

# Taxonomy and distribution of Plio-Pleistocene *Buccinum* (Gastropoda: Buccinidae) in northeast Japan

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Received 11 April 2001; Revised manuscript accepted 29 June 2001

**Abstract.** Twelve species of *Buccinum* are recorded from the Plio-Pleistocene of northeast Japan. Two new species, *Buccinum shibatense* and *B. saitoi*, are proposed, and a total of six distributional types (Types A–F<sub>J</sub>) are recognized among the 12 species. Three extinct species comprise the type F<sub>J</sub>, which is endemic to the Japan Sea borderland. Type A is for species that are extinct in the Japan Sea, but are still living in the Sea of Okhotsk and Bering Sea. Type B species are known as fossils only along the Japan Sea margin, and now live in the northern Japan Sea as well as in the Northwest Pacific and the Sea of Okhotsk. Type C species have been recorded as fossils from the Pacific and the Japan Sea coasts and still live in both coasts. Type D species live only on the Pacific side, and are recorded as fossils only from there. Type E species occur as fossil and living specimens only in the Japan Sea. Species in both types A and F<sub>J</sub> species underwent extinction owing to anoxic conditions during Pleistocene glacial episodes along the Japan Sea borderland. The type E species survived in the lower sublittoral to upper bathyal waters of the Japan Sea which had normal salinity and were oxic.

**Key words:** *Buccinum*, distribution, Pliocene, Pleistocene, taxonomy

## Introduction

*Buccinum* is a common group of gastropods which lives in cold and rather deep water around the North Pacific Ocean. Some species of *Buccinum* invaded the Arctic and North Atlantic Oceans after the opening of the Bering Strait in the late Miocene or Pliocene at 4.8–5.5 Ma (Marincovich and Gladenkov, 1999) in the same manner as did the gastropod *Neptunea* (Durham and MacNeil, 1967; Vermeij, 1991).

The modern species of *Buccinum* have been taxonomically summarized by Golikov (1980) and Tiba and Kosuge (1984). Golikov (1980) described 86 species and 6 subspecies from the world ocean while Tiba and Kosuge (1984) recorded 107 species and 9 subspecies from just the North Pacific. In another study, 68 species and 13 subspecies have been reported in and around Japan (Higo *et al.*, 1999). These differences in number of species and subspecies result mainly from the wide range of morphological variation that obscures the limits of species and subspecies in this genus. Mitochondrial DNA sequences show that the genus can be subdivided into five clades (probably equivalent to subgenera) that are nearly concordant with the characteristics of shell morphology: the *B. felis*, *B. inclytum*, *B. anivanum*, *B. middendorffi* and *B. tsubai* groups (Endo and

Ozawa, 2001).

Recently, Amano *et al.* (1996) and Amano (1997) summarized the taxonomy and distribution of Plio-Pleistocene buccinids, Ancistrolepidinae and *Neptunea*, from the Japan Sea borderland. These studies demonstrated for both Ancistrolepidinae and *Neptunea* that many species which no longer live in the Japan Sea continue to dwell in the Sea of Okhotsk and Bering Sea. These authors noted that such species suffered extinction in the Japan Sea owing to paleoenvironmental changes during the Quaternary ice ages. In order to gain further insights into this phenomenon, it is necessary to examine the distributional pattern of additional taxa. *Buccinum* is well suited to this purpose, because of its ecological similarity to Ancistrolepidinae and *Neptunea*.

Before discussing the distributional pattern of *Buccinum*, it is necessary to clarify the relationships between the species. However, since most species generally have a thin and fragile shell, it is difficult to obtain well preserved specimens. This unsettled classification of the modern species and the poor preservation of fossils preclude a taxonomic summary of this genus in northeastern Japan. In this paper, we will reexamine some well preserved Plio-Pleistocene specimens of *Buccinum* and will add two new species to the genus.

Based on our taxonomical reexamination, we also will discuss the distributional pattern of the genus.

**Materials**

Fossils identified as *Buccinum* were recently collected from the following ten localities (Figure 1).

Loc. 1. Large cliff 2.2 km upstream from the mouth of Sakashi-no-sawa, Teshio Town, Hokkaido; gray siltstone; late Pliocene Yuchi Formation.

Loc. 2. Outcrop along Shichirinagahama beach about 1.5 km north to Kawajiri, Ajigasawa Town, Aomori Prefecture; greenish gray sandy siltstone; late Pliocene Nurusawa Formation.



Figure 1. Collecting localities of *Buccinum* (using the topographical maps of "Onoppunai," "Matsunoyama-Onsen," "Iiyama," scale 1:50,000; "Morita," "Echigo-Shimoseki," "Sugatani," "Ojiya" and "Kanazawa," scale 1:25,000 published by Geographical Survey Institute of Japan).

Loc. 3. Riverside cliff along a side creek of the Onnagawa River, about 600 m south of Housaka Bridge, Sekikawa Village, Niigata Prefecture (Loc. 4 of Amano *et al.*, 1996); siltstone; late Pliocene Kuwae Formation.

Loc. 4. Small outcrop on the Koide River about 1.1 km upstream of its mouth, Shibata City, Niigata Prefecture (Fossil locality of Amano, 1998); muddy fine-grained sandstone; late Pliocene Kuwae Formation.

Loc. 5. River bank along the Shinano River, 250 m north-east of Unoki, Ojiya City, Niigata Prefecture (Loc. 7 of Amano, 1997); conglomerate; early Pliocene Kawaguchi Formation

Loc. 6. Riverside cliff of the Sabaishi River about 300 m east to Azamihira, Matsudai Town, Niigata Prefecture; pebble-bearing sandstone; late Pliocene Higashigawa Formation.

