: This species resembles *Bathymodiolus platifrons, B. japonicus* and *B. hirtus* described by Hashimoto and Okutani (1994) and Okutani et al. (2004) from Japanese waters. However, this species is distinguished from the similar taxa listed above based on umbo projection from anterior margin, strait ventral margin, as well as shell length of 50 mm. Nobuhara et al. (2008) indicated that bathymodiolin became large in the middle Miocene. However, this species is 50 mm in shell length. It may be necessary in the future to discuss about the possibility of erecting this taxon as a new species.

Genus *Adipicola* Dautzenberg, 1927
Type species: *Myrina denhami* Adams and Adams, 1854 =*Modiolus pelagica* Woodward, 1854 (by monotypy); Recent, South Atlantic.

***Adipicola* sp.**
Plate 3, fig. 7

Locality: Kanoura (Lower part of the Middle Formation).

Measurements (in mm):

Sample No.	valve	Length	La	Height	Height/ Length	Plate
GK-L12012	right valve	37.4	11.2	14	0.37	Plate 3, fig. 7

Description: Shell small (length: 37.4 mm), elongate quadrangular, ligament external. Antero-postero dorsal margin nearly straight. Anterior margin slightly narrow, rounded, posterior margin smoothly rounded, ventral margin slightly concave. Umbo directed forwards, situated at between anterior about one and third. Growth line distinct at posterior margin of shell.

Remarks: Bivalves belonging to genus *Adipicola* are known as whale-fall community of the present or the past (Amano and Little, 2005; Dell, 1995; Okutani et al., 2004; Tsuchida and Tabakotani, 1997). Okutani and Miyazaki (2007) described *Benthomodiolus geikotsucola* from deep sea floor of the northeast Pacific. This species closely resembles *Adipicola pacifica*. However, the calcareous shell has not been preserved and thus the inner structure cannot be observed. This species occurred from the mudstone around Kanoura Limestone which is the authigenic cold-seep carbonate. Consequently, in this study, the author assigns this taxon as *Adipicola* sp. until well-preserved specimens with structures are studied.

Class Bivalvia Linnaeus, 1758
Order Veneroida Adams and Adams, 1856
Superfamily Glossaceae Gray, 1847
Family Vesicomyidae Dall and Simpson, 1901
Genus *Calyptogena* Dall, 1891
Type species: *Calyptogena pacifica* Dall, 1891 (by monotypy); Recent, East Pacific.

***Calyptogena* sp. A**
Plate 4, figs. 1-4, Plate 5, figs. 1-6, Plate 6, figs. 1-4

Locality: Kanoura Limestone (Lower part of the Middle Formation), Tanohama Limestone (Upper part of the Lower Formation) and mudstone around Kanoura Limestone (Lower part of the Middle Formation).

Measurements (in mm):

Sample No.	valve	Length	La	Height	Height/ Length	Width	Plate
GK-L12013	left valve	41.9	6.9	16.5	0.39	−	Plate 4, fig. 1
Aok-007	right valve	40.3+	9.6	−	−	−	Plate 4, fig. 2
Aok-008	left valve	39.0+	−	13.2	−	−	Plate 4, fig. 3
GK-L12014	right valve	44.4+	−	−	−	−	Plate 4, fig. 4
GK-L12015	right valve	45.4	6.1	18.2	−	13.2	Plate 5, figs. 1, 2
GK-L12016	left valve	35.3	5.1	15.3	0.43	−	Plate 5, figs. 3, 4
GK-L12017	right valve	32.7+	4.9	17.3	−	−	Plate 5, fig. 5
GK-L12018	right valve	37.9+	−	15.5	−	−	Plate 5, fig. 6
GK-L12020	right valve	37.3	8.5	−	−	−	Plate 6, fig. 1
GK-L12021	left valve	37.5+	6.5	11.3	−	−	Plate 6, fig. 2
GK-L12022	left valve	36.9+	−	9.1	−	−	Plate 6, fig. 3
GK-L12023	left valve	46.5	6.3	11.3	−	−	Plate 6, fig. 4

Description: The largest one can be measured about 47mm in length, although it is deformed. Shell thick, not so inflated, elongated slightly inequivalve.

Ligament external. Anterior margin rounded, ventral margin strait. Posterior margin slightly broad, smoothly rounded. Postero-dorsal margin nearly straight. Umbo low, reaching slightly above hinge line and is located at between anterior about one sixth of valve length. Hinge structures are unknown.

