Subfossil Land Snail Fauna (Mollusca) of Central Chichijima, Ogasawara Islands, with Description of a New Species[1]

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Abstract: The fossil record provides useful information to estimate what island communities were like before human colonization. We examined the species composition of the subfossil land snail fauna of dune deposits at the Yatsuse River, central Chichijima, Ogasawara Islands, and compared it with the species recorded in Chichijima since the nineteenth century. The 22 species in the dune deposits included 13 species that are now extinct in Chichijima. Live specimens of 11 of these extinct species were recorded in the early twentieth century, but no living *Mandarna pallasiana* and *Ogasawarana obtusa* Chiba et al., n. sp., have ever been recorded. Age of the sediment, estimated by radiocarbon (^{14}C) dating, was 720 years B.P., and it is possible that these two land snail species became extinct as a result of the impact of human colonization of the island, which started in 1830. Specifically, *Ogasawarana obtusa*, n. sp., became extinct before the start of taxonomic studies of the land snails of Ogasawara. The sample included *Hawaiia minuscula*, which is generally now considered a cosmopolitan species introduced from North America. This finding suggests that *Hawaiia minuscula* is not alien in Ogasawara but indigenous.

Recent palaeontological research has shown that prehistoric human activity is a major cause of degradation of island ecosystems (James et al. 1987, Hotchkiss and Juvik 1999, Burney et al. 2001). It is important to know how communities and ecosystems were changed by initial human colonization. Land snails of islands provide excellent model systems to investigate the impacts of human colonization on communities, because serious extinctions have been recorded on a number of islands and because the prehistoric land snail faunas are often preserved as fossils in sediments, making it relatively easy to infer how species have gone extinct as a result of human activity (Christensen and Kirch 1986, Cook et al. 1993, Goodfriend et al. 1994, Cameron and Cook 1996, Preece 1998, Cowie and Grant-Mackie 2004).

The Ogasawara Archipelago in the northwestern Pacific harbored approximately 100 native land snail species, 90% of which were endemic (Kuroda 1930, Habe 1969, Kurozumi 1988, Tomiyama and Kurozumi 1991). On Chichijima, the largest island, 51 species have been described and more than 50% of these are thought to have been lost (Tomiyama and Kurozumi 1991). Two species of land snails from Ogasawara were first collected on a voyage by Captain Frederick Beechey in 1827 (*Mandarina mandarina* and *Mandarina luhuana*), and most of the land snail species of Ogasawara were described by H. A. Pilsbry and Y. Hirase in the early twentieth century. However, human colonization of Ogasawara began in 1830 with seven immigrants from Hawai'i, and it is not known what the land snail community of Ogasawara was like before human colonization and how this initial human colonization affected the

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native land snail fauna. Because details of the history of human colonization of Ogasawara were recorded in a number of historical documents, fossil materials from before human colonization may provide useful information for understanding the process of extinction caused by human activity.

In this study, we examined the species composition of the subfossil land snail fauna of dune deposits in the central part of Chichijima to characterize the composition of the land snail fauna of Ogasawara before the first human colonization. We compare the species composition of the subfossil fauna with that of the fauna recorded since the early nineteenth century and discuss the impact of the first human colonization on the native land snail fauna of Ogasawara. In addition, based on the occurrence of subfossil species, we show that a species formerly proposed as an alien species is indigenous.

MATERIALS AND METHODS

Samples

Subfossil land snails were found in Holocene dune deposits that were uncovered at a dredging site on the Yatsuse River at Kitafukurozawa, in central Chichijima (Figure 1). The deposits consist of fine to coarse sand and include lenses of silt. The uppermost parts of the deposits are covered by silt and soil. The base of the sand layer remains buried. This sampling site is 1 km inland from the coast, and no dunes are now present at the site. However, it was formerly near the beach and coastal dunes because the deposits include a number of fragments of corals and Foraminifera. The Yatsuse River may have been a narrow bay, with the coastal dune around it.