Loc. 7. Outcrop at Taihei, Matsudai Town, Niigata Prefecture; black mudstone; early Pliocene Kurokura Formation (upper part).

Loc. 8. Riverside cliff of the Shibumi River 400 m east of Taihei, Matsudai Town, Niigata Prefecture; black mudstone; early Pliocene Kurokura Formation (upper part).

Loc. 9. Outcrop at Kutta, Iiyama City, Nagano Prefecture; siltstone; early Pliocene Nagasawa Formation.

Loc. 10. River bank of the Saikawa River, 1.1 km upstream from the Okuwa Bridge, Kanazawa City, Ishikawa Prefecture (Loc. 12 of Amano *et al.*, 1996); fine-grained sandstone; early Pleistocene Omma Formation

We examined all specimens stored at the Joetsu University of Education (JUE), including the above-cited specimens as well as those obtained in the following studies: Amano and Kanno (1991), Nakata and Amano (1991), Amano and Karasawa (1993), Amano (1994) and Amano and Sato (1995). In addition, specimens including types were reexamined at the following institutions and museums: Tohoku University (IGPS), Saito Ho-on Kai Museum of Natural History (SHM), University of Tsukuba (IGUT), National Science Museum (NSM), and Kyoto University (JC). Moreover, private collections of Mr. Masayuki Shimizu (Tateyama Mus.) were also examined.

In addition to our collections and those mentioned above, geographical distributions were compiled from a critical survey of the literature (Iwai, 1965; Noda and Masuda, 1968; Baba, 1990).

### Systematic description of new species

Family Buccinidae Rafinesque, 1815

Genus *Buccinum* Linnaeus, 1758

*Buccinum shibatense* sp. nov.

Figure 2. 3, 2. 6

*Type specimen*.—Holotype, JUE no. 15699, 39.7 mm high, 23.3 mm wide; Paratype, JUE no. 15700, 25.6 mm high, 24.6 mm wide.

*Type locality*.—Loc. 4.

*Diagnosis*.—Small species of *Buccinum* characterized by numerous spiral cords (36 to 40 on body whorl), two fine columellar plaits at base of inner lip, and thick outer lip weakly crenulated on inner side.

*Description*.—Shell rather small for genus, conico-ovoidal shape; protoconch one and a half smooth whorls; teleoconch of seven whorls. Height of body whorl occupying about five-eighths of shell height. Suture shallow and slightly undulating on body whorl. Axial sculpture of many fine growth lines; spiral cords low, separated by shallow grooves, 16 (holotype) and 20 (paratype) on penultimate whorl, 36 (holotype) to 40 (paratype) on body whorl. Spiral cords on body whorl with one shallow groove. Aperture ovate; inner lip covered by thin calcareous callus, two fine and distinct columellar plaits at its base; outer lip thick, with 19 weak striae along inner side, excavated behind. Siphonal canal shallow and slightly twisted; posterior sinus narrow and short.

*Remarks*.—At a glance, this species resembles *Pseudoliomesus ooides* (Middendorff, 1849) in its shell outline and slightly twisted basal part of the inner lip. It differs from *P. ooides* by lacking a deep suture or a subsutural area.

*Comparison*.—The present species is closely allied to *Buccinum habui* Tiba, 1984, now living at 400–500 m depth off southern Hokkaido (Higo *et al.*, 1999). *B. habui* is also characterized by numerous spiral cords (26 on penultimate; 44 on body whorl), one or two fine columellar plaits at the base of the inner lip, and weak crenulations in the inner side of the thick outer lip. However, *B. shibatense* can be easily distinguished from *B. habui* by its larger shell size, less slender shell outline, existence of a posterior sinus, and slightly twisted siphonal canal.