***Calyptogena* sp. B**
Plate 4, figs. 5-6, Plate 5, figs.7-8, Plate 6, fig. 5

Locality: Kanoura Limestone (Lower part of the Middle Formation), Tanohama Limestone (Upper part of the Lower Formation) and mudstone around Kanoura Limestone (Lower part of the Middle Formation)

Measurements (in mm):

Sample No.	valve	Length	La	Height	Width	Plate
Aok-009	right valve	51.1+	7.5	15.5	8.5	Plate 4, fig. 5, 6
GK-L12019	right valve	32.1+	4.2	12.4	8.5	Plate 5, fig. 7, 8
GK-L12024	right valve	43.9	5	−	−	Plate 6, fig. 5

Description: The largest one can be measured about 51 mm in length, although posterior end is not observed. Shell rather thick, antero-posteriorly significantly elongated, inequilateral slightly inequivalve. Ligament is external along dorsal side. Anterior margin rounded, ventral margin long, rather strongly concave centrally. Anterior dorsal margin descending at an angle of about 30° from umbo. Umbo quite low, reaching slightly above hinge line and located at anterior side and one seventh of valve length. Hinge structure is unknown.

Remarks on *Calyptogena spp*.: In Japan, many fossil species and present species of *Calyptogena* are described thus far (Amano and Kiel, 2006; Kanno et al., 1998; Métivier et al., 1986; Kojima and Ohta, 1997; Kuroda, 1943; Okutani, 1957, 2000, 2008; Okutani and Métivier, 1986; Okutani et al., 1992, 1993, 1996, 1997, 2000, 2002).

Calyptogena sp. A closely resembles *Calyptogena* (*Archivesica*) *similaris* described by Okutani et al. (1997). However, there are differences in that *Calyptogena* sp. A of shell length is a half size or less and anterior margin and antero-dorsal margin are rounded. *Adulomya* cf. *uchimuraensis* reported by MITI (1972) is long as 150 mm (Kanno et al., 1998). And *Calyptogena* sp. A is more elongated than *C. akanudaensis*. Therefore, this species is different from these two species. This species closely resembles *Adulomya hokkaidoensis* in shell length and form, which is described by Amano and Kiel (2006) from the Miocene Chikubetsu Formation as a part of whale-fall community. However, *Adulomya hokkaidoensis* is known only from the whale-fall community. However, hinge structure of *Calyptogena* sp. A cannot be observed. Consequently, in this study, the author assigns this taxon as *Calyptogena* sp. A. Most of fossil bivalves from mudstone around Kanoura Limestone are considered as this species, although they are deformed.

Calyptogena sp. B resembles the modern species *Calyptogena* (*Ectenagena*) *phaseoliformis*. However, *Calyptogena* sp. B is distinguished from the thick shell and 50 mm or less in shell length. *Adulomya uchimuraensis* is different from this species because that ventral margin is straight or only a little concave toward dorsal. It is considered that this species is the same as that occurred from mudstone, but the specimen is significantly deformed. Hinge structure cannot be observed. Therefore, in this study, the author assigns this taxon as *Calyptogena* sp. B.

5. Conclusions

The middle part of the Neogene Taishu Group including the cold-seep carbonates was originated from the authigenic chemosynthetic fossil molluscan faunas, which are distributed in Tsushima Islands, Nagasaki Prefecture. It is considered that the Taishu Group was deposited in deep sea environments of greater than 500 m depth. In this paper, the author classified the bivalves from the cold-seep carbonates and mudstones. The assemblages are identified as ten species belonging to seven genera as follows: *Bathymodiolus* sp., *Adipicola* sp., *Calyptogena* spp., *Acharax* spp., *Acila* sp., *Nuculana* sp., and *Yoldia* sp. These fossil bivalves may be considered to be new species pending on further studies. It will be necessary in the future to classify them based on detailed hinge structures of well-preserved specimens.