The subfossil land snail shells were distributed in a slightly calcareous sand layer approximately 50 cm thick (Figure 1). We selected the part of the deposits in which the land snail shells are the most abundant, and a 30 by 30 by 50 cm block was excavated from a position deeper than 10 cm from the deposit surface to avoid contamination with modern snail shells. The subfossil shells were separated from the block using a sieve. The samples used for this study were deposited at the Institute of Boninology (Chichijima-Aza-Miyanohamamichi, Ogasawara [CIBML]).

Dating of the Subfossil Sample

The age of the subfossil shells was determined by radiocarbon (^{14}C) dating at the Geo-Science Laboratory Co., Ltd (Ueda, Tenpaku-ku, Nagoya) and the Institute of Accelerater Analysis, Ltd. (IAA) (Noboritoshinmachi, Tamaku, Kawasaki). The materials used for radiocarbon dating were all land snail shells. The radiocarbon date was corrected for isotopic fractionation (Goodfriend and Stipp 1983), and its bulk date was based on a pooled sample of *Mandarina chichijimana*. The calendar calibration was calculated using the newest calibration data (Reimer et al. 2004) and using the mathematical cubic spline fit (Talma and Vogal 1993). An anomaly of ^{14}C in the snail shell has been reported (Goodfriend and Stipp 1983), and it is one of the problems in ^{14}C analysis of the fossil samples. To check the error due to the age anomaly, the ^{14}C age of the shells of living snails of *M. chichijimana* was determined.

Identification

Each subfossil shell was identified to species, and numbers of shells of each species found in the block were recorded. The occurrence of species in the subfossil samples was compared with previous records of land snail species in Ogasawara (Kuroda 1930, Habe 1969, Tomiyama and Kurozumi 1991). Museum collections of Ogasawara land snails (University Museum, University of Kyoto; Yokosuka City Museum; National Science Museum, Tokyo; Academy of Natural Sciences of Philadelphia) were also used to assist identification.

RESULTS

The ^{14}C age obtained for the subfossil sample was 720 ± 70 yr B.P. The real (calibrated) calender age of the sample was 550–780 yr B.P. No age anomaly was detected in the