### *Buccinum saitoi* sp. nov.

Figure 2. 8, 2. 9

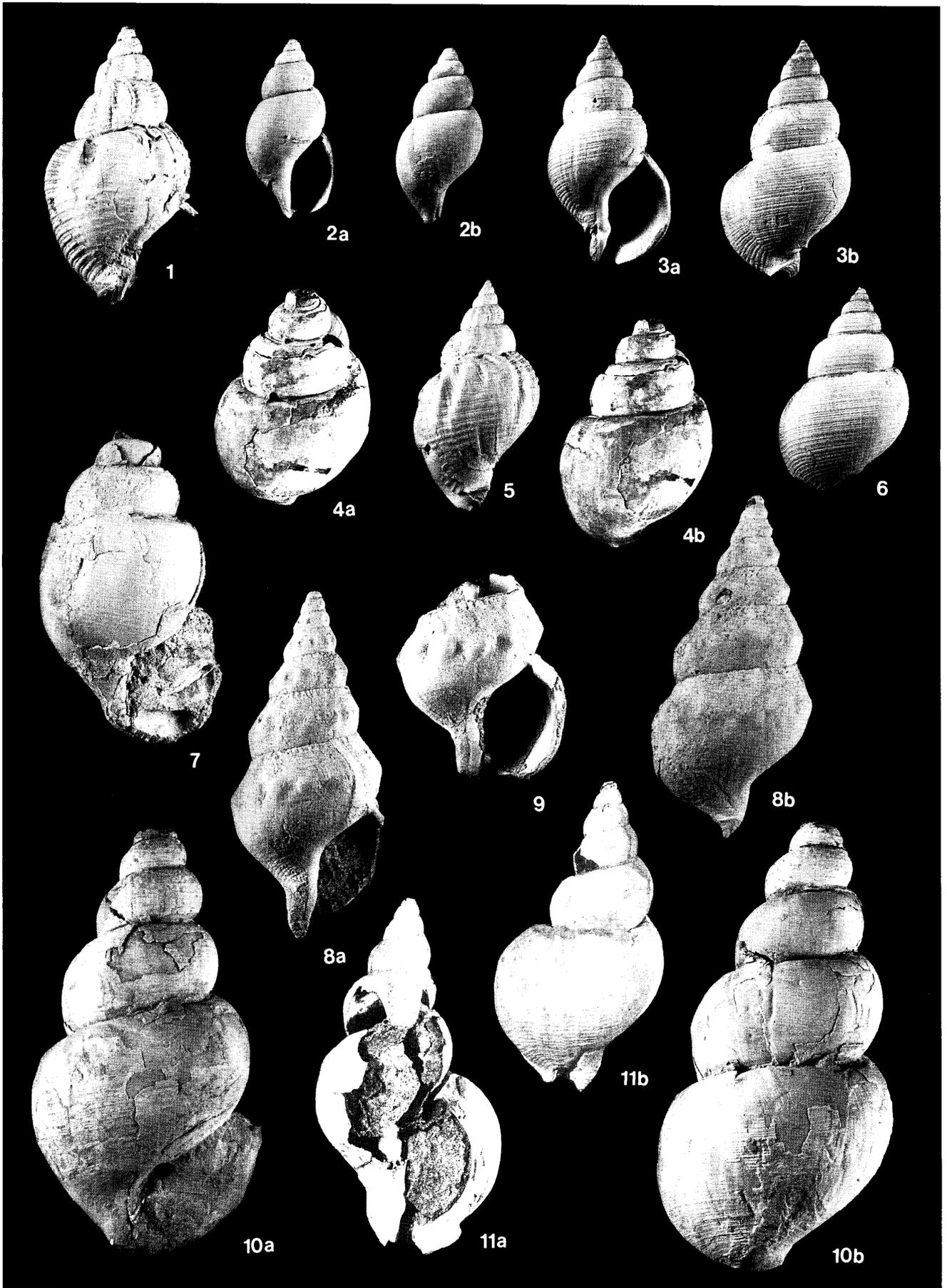
*Type specimen*.—Holotype, JUE no. 15701, 58.8+ mm high, 29.1 mm wide; Paratype, JUE no. 15702, 31.8 mm wide.

*Type locality*.—Loc. 4.

*Diagnosis*.—Medium-size *Buccinum* characterized by thick and high spire, numerous and fine subsutural granulations, distinct nodes on shoulder (13 on body whorl).

*Description*.—Shell size medium for genus, slender and thick; protoconch poorly preserved and of more than one whorl; teleoconch of six whorls. Spire rather high, occupying about half of shell height. Suture shallow and slightly undulating on body whorl, with many fine subsutural granulations. Above shoulder, 13 oblique low axial ribs; 13 distinct nodes at shouldered edge; spiral cords low, fine, separated by narrow grooves, 13 on penultimate and 15 on body whorl. Below shoulder including base, surface sculpture consisting only of spiral cords; 8 on penultimate and 25 on body whorl. Aperture ovate; inner lip covered by thin calcareous callus, nearly straight at its base; outer lip thick, smooth on inner side, excavated behind. Siphonal canal shallow; posterior sinus narrow and very short.

*Comparison*.—The present new species is closely allied to *Buccinum verrucosum* Tiba, 1980 now living in the Sea of Okhotsk. *B. verrucosum* shares the following characteristics with the present new species: similar shell outline, thick shell, many fine subsutural plications, axial ribs above the shoulder and some granulations on the shoulder. However, *B. verrucosum* differs from *B. saitoi* by having three strong



spiral cords and two obscure columellar plaits.

*Buccinum opisoplectum* Dall, 1907 can be easily distinguished from *B. saitoi* in having a smaller shell, lacking granulation on the shoulder and having three strong spiral cords.

*Etymology.*—This species is named after Mr. Atsushi Saito of Niigata Higashi High School, who collected the type specimens.

#### Revision of some fossil species

*Buccinum sinanoense* was originally established by Makiyama (1927) based on the specimen (Figure 3. 4) from the early Pliocene Joshita Formation in Nagano Prefecture. Nomura (1937) illustrated a specimen as *B. sinanoense* Kuroda (?) [sic] from the Pliocene Kannonji Formation in Yamagata Prefecture. Based on an examination of his specimen, it is not referable to *B. sinanoense* because of its low and large body whorl. However, the poor preservation of its shell surface prevents us from definitely assigning this specimen to a species.

*Buccinum aomoriensis* Hatai, Masuda and Suzuki, 1961 is represented by a single specimen (Figure 3. 9) from the early Pleistocene Hamada Formation in Aomori Prefecture. This species is characterized by a large shell (shell height = 95.0 mm), many fine subsutural plications, 17 axial folds on the penultimate whorl, two strong spiral cords with two to seven intercalating cords on each whorl, and an inner lip with two columellar plaits. When they established this species, Hatai *et al.* (1961) did not compare their species with the closely related species, *B. inclytum* Pilsbry, 1904. The two species cannot be consistently distinguished, so we consider *B. aomoriensis* to be a junior synonym of *B. inclytum*.

Akamatsu and Suzuki (1992) illustrated a fragmentary specimen from the early Pleistocene Shimonopporo Formation as *Buccinum opisthoplectum* Dall [sic]. However, judging from their figure, this specimen is referable to *B. inclytum* because of its large shell (more than 50 mm without body whorl) and three rather strong spiral cords.

Hatai and Nisiyama (1952) proposed the new species *Buccinum wakimotoense* based on a specimen from the middle Pleistocene Shibikawa Formation in Akita Prefecture, which Kanehara (1942) referred to as "*B. schantaricum* Middendorff." However, they did not give a description or definition at that time. Judging from Kanehara's (1942) figure and a specimen from the Shibikawa Formation (Figure 2. 5), there is no difference between *B. wakimotoense* and the modern *B. middendorffi* Verkrüzen, 1882 as pointed out by Masuda and Noda (1976). Therefore, *B. wakimotoense* is a junior synonym of *B. middendorffi*.