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Plate 1

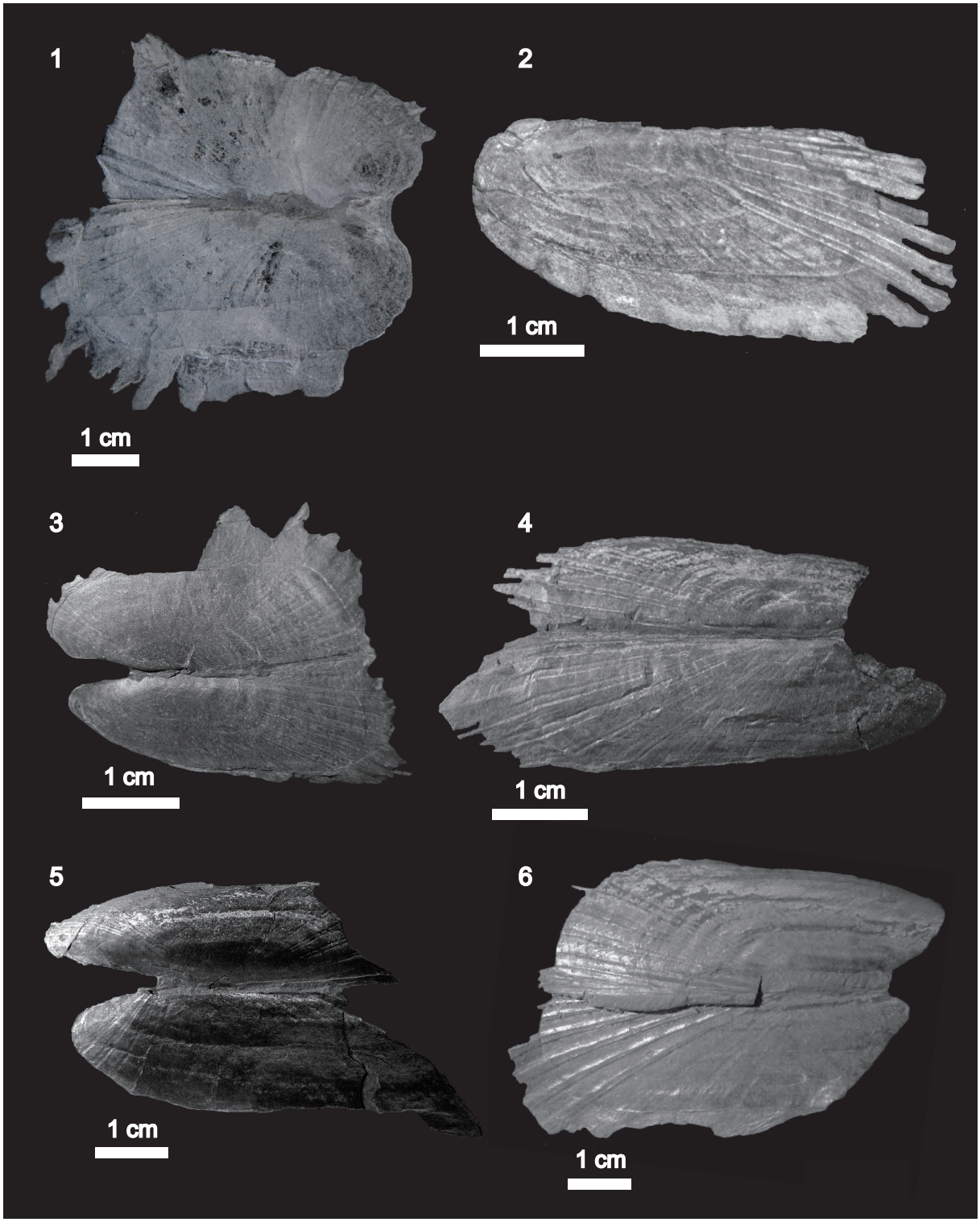

Plate 1. **1-6**. ***Acharax* spp**. from Nita (fig. 1: *Acharax* sp. A [Sample ID: Aok-001]; fig. 2: *Acharax* sp. B [Aok-002]; fig. 3: Left valve of *Acharax* sp. B [GK-L12000]; fig. 4: *Acharax* sp. B [Aok-003]; figs. 5, 6: *Acharax* sp. B [GK-L12001], fig. 5: Anterior side; fig. 6: Posterior side).