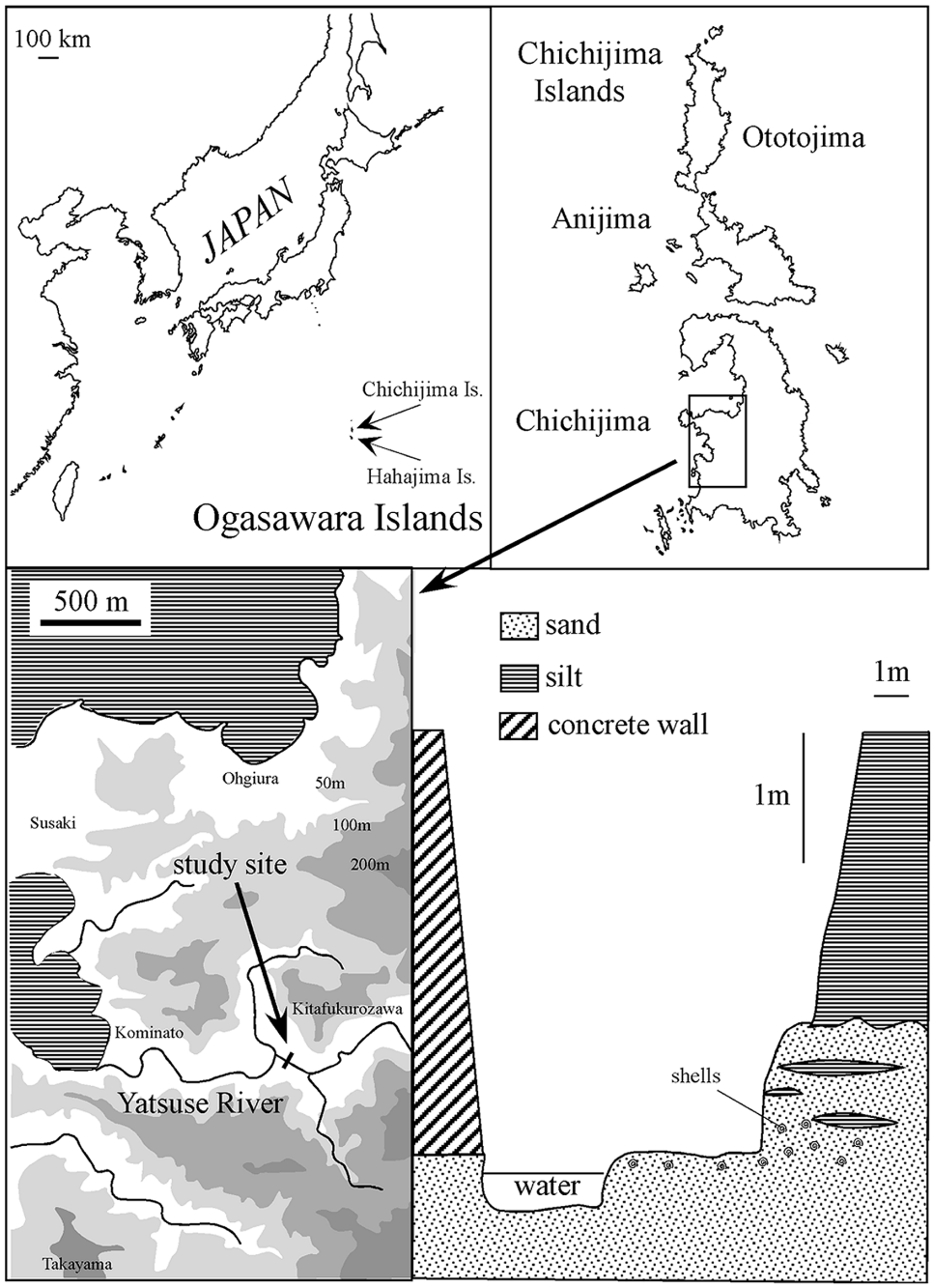

FIGURE 1. A map of Chichijima of the Ogasawara Islands, showing the location of the study site, and a diagrammatic cross section of the study site.

TABLE 1

Species Found in the Subfossil Sample, with Their Current Status in Chichijima and Ogasawara, and Whether They Are Endemic or Nonendemic to Ogasawara

Species	Collection No.	*n*	Status in Chichijima	Status in Ogasawara	Endemicity
Ogasawarana discrepans Pilsbry	CIBML2007001	15	Living	Living	Endemic
Ogasawarana obtusa, n. sp	CIBML2007002–003	3	Extinct	Extinct	Endemic
Paludinella minima Habe	CIBML2007004	13	Living	Living	Endemic
Lamellidea ogasawarana Pilsbry & Cook	CIBML2007005	7	Living	Living	Endemic
Lamellidea nakadai Pilsbry & Hirase	CIBML2007006	9	Extinct	Extinct	Endemic
Elasmias kitaiwojimanum Pilsbry & Hirase	CIBML2007007	2	Extinct	Living	Endemic
Gastrocopta ogasawarana Pilsbry	CIBML2007008	2	Extinct	Living	Endemic
Gastrocopa boninensis Pilsbry	CIBML2007009	3	Living	Living	Endemic
Boninena callistoderma Pilsbry	CIBML20070010	3	Extinct	Living	Endemic
Hirasea chichijimana Pilsbry & Hirase	CIBML20070011	1	Extinct	Living	Endemic
Hirasea diplomphalus Pilsbry & Hirase	CIBML20070012	2	Extinct	Living	Endemic
Hirasea operculina Gould	CIBML20070013	2	Extinct	Living	Endemic
Hirasea goniobasis Pilsbry & Hirase	CIBML20070014	14	Extinct	Extinct	Endemic
Hirasea hypolia Pilsbry	CIBML20070015	1	Extinct	Extinct	Endemic
Liardetia boninensis Pilsbry & Hirase	CIBML20070016	2	Living	Living	Endemic
Lamprocystis hahajimana Pilsbry	CIBML20070017	7	Extinct	Living	Endemic
Vitrinula chichijimana Pilsbry & Hirase	CIBML20070018	1	Extinct	Extinct	Endemic
Hawaiia minuscula Binny	CIBML20070019–20	7	Living	Living	Cosmopolitan
Boninosuccinea punctulispira Pilsbry	CIBML20070021	1	Extinct	Living	Endemic
Mandarina chichijimana Chiba	CIBML20070022	18	Living	Living	Endemic
Mandarina hirasei Pilsbry	CIBML20070023	2	Living	Living	Endemic
Mandarina pallasiana Pfeiffer	CIBML20070024	12	Extinct	Extinct	Endemic