*Buccinum rhodium* Dall, 1919 lives in the Sea of Okhotsk

and Bering Sea (Tiba and Kosuge, 1984). It has 22 strong sigmoid axial ribs. The specimen figured by Fujii and Shimizu (1988; Figure 3. 7) as *Plicifuscus* [this should be "*Plicifuscus*"] cf. *plicatus* [sic] from the Pliocene Mita Formation in Toyama Prefecture has a rather large body whorl, 18 sigmoid axial ribs and 40 spiral cords. Judging from the outline and shell sculpture, their specimen is referable to *B. rhodium*. The spiral cords of modern specimens are generally weaker than on fossils.

Nomura (1937) recorded one specimen as *Ancistrolepis fragilis* Dall var. (Figure 3. 5) from the Pliocene Kannonji Formation in Yamagata Prefecture. However, it lacks a deeply channeled suture which is characteristic of Ancistrolepidinae. This specimen should be referred to *Buccinum unuscarinatum* Tiba, 1981, which lives in the Sea of Okhotsk, because of the one keel at its shoulder and many fine weak spiral cords.

*Buccinum* cf. *striatissimum* Sowerby was described by Ozaki (1958) from the Plio-Pleistocene Iioka Formation in Chiba Prefecture. His specimen has a constricted body whorl, a large protoconch, and a deeply channeled subsutural area, all of which are characters of Ancistrolepidinae. Therefore, the Iioka specimen is not a *Buccinum*.

*Buccinum suruganum kasimensis* was established by Ozaki (1958) as a new subspecies, based on one imperfect specimen (NSM P1 4402) from the Pliocene Naarai Formation. Based on our reexamination of this specimen, it is clear that the number of spiral cords (four cords on the penultimate whorl) and the condition of interspaces of the ribs are included in the variation of *B. leucostoma* Lischke, 1872.

When he established *Buccinum yoroianum* as a new species, Ozaki (1958) designated a small specimen (Figure 2. 2) as the paratype. However, this paratype specimen differs from the holotype in having very weak spiral cords and well inflated whorls. Based on the shell outline, size and sculpture of the paratype specimen, it is assigned to *B. bulimiloideum* Dall, 1907.

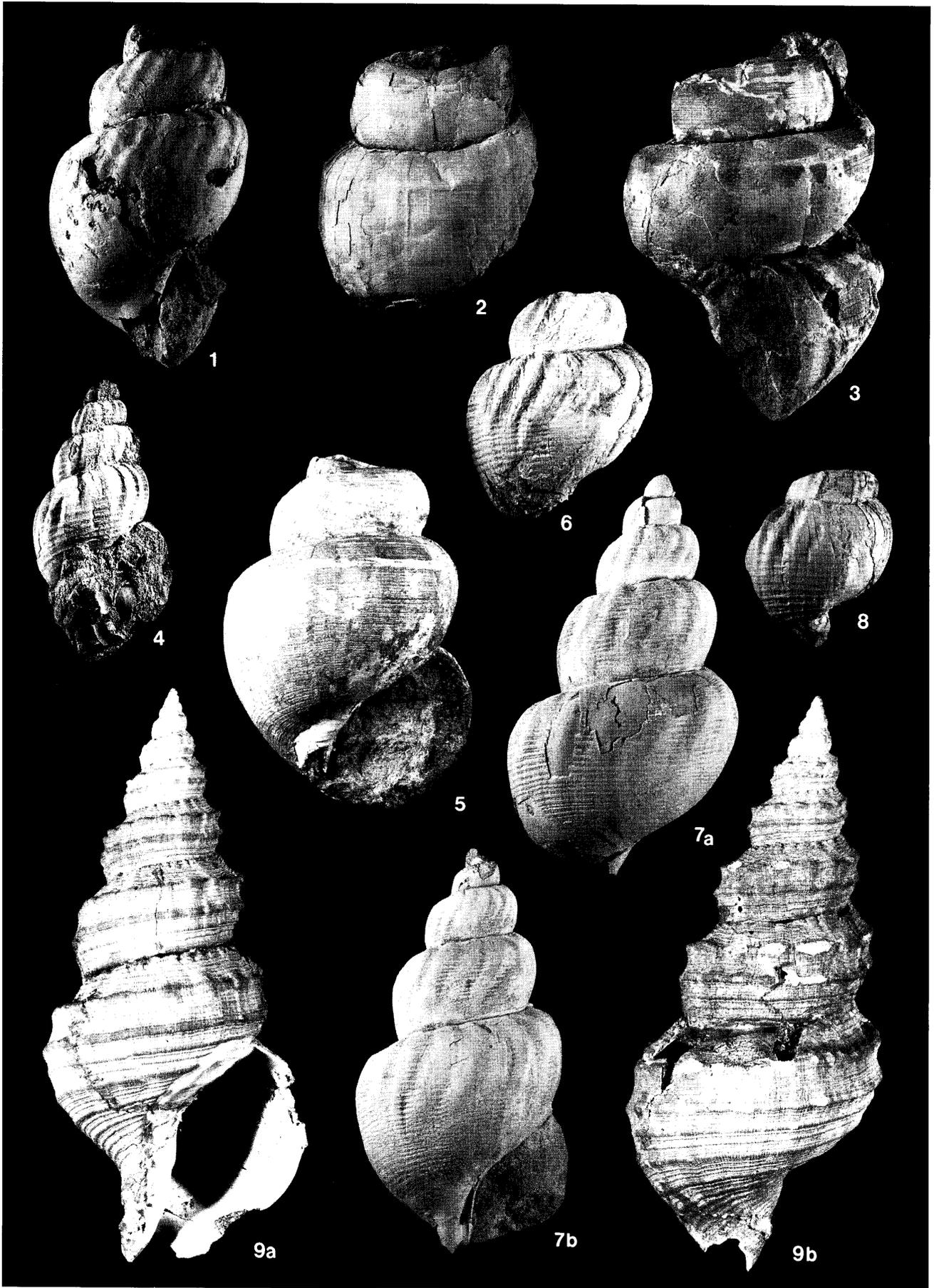
#### Distributional patterns

The twelve Plio-Pleistocene species of *Buccinum* and their geological distributions in northeastern Japan are shown in Table 1. There are six types of distribution (Types A-F; Figures 4, 5).