Plate 2

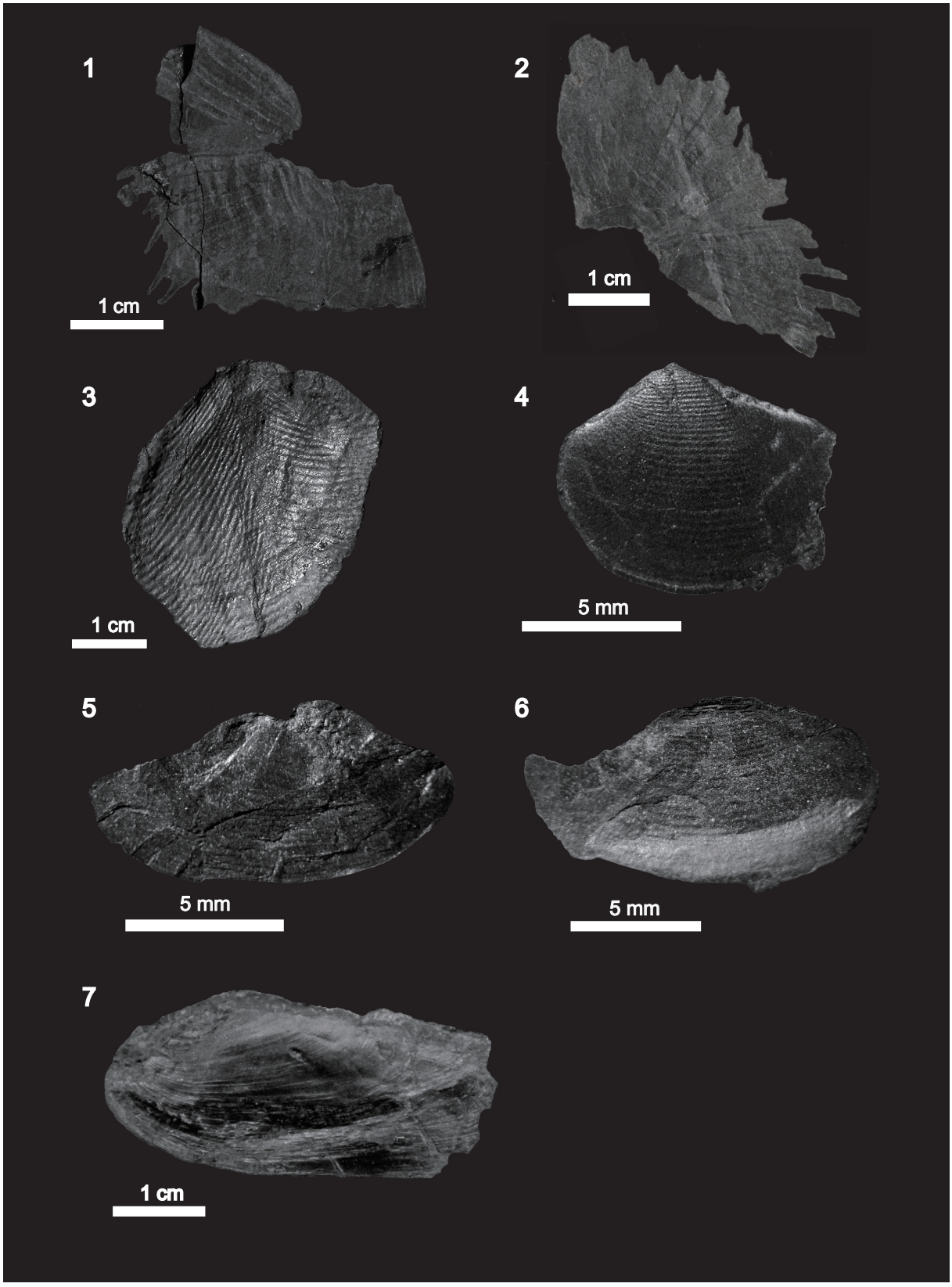

Plate 2. **1, 2. *Acharax* sp. C** from Kanoura (fig. 1: *Acharax* sp. C [GK-L12002]; fig. 2: *Acharax* sp. C [GK-L12003]), **3. *Acila* sp.** from Fukusaki [GK-L12004], **4-7. Nuculanidiae,** Unidentified species from Nita (fig. 4: Left valve of *Nuculana* sp. [Aok-003]; fig. 5: Right valve of *Yoldia* sp. [Aok-004]; fig. 6: Right valve of *Yoldia* sp. [Aok-005]; fig. 7: Unidentified species [GK-L12005]).