analysis of modern *Mandarina* shells. Thus, this fossil sample represents the land snail fauna of this part of Chichijima a few hundred years before the first human colonization of Ogasawara and exemplifies the land snail fauna of Chichijima just before human colonization.

In total, 22 subfossil land snail species were identified (Table 1), representing approximately 40% of the species previously recorded in Chichijima. Among these subfossil species, 21 have been recorded since the nineteenth century, but 13 are now extinct in Chichijima. Live specimens of 11 of these extinct species were recorded in the early twentieth century.

We found one subfossil species of *Ogasawarana*, a helicinid genus endemic to Ogasawara, which has a shell morphology distinct from any species of *Ogasawarana* previously recorded. This species was not recorded in any previous studies and is not found in any museum collections. It was extinct before malacologists studied the land snails of Ogasawara. The sample included a large species, *Mandarina pallasiana*, previously suggested to be a fossil of the latest Pleistocene or early Holocene. The age of the subfossil sample showed, however, that the extinction of this species was fairly recent, although also before studies of the land snail fauna of Ogasawara began.

All the species in the sample were endemic to Ogasawara except one, *Hawaiia minuscula* (Figure 2). This species was previously believed to have been an introduced species. However, its occurrence in the subfossil sample indicates that it is not an alien but is indigenous to Ogasawara.

DISCUSSION

The subfossil land snails occurring at the Yatsuse River site provide an insight into how the land snail fauna of Ogasawara changed during the initial stages of human colonization. At least two species became extinct in Chichijima before taxonomic studies of