Type A (*B. rhodium* and *B. unuscarinatum*) is for species that are extinct in the Japan Sea, but are still living at lower sublittoral to upper bathyal depths in the Sea of Okhotsk and Bering Sea. Some Ancistrolepidinae and *Neptunea* show a similar distribution (Amano *et al.*, 1996; Amano, 1997).

*Buccinum middendorffi* and *B. inclytum* belong to Type B. Fossils of these species are known only from the Japan Sea

← **Figure 2.** 1, 5. *Buccinum middendorffi* Verkrüzen. 1, x1, JUE no. 15706, Loc. 1, Yuchi Formation. 5, x1, JUE no. 15707, Loc. Anden, Akita Pref., Shibikawa Formation. 2a, b. *Buccinum bulimiloideum* Dall, x1.5, NSM no. 4464, "Paratype" of *B. yoroianum* Ozaki, Iioka Formation. 3a, b, 6. *Buccinum shibatense* sp. nov. 3a, b, x1, JUE no. 15699, Holotype; 6, x1, JUE no. 15700, Paratype; Loc. 4, Kuwae Formation. 4a, b, 7. *Buccinum tsubai* Kuroda. 4a, b, IGUT no. 15602, Loc. Kitaubushi, Hokkaido, Yuchi Formation. 7, x1, JUE no. 15708, Loc. 6, Higashigawa Formation. 8a, b, 9. *Buccinum saitoi* sp. nov. 8a, b, x1, JUE no. 15701, Holotype; 9, x1, JUE no. 15702, Paratype; Loc. 4, Kuwae Formation. 10a, b. *Buccinum striatissimum* Sowerby, x0.8, JUE no. 15709, Loc. 8, Kurokura Formation. 11a, b. *Buccinum ochotense* (Middendorff), x0.9, IGPS no. 90462, Loc. 6 of Hatai *et al.* (1961), Hamada Formation.



**Table 1.** Distribution of the Plio-Pleistocene *Buccinum*. \* living depth after Higo *et al.* (1999).

Species	Age and formation	Depth range*
Type A		
<i>Buccinum rhodium</i> Dall	Pliocene Nakawatari F., Nagasawa F., Mita F.	100–300m
<i>B. unuscarinatum</i> Tiba	Pliocene Kannonji F., Kuwae F., Kurokura F. Nagasawa F., Nadachi F.	—
Type B		
<i>B. middendorffi</i> Verkrüzen	Pliocene Yuchi F.; Early Pleistocene Omma F.; Middle Pleistocene Shibikawa F.	0–10m
<i>B. inclytum</i> Pilsbry	Early Pleistocene Shimonopporo F., Hamada F.	0–50m
Type C		
<i>B. ochotense</i> (Middendorff)	Pliocene Gobanshoyama F.; Early Pleistocene Shimonopporo F., Hamada F., Daishaka F.	0–50m
Type D		
<i>B. leucostoma</i> Lischke	Pliocene to early Pleistocene Kazusa G.	50–600m
<i>B. bulimiloideum</i> Dall	Early Pleistocene Iioka Formation	300–900m 0–50m
Type E		
<i>B. striatissimum</i> Sowerby	Pliocene Narusawa F., Kurokura F., Nagasawa F., Nadachi F.	200–500m
<i>B. tsubai</i> Kuroda	Pliocene Yuchi F., Kawaguchi F., Higashigawa F., Mita F.	100–700m
Type F <sub>J</sub>		
<i>B. sinanoense</i> Makiyama	Pliocene Joshita F., Ogikubo F.	—
<i>B. shibatense</i> sp. nov.	Pliocene Kuwae F.	—
<i>B. saitoi</i> sp. nov.	Pliocene Kuwae F.	—

borderland. Type B species now live in the upper sublittoral zone of the northern Japan Sea as well as the Northwest Pacific and the Sea of Okhotsk.

Type C includes only one species, *B. ochotense*. This type of species is the same as the C type of *Neptunea* which has been recorded as fossils from the Pacific and the Japan Sea coasts and also lives in the upper sublittoral zone of both coasts.

Two species (type D) live only from the lower sublittoral to the upper bathyal zone on the Pacific side, and their fossils are also recorded only from the Pacific side. These are *B. leucostoma* and *B. bulimiloideum*. Such a distribution has also been observed in the buccinids *Clinopegma unicum*, *Neptunea kuroshio*, *N. fukuae* and *N. kanagawaensis* (Amano *et al.*, 1996; Baba, 1990; Kato, 1993).

Type E species (*B. striatissimum* and *B. tsubai*) are known as fossil and living specimens only from the Japan Sea. No species of *Neptunea* or Ancistrolepidinae shows this type of distribution.