Plate 3

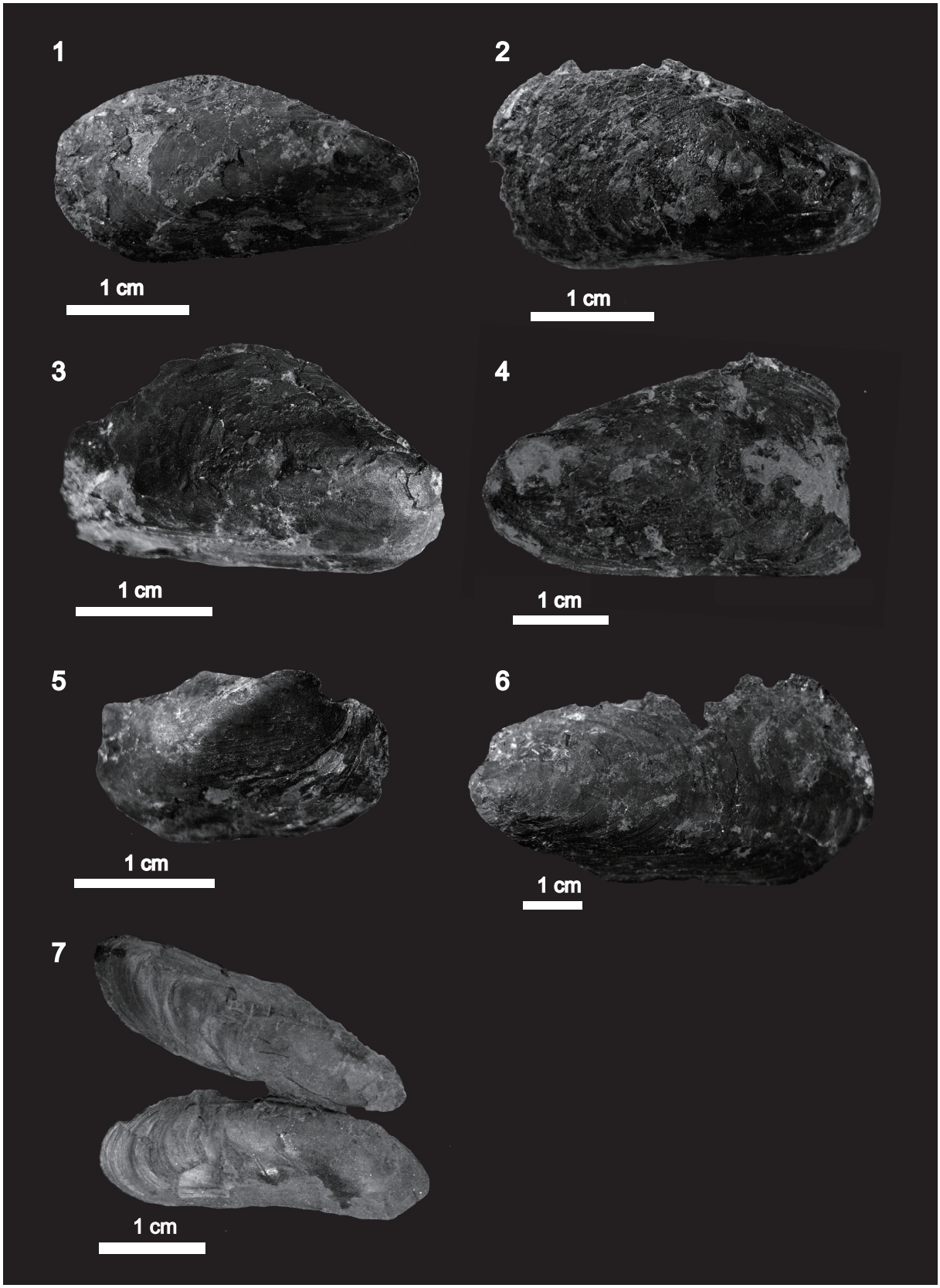

Plate 3. **1-6. *Bathymodiolus* sp.** from Fukusaki Limestone (fig. 1: Right valve [GK-L12006]; fig. 2: Right valve [GK-L12007]; fig. 3: Right valve [GK-L12008]; fig. 4: Left valve [GK-L12009]; fig. 5: Right valve [GK-L12010]; fig. 6: Left valve [GK-L12011]]]), **7. *Adipicola* sp.** [GK-L12012].