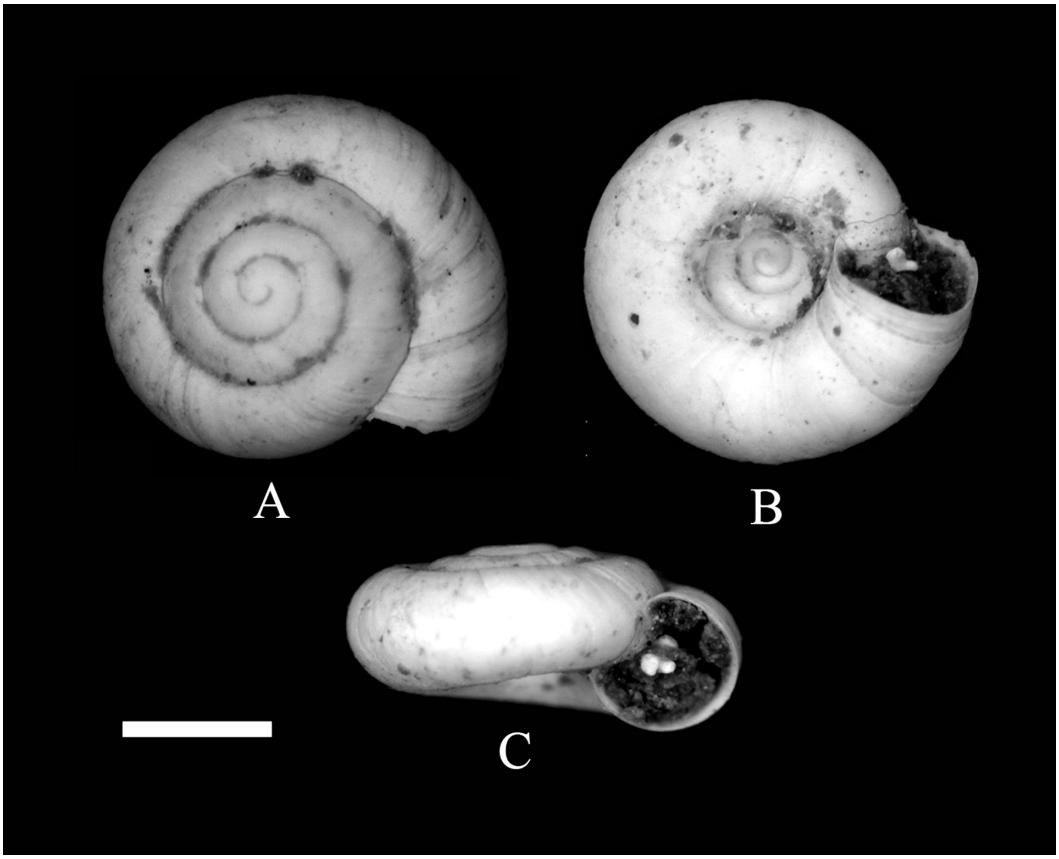

FIGURE 2. *Hawaiia minuscula* (CIBML2007002). *A*, apical view; *B*, abapical view; *C*, side view. Scale bar = 1 mm.

Ogasawara land snails began. This extinction is most likely to have resulted from earlier human colonization in the early nineteenth century, because major climatic change that could induce extinction of more than three species is difficult to imagine in Ogasawara during 700–200 yr B.P. The first colonizers and occasional visitors to Ogasawara in the early nineteenth century brought goats, pigs, cats, and dogs to Chichijima (Hawks 1856), and predation or habitat degradation by the introduced animals might have caused the extinction of these land snail species. In addition, the forests of Chichijima were entirely cut down before the early twentieth century by immigrants from Japan who colonized after 1876 (Funakoshi 1992), so habitat loss before the twentieth century is another plausible cause of the extinction. Although a stone artifact that was assumed to be of prehistoric period was found in Chichijima (Oda 1981) and humans may have visited Chichijima before the nineteenth century, there is no evidence of prehistoric human settlement in Ogasawara except for the Kazan Islands (Oda 1990). Thus, it is most likely that the extinction of these species occurred during the nineteenth century.

The fossil record suggests that no more than 20 species previously coexisted at this locality in Chichijima. There are no localities where more than 20 species coexist in the modern Ogasawara Islands except on Anijima, where no cultivation has occurred and the original habitats have been preserved. Fewer than 10 species currently coexist in

the same locality (within 100 m^2) in Chichijima. This suggests that the impact of human activity on the native land snail fauna has extended over the entire island. Alternatively, the high species diversity in the fossil sample might be a result of mixing with older fossils that were reworked from lower horizons. If faunal composition was changing as a result of climatic changes during the Holocene, mixing of fossil samples of different ages could appear to increase species richness in the sample. Although details of climatic change in Ogasawara are not known, it is unlikely that the climate during the Holocene changed so much that faunal composition changed, because the climate of these subtropical oceanic islands would be much more stable than that of continental temperate regions. Another possibility is that mixing of the shells was the result of their being transported from elsewhere. If species composition differed among areas and shells were transported from distant areas and mixed after the death of the snails, then species richness in the sample would appear higher than it actually was in the naturally occurring fauna. Small and thin-shelled species cannot be transported long distances without breaking. Because the shells of species with very thin shells, such as species of *Hirasea* and *Lamprocystis*, are not fragmented in the samples, they were not moved long distances, even if they were transported from elsewhere.