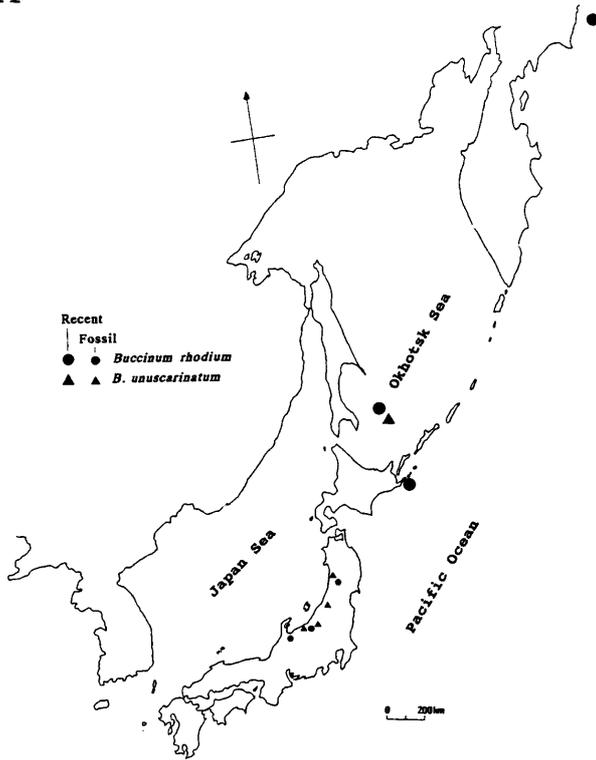
Three extinct species (*B. sinanoense*, *B. shibatense* and *B. saitoi*) comprise type F<sub>J</sub>, endemic to the Japan Sea borderland. It is noteworthy that no extinct species of *Buccinum* is confined to the Plio-Pleistocene of the Pacific Ocean side. This type of distribution does not occur in Ancistrolepidinae (Amano *et al.*, 1996) and *Neptunea* (E type; Amano, 1997).

#### Discussion of distribution

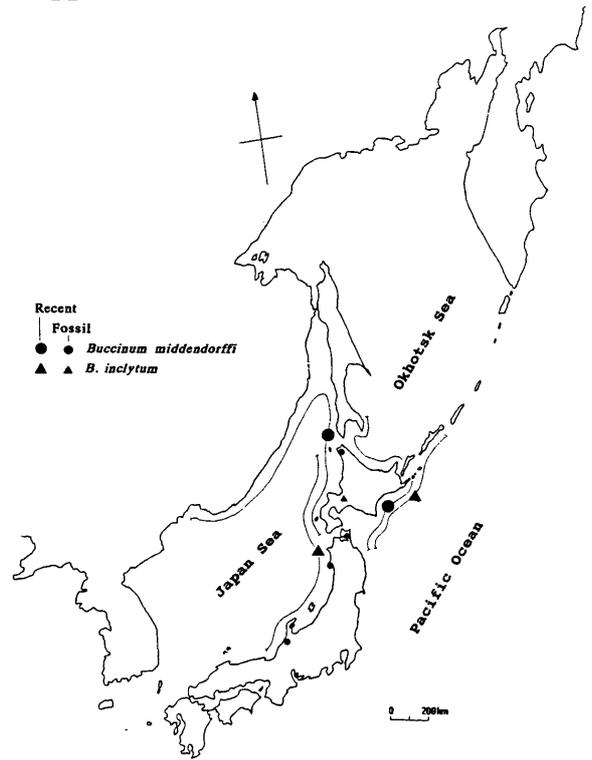
Species of types A and F<sub>J</sub> underwent extinction during the Pleistocene in the Japan Sea borderland. Tada (1994) noted that bottom sediments alternated between oxic and anoxic conditions with the glacio-eustatic sea level changes many times after the late Pliocene. He also pointed out that remarkable sea level oscillations are recognized during the last 0.8 m.y. During the low glacial sea level stands, freshwater input reduced salinity and created euxinic conditions in the enclosed Japan Sea. The type A species occurred

← **Figure 3.** 1, 6, 7a, b. *Buccinum rhodium* Dall. 1, ×1, JUE no. 15360, Loc. N5 of Nakata and Amano (1991); 6, ×1, JUE no. 15703, Loc. 9; Nagasawa Formation. 7a, b, ×1, Loc. Rengeji, Toyama Pref., illustrated by Fujii and Shimizu (1988) as *Plicifuscus cf. plicatus*, Mita Formation. 2, 3, 5. *Buccinum unuscarinatum* Tiba. 2, ×1, JUE no. 15704, Loc. 7, Kurokura Formation. 3, ×0.8, JUE no. 15613, Loc. 32 of Amano and Kanno (1991), Nadachi Formation. 5, ×1, SHM no. 8407, Loc. Futago, Yamagata Prefecture, illustrated by Nomura (1937) as *Ancistrolepis fragilis* var., Kannonji Formation. 4. *Buccinum sinanoense* Makiyama, ×1, JC no. 610024, Holotype, Joshita Formation. 8. *Buccinum middendorffi* Verkrüzen, ×1, JUE no. 15705, Loc. 10, Omma Formation. 9 a, b. *Buccinum inclytum* Pilsbry, IGPS no. 90509, Hamada Formation, "Holotype" of *B. aomoriensis* Hatai, Masuda and Suzuki.