Plate 4

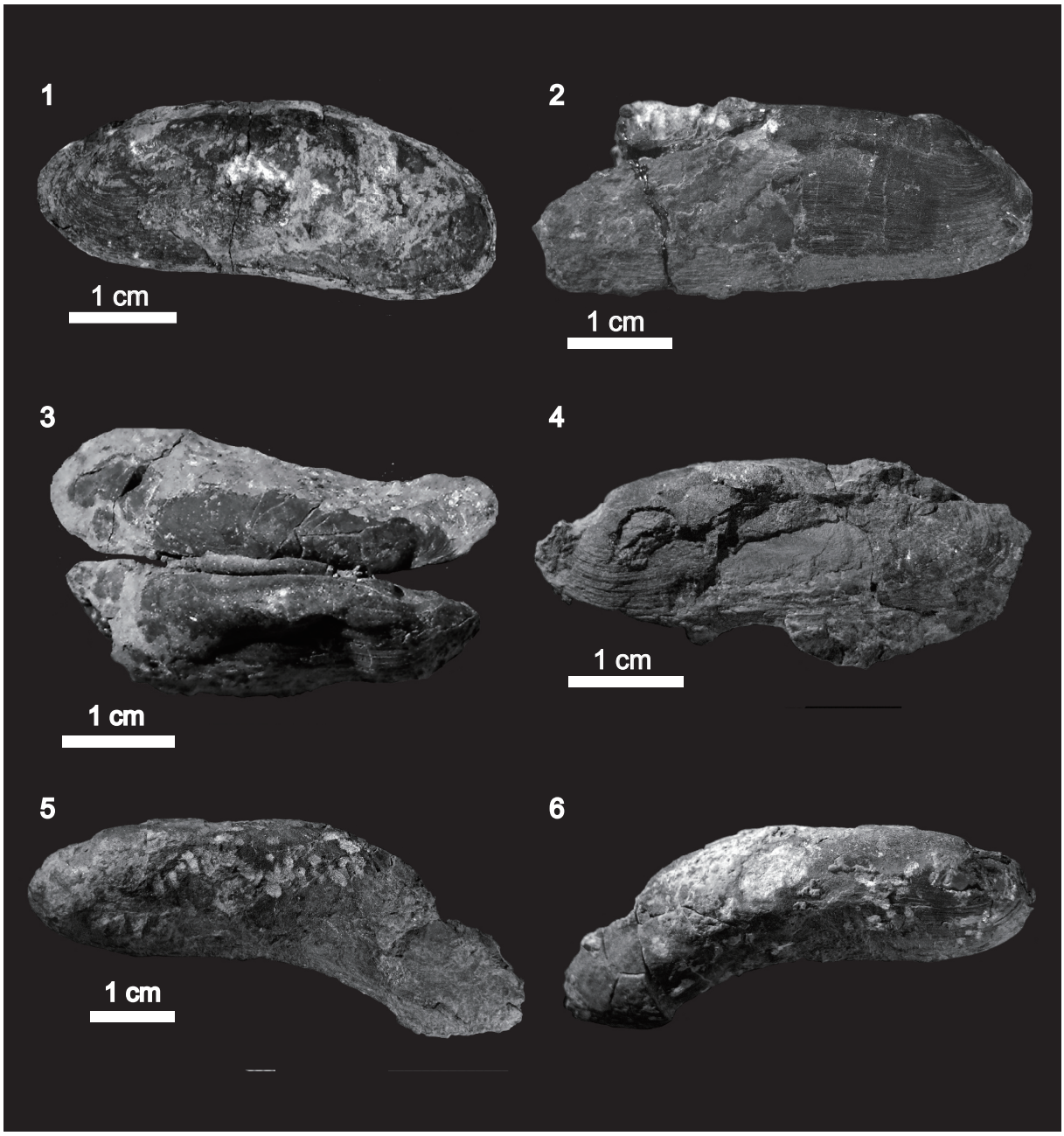

Plate 4. ***Calyptogena*** **spp.** from Kanoura Limestone. **1-4.** ***Calyptogena*** **sp. A** (fig. 1: Left valve [GK-L12013]; fig. 2: Right valve [Aok-007]; fig. 3: Dorsal side (Aok-008). fig. 4: Left valve (GK-L12014)), **5, 6.** ***Calyptogena*** **sp. B** [Aok-009] (fig. 5: Right valve; fig. 6. Left valve).