The presence in the fossil sample of a species with no records since the nineteenth century and a species possessing a unique morphology suggests that the land snail fauna of Ogasawara before human colonization may have included a number of species phylogenetically and morphologically distantly related to the species recorded after human colonization, when taxonomists began to study the Ogasawara land snail fauna. Hence, investigation of the Holocene fossil sequence is important for our understanding of the diversity of the original fauna and how human activity affected it. The subfossil sample includes the species *Hawaiia minuscula*, which formerly was considered as an alien species introduced from elsewhere to Ogasawara before the early twentieth century. It was believed that *Hawaiia minuscula* was introduced from North America to Asia, Europe, and the Pacific region by human transportation. However, the finding of *Hawaiia minuscula* in deposits from 700 yr ago implies that this species was already present in Ogasawara before European colonization of the New World. It is unlikely that this species colonized Ogasawara from the New World before human colonization. This species is indigenous to North America, because a number of studies document presence of the fossils of this species in North America since at least the late Tertiary (Schultz and Cheatum 1970, Miller and Eshelman 1985). Hence, it is most likely that populations of *Hawaiia minuscula* in eastern Asia, as well as those in Ogasawara, were not introduced from the New World by human activity but are indigenous. Because there is not enough information on the fossil land snails of eastern Asia, phylogenetic and biogeographical studies using molecular markers are needed to confirm this suggestion. Although further studies are needed, these findings suggest that populations of *Hawaiia minuscula* in the Pacific Islands have complex origins and a complex history of immigration: they could be mixtures of indigenous populations and nonindigenous populations with different origins.

SYSTEMATIC DESCRIPTION

Order NERITOPSINA Cox & Knight, 1960
Family HELICINIDAE Férussac, 1822
Genus *Ogasawarana* Wagner, 1905

Type species: *Ogasawarana ogasawarana* (Pilsbry, 1902)

Ogasawarana obtusa Chiba, Sasaki, Suzuki & Horikoshi, n. sp.
Figures 3*A,B,C*

DIAGNOSIS: Shell flat for the genus with about 3.5 whorls, a large body whorl, rounded periphery, smooth surface and a large, elliptical aperture.

DESCRIPTION: Shell medium in size for the genus, about 3.5 expanding whorls. Spire depressed, with height/diameter ratio about