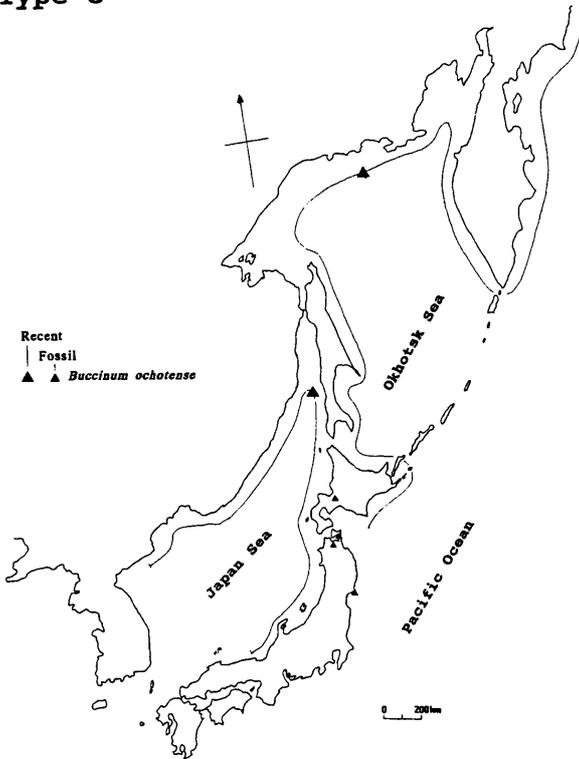
**Type A**



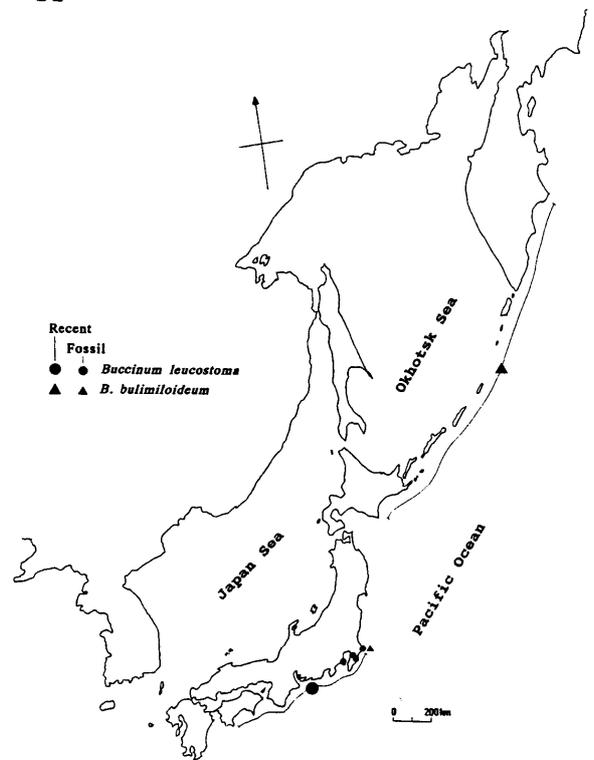
**Type B**



**Type C**



**Type D**



**Figure 4.** Distributional pattern (types A-D) of *Buccinum*.

from the lower to upper Pliocene while the type Fj species ranged from the lower to middle Pliocene. Thus, it is reasonable to infer that type A species became extinct in the Japan Sea whereas the Sea of Okhotsk and Bering Sea populations survived. The narrowly distributed endemic Fj type species became extinct after the late Pliocene.

Two explanations are available to explain the distribution pattern of the types B and C. First, the species of these types survived the deteriorated environment in the Japan Sea during the Quaternary ice ages. Second, the populations of species in types B and C became extinct in the Japan Sea, but survived on the Pacific side. Species of both types live in upper sublittoral depths while those of other types dwell in lower sublittoral to upper bathyal waters. Based on the presence of type A and Fj species and the low-salinity surface water of the glacial age, it is reasonable to accept the second hypothesis. Thus, the modern populations of types B and C species in the Japan Sea may represent recent invasions through its shallow northern entrance.

The fossil records of the type D species are concentrated in the Pacific side of central Japan (Kanto Region). These species are also deep-water dwellers and survived the glacial episodes only in the Pacific Ocean.

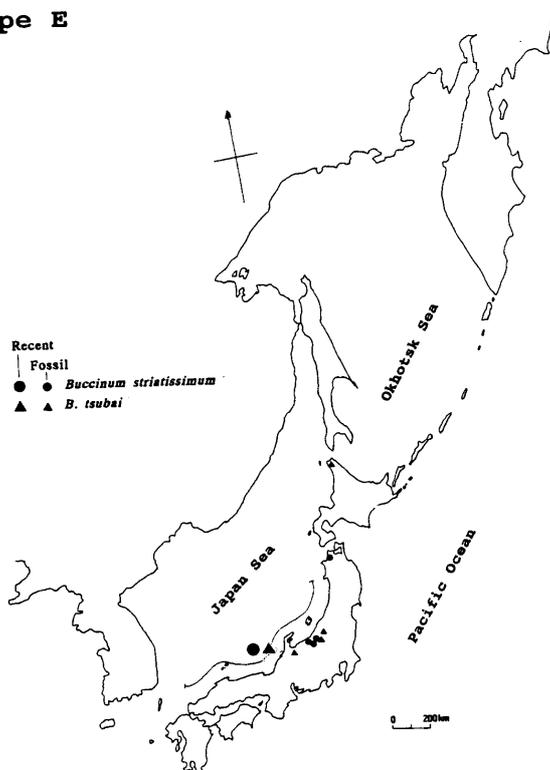
Type E species that survive as endemics in the Japan Sea live in intermediate waters. As already noted by Amano (1996), *Portlandia toyamaensis* (Kuroda, 1929) also shows this type of distribution. The same pattern occurs in the buccinids *Mohnia yanamii* (Yokoyama, 1926) and *Lusivoluptosius furukawai* (Oyama, 1951). *Mohnia yanamii* is a

**Table 2.** Bathymetric distribution of the Japan Sea endemic species with fossil records. \* living depth after Higo *et al.* (1999).

