

FULL PAPER

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## Floristic study of *Geastrum* in Japan: three new records for Japanese mycobiota and reexamination of the authentic specimen of *Geastrum minus* reported by Sanshi Imai

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**Abstract** *Geastrum berkeleyi*, *G. fornicatum*, and *G. minimum* are newly recorded from Japan. A peristome of *G. fornicatum* has hitherto been described as indistinct, whereas the Japanese specimens have a well-delimited, fibrillose peristome. *Geastrum minus*, reported for the first time from Japan by Sanshi Imai, represents *G. quadrifidum*. Macroscopic and microscopic features of those four taxa are described and illustrated based on Japanese specimens.

**Key words** Basidiomycota · Gasteromycetous fungi · Geastraceae · *Geastrum*

### Introduction

The genus *Geastrum* Pers., which is a member of the Geastraceae, Geastrales, is characterized by an exoperidium divided into two or three layers, an endoperidium with peristome, a gleba with distinct or indistinct columella, and with or without a stalk. Immature basidiomata are globose or subglobose to obovate or lageniform, hypogeous, subhypo-

geous, or epigeous. The exoperidium splits at maturity from the top in a stellate manner and exposes an endoperidial body attached at one point of the fibrous layer of the exoperidium (Sunhede 1989). Ecologically, the members of this genus grow on various habitats, e.g., from sandy soil of arid or semiarid areas to rich soil, humus, or decayed wood in humid forest.

This genus has been systematically revised by several authors (Staněk 1958; Ponce de Leon 1968; Demoulin 1984; Dörfelt and Müller-Uri 1984; Dörfelt and Heklau 1987; Sunhede 1989), and currently about 50 species are included in this group (Kirk et al. 2001). *Geastrum* has been intensively studied in Europe (Staněk 1958; Dörfelt et al. 1979; Calonge 1981; Sunhede 1989), Central and South Africa (Bottomley 1948; Dissing and Lange 1962), North America (Lloyd 1902; Long and Stouffer 1948), and Latin America (Pérez-Silva et al. 1999; Baseia et al. 2003; Esqueda et al. 2003; Leite et al. 2007). However, this genus is poorly documented in Northeast Asia. Although 15 species of *Geastrum* have hitherto been recorded from Japan (Imai 1936; Kawamura 1954; Ito 1959; Yoshimi and Hongo 1989; Sakamoto and Kasuya 2008), this genus has not yet been comprehensively studied in this country.

Recently, during our floristic investigations of *Geastrum* from Japan (Yamamoto and Yamamoto 2007; Sakamoto and Kasuya 2008), some noteworthy specimens of this genus have been examined. In this article, we describe and illustrate three new distributional records from Japan, based on morphological observations: *G. berkeleyi* Masee, *G. fornicatum* (Huds.) Hook., and *G. minimum* Schwein. Moreover, we reexamine and discuss authentic specimen of "*Geastrum minus*" auct. non (Pers.) G. Cunn.: Imai (1936). Imai (1936) newly recorded this fungus from Japan with an orthographic error, "*G. minum*," and he put *G. quadrifidum* Pers. (as *G. quadrifidum*  $\beta$  *minum* Pers.) and *G. minimum* (as *Geaster minimum* Schwein.) into synonymies of "*G. minus*" (Imai 1936). However, *G. quadrifidum* and *G. minimum* are now defined as two separated, good, natural taxa (Staněk 1958; Dörfelt et al. 1979; Calonge 1981, 1998; Sunhede 1989). The description of "*G. minus*" (Imai 1936) is very brief and is mainly based on macroscopic characters

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without detailed descriptions of microscopic features. Therefore, reexamination of the authentic specimen of “*G. minus*” (Imai 1936) is needed to clarify its taxonomic position. According to our morphological observations, Imai’s authentic material (Imai 1936) represents *G. quadrifidum*. Therefore, we redescribed and illustrated *G. quadrifidum* from Japan based on Imai’s specimen and the additional Japanese materials.