Plate 5

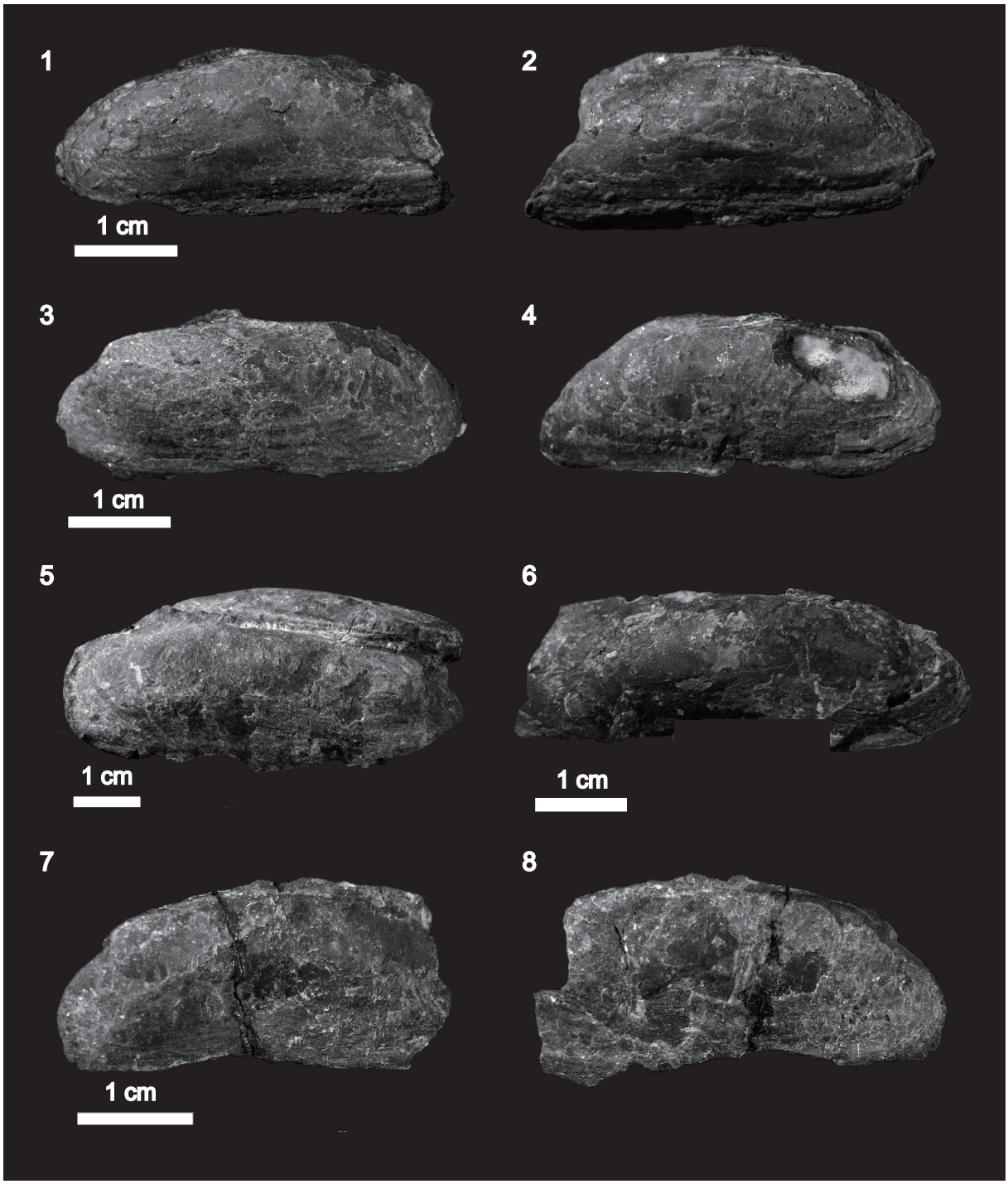

Plate 5. ***Calyptogena*** **spp.** from Tanohama Limestone. **1-6.** ***Calyptogena*** **sp. A. 1, 2.** ***Calyptogena*** **sp. A** ([GK-L12015]: fig. 1: Right valve; fig. 2: Left valve), **3, 4.** ***Calyptogena*** **sp. A** ([GK-L12016]: fig. 3: Right valve; fig. 4: Left valve), **5.** ***Calyptogena*** **sp. A** [GK-L12017]. **6.** ***Calyptogena*** **sp. A** [GK-L12018], **7, 8.** ***Calyptogena*** **sp. B** ([GK-L12019]: fig. 7: Right valve; fig. 8: Left valve).