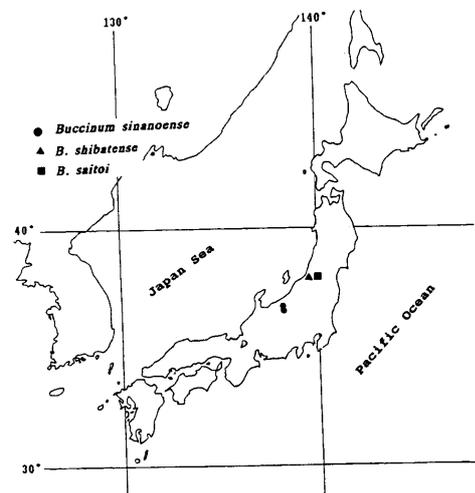
Species	Depth (m)*
<i>Alvania sitta</i> (Yokoyama)	200-204
<i>Lusivoluptosius furukawai</i> (Oyama)	200-350
<i>Mohnia yanamii</i> (Yokoyama)	50-400
<i>Buccinum striatissimum</i> Sowerby	200-500
<i>B. tsubai</i> Kuroda	100-700
<i>Curtitoma exquisita</i> (Yokoyama)	300-400
<i>Propebela komakahida</i> (Otuka)	200-350
<i>P. tayensis</i> (Nomura and Hatai)	150
<i>Yoldia kikuchii</i> Kuroda	100-150
<i>Portlandia toyamaensis</i> (Kuroda)	100-600

characteristic species of the Omma-Manganji fauna (Otuka, 1939) and now lives in 50-400 m depth in the Japan Sea (Higo *et al.*, 1999). *Lusivoluptosius furukawai* is also known as an endemic species in the Japan Sea (200-350 m depth; Higo *et al.*, 1999) and there is one fossil specimen from the lower Pleistocene Sawane Formation at Tohoku University (IGPS no. 73410). Summarizing the Japan Sea endemic species that have fossil records (Table 2), all live in depths from 100 m-400 m. Horikoshi (1986) suspected that some species at an intermediate depth could survive during the Quaternary glacial ages. Based on radiolarian fossils from a core at GH-95 St 1208, off Shakotan Peninsula,

### Type E



### Type Fj



**Figure 5.** Distributional pattern (types E, Fj) of *Buccinum*.

**Table 3.** Distributional types of *Buccinum*, *Neptunea* and *Ancistrolepidinae*.  
\*Amano (1997) \*\* Amano *et al.* (1996)

Types	<i>Buccinum</i>	<i>Neptunea</i> *	<i>Ancistrolepidinae</i> **
FJ	<i>B. sinanoense</i>	<i>N. eos</i>	<i>Ancistrolepis masudaensis</i>
	<i>B. shibatense</i>	<i>N. hataii</i>	<i>A. koyamai</i>
	<i>B. saitoi</i>	<i>N. nikkoensis</i>	<i>A. peulepis</i> <i>A. aff. hikidai</i> <i>Clinopegma fragilis</i>
A	<i>B. rhodium</i>	<i>N. lamellosa</i>	<i>Ancistrolepis grammatus</i>
	<i>B. unuscarinatum</i>	<i>N. satura</i>	<i>Clinopegma borealis</i>
		<i>N. insularis</i>	<i>Bathyancistrolepis trochoideus</i>
		<i>N. vinosa</i>	
B	<i>B. middendorffi</i>	<i>N. lyrata</i>	—
	<i>B. inclytum</i>	<i>N. bulbacea</i>	
		<i>N. rugosa</i>	
C	<i>B. ochotense</i>	<i>N. intersculpta</i>	—
		<i>N. arthritica</i>	
D	<i>B. leucostoma</i>	<i>N. kuroshio</i>	<i>Clinopegma unicum</i>
	<i>B. bulimiloideum</i>	<i>N. fukueae</i>	
		<i>N. kanagawaensis</i>	
E	<i>B. striatissimum</i>	—	—
	<i>B. tsubai</i>		

Hokkaido, Itaki *et al.* (1996) inferred normally saline and oxic water at depths of 200–300 m during the last glacial age (18–15 kyr BP). The inferred survival depth (200–300 m) of radiolarians is similar to that for the molluscs (100–400 m). Therefore, the endemic molluscs noted above, including type E of *Buccinum*, might have been able to survive the Quaternary glacial ages in the normal saline and oxic water lying between the brackish surface and the euxinic bottom waters.

Based on the discussion above, we synthesize the distributional pattern of *Buccinum*, *Neptunea* and *Ancistrolepidinae* in Table 3. It is noteworthy that 20 species (56%) belong to the type FJ or A, and there are no extinct species whose fossil records are confined to the Pacific side. Many authors have cited temperature change as one of the important causes of extinction (ex. Stanley, 1984). However, from the above lines of evidence, we postulate that the extinction of species was induced by environmental change in the Japan Sea accompanying the glacio-eustatic sea level changes during the Quaternary ice ages, not by sea surface temperature.

Valentine and Jablonski (1991) noted that marine invertebrate faunas that are not perched are unlikely to suffer extinction by eustatic sea-level changes alone. They also pointed out that the trapped fauna in enclosed areas are vulnerable to any local environmental deterioration. The present study reveals the mechanism of extinction associated with glacio-eustatic sea level changes in a marginal sea.

Tada (1994) illustrated the two-layer model of the Japan Sea during the glacial period with a surface brackish layer and deep anoxic water. However, the existence of type E

species in *Buccinum* suggests the possibilities of normal oceanic water between these two layers.

#### Acknowledgments

I am grateful to Geerat J. Vermeij (Univ. California, Davis) and Louie Marinovich, Jr. (California Acad. Sci.) for their critical reading of the manuscript. I thank Hiroshi Noda (Univ. Tsukuba), Masanori Shimamoto (Tohoku Univ.), Tomoki Kase (Nat. Sci. Mus.), Sadako Takeuti (Saito Ho-on Kai Mus.), Masayuki Shimizu (Tateyama Mus.), and Atsushi Saito (Niigata Higashi High School) for their help in examining some fossil specimens.

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