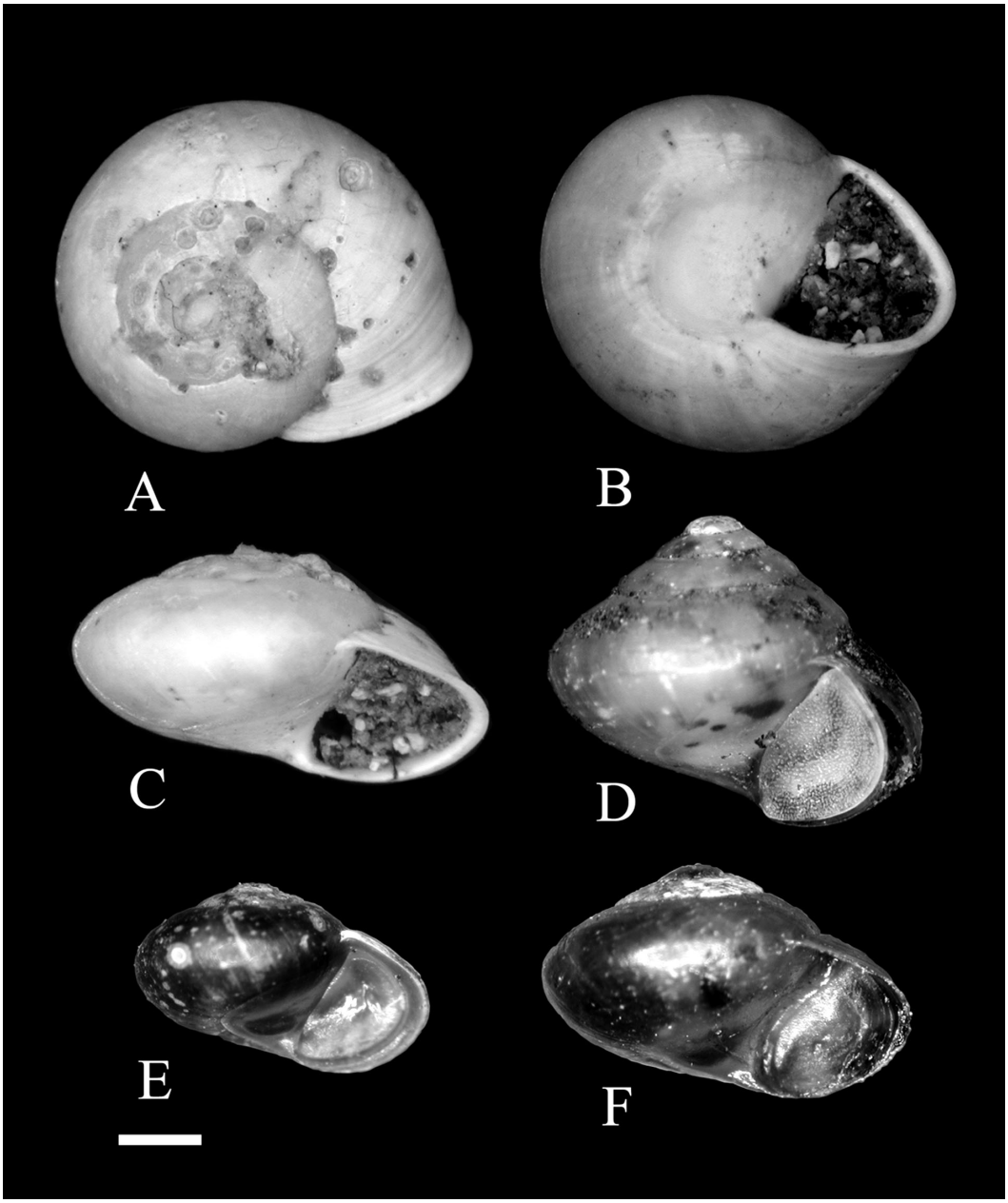

FIGURE 3. *Ogasawarana obtusa* Chiba et al., n. sp. (CIBML20070019). *A*, apical view; *B*, abapical view; *C*, side view; *D*, *Ogasawarana capsula* (Pilsbry, 1902); *E*, *Ogasawarana comes* (Wagner, 1905); *F*, *Ogasawarana nitida* Minato, 1980. Scale bar = 1 mm.

0.55. Sutures shallow, slightly convex, whorls adpressed. Body whorl large relative to spire, broadly rounded with no peripheral angularity. Shell surface very smooth, with fine growth lines but no spiral lines. Aperture large, oval, outer lip expanded with beveled thickening behind reflected margin. Umbilicus closed by solid callus pad. Shell diameter 4.9–5.3 mm. Shell height 2.7–2.8 mm.

MATERIAL EXAMINED: Holotype, CIBML 2007002. Paratypes ($n = 2$), CIBML 2007003. Type locality: Kitafukurozawa, Chichijima, Ogasawara; Holocene, 720 yr B.P.

DISCUSSION: Among the 14 species of *Ogasawarana* described since the early twentieth century, the only species having a shell with a smooth surface, no spiral lines, and no peripheral angularity are *O. nitida*, *O. comes*, and *O. capsula* (Minato 1980) (Figure 3). *Ogasawarana obtusa* differs from *O. nitida* in having a larger and thicker shell with a relatively larger body whorl and aperture. *Ogasawarana obtusa* differs from *O. comes* in having a much larger and flatter shell, with a relatively larger body whorl and aperture. In addition, the outer lip of *O. comes* is much thicker than that of *O. obtusa*. *Ogasawarana capsula* has a conical shell with a very high spire, and its shape is very different from that of *O. obtusa*. The new species described here has been overlooked in the study of land snails in Ogasawara, because it probably went extinct in Chichijima before the start of taxonomic studies of the land snails of Ogasawara.

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