Plate 6

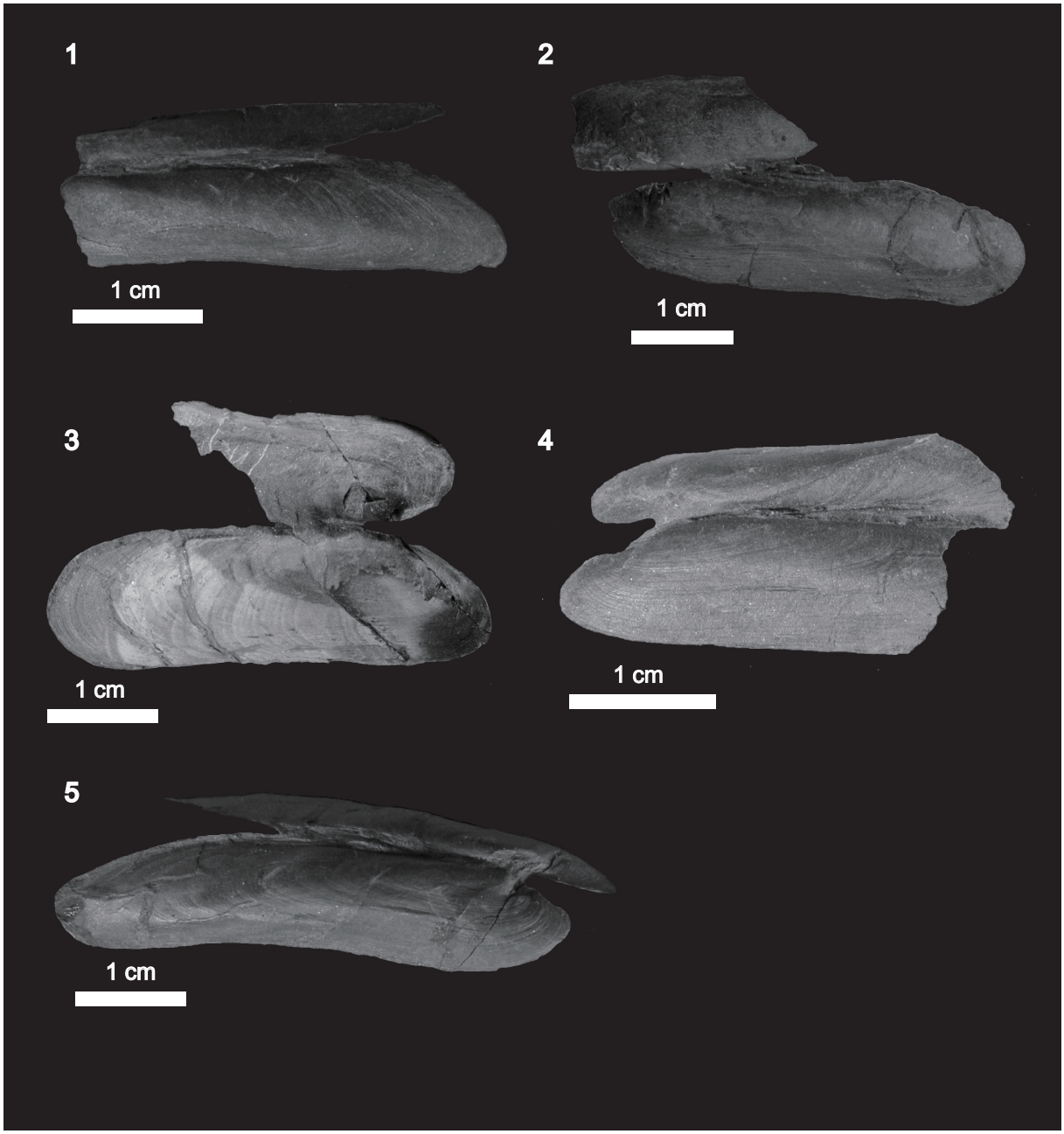

Plate 6. ***Calyptogena*** **spp.** from mudstone around Kanoura Limestone. **1-4.** ***Calyptogena*** **sp. A** (fig. 1: Right valve [GK-L12020]; fig. 2: Right valve [GK-L12021]; fig. 3: Left valve Right valve [GK-L12022]; fig. 4: Left valve [GK-L12023]), fig. 5. Left valve of ***Calyptogena*** **sp. B** [GK-L12024].