## Materials and methods

The specimens examined in this study are deposited in the herbaria of the National Museum of Nature and Science, Tokyo (TNS), Hokkaido University Museum, Sapporo (SAPA), and Ibaraki Nature Museum, Bando (INM). Macroscopic characters were described by observations on dried or fresh materials. For light microscopic observations, free-hand sections of dried or fresh specimens were mounted in water, 3% or 5% (w/v) KOH, and 30% ethanol solution on glass slides. More than 40 randomly selected basidiospores were measured under a light microscope at 1000× magnification. Length measurements excluded the apiculus. The surface features of basidiospores were also observed by scanning electron microscopy (SEM). For SEM, small portion from the gleba were dusted onto double-sided adhesive tape on a specimen holder and coated with platinum-palladium using an E-1030 Ion Sputter Coater (Hitachi, Tokyo, Japan). They were examined with a S-4200 SEM (Hitachi) operating at 20 kV.

## Three new records of *Geastrum* in Japan

*Geastrum berkeleyi* Masee, Ann. Bot. 4:79, 1889.

Figs. 1, 7–9

= *G. pseudostriatum* Hollós, Math. Termész. Értés 19:505, 1901.

= *G. hollosii* V.J. Staněk, Geastraceae. In: Pilát (ed.), Flora CSR B-1, p. 789, 1958.

Basidiomata hypogeous to subhypogeous, globose to subglobose when young, about 20–50 mm in diameter, surface encrusted with debris, pale brown to brown. Expanded basidiomata 40–70 mm across, exoperidium splitting into 5–9 rays that become reflexed and usually arched downward, nonhygroscopic, although sometimes partly curled back when dry. Mycelial layer well developed, whitish, with plant debris and soil particles. Fibrous layer papery, pale brown to brown. Pseudoparenchymatous layer whitish at first, later becoming brown to dark brown, tending to fragment and peel off in several patches. Endoperidial body stipitate, subglobose to pyriform, 10–20 mm in diameter, often constricted below and with an indistinct apophysis. Stalk short, 1–3.5 mm long, pale brown to brown. Endoperidium brown to grayish brown, conspicuously roughened with minute, irregular verrucae except for a

smooth, circular area surrounding the peristome. Peristome conical, 2–3.5 mm long, distinctly plicate with about 20–30 folds. Columella depressed globose, subglobose to clavate. Mature gleba olivaceous brown to dark brown.

Pseudoparenchymatous layer consisting of thin-walled, hyaline to pale brown, bladder-like hyphae 10–35 µm wide. Hyphae of the columella 1.5–7 µm in diameter, thick walled, pale brown to hyaline. Hyphae of the capillitium yellowish brown, thick walled, 2–10 µm in diameter, tapered gradually toward subacute tips, surface smooth or encrusted. Basidia not seen. Basidiospores globose, densely verrucose, thick walled, olivaceous brown to dark brown, 4.5–6.5 µm in diameter (mean = 5 µm) excluding ornaments, 5–7 µm in diameter (mean = 5.5 µm) including ornaments, verrucae to 0.5 µm high, basal apiculus prominent.

Habitat: Solitary or scattered on well-drained, rich calcareous soil in evergreen broad-leaved forest.

Distribution: Japan (Kochi), China (Zhou et al. 2007), and Europe (Masee 1889; Calonge 1981, 1998; Kotlaba and Pouzer 1987; Sunhede 1989; Pegler et al. 1995).

Specimens examined: Japan, Kochi Pref., Takaoka-gun, Sakawa-cho, Nishiyama-ko, October 20, 2006, coll. Y. Yamamoto, TNS-F-16965; Kochi Pref., Takaoka-gun, Ochi-cho, Mt. Yokogura, October 2, 2007, coll. Y. Yamamoto, TNS-F-16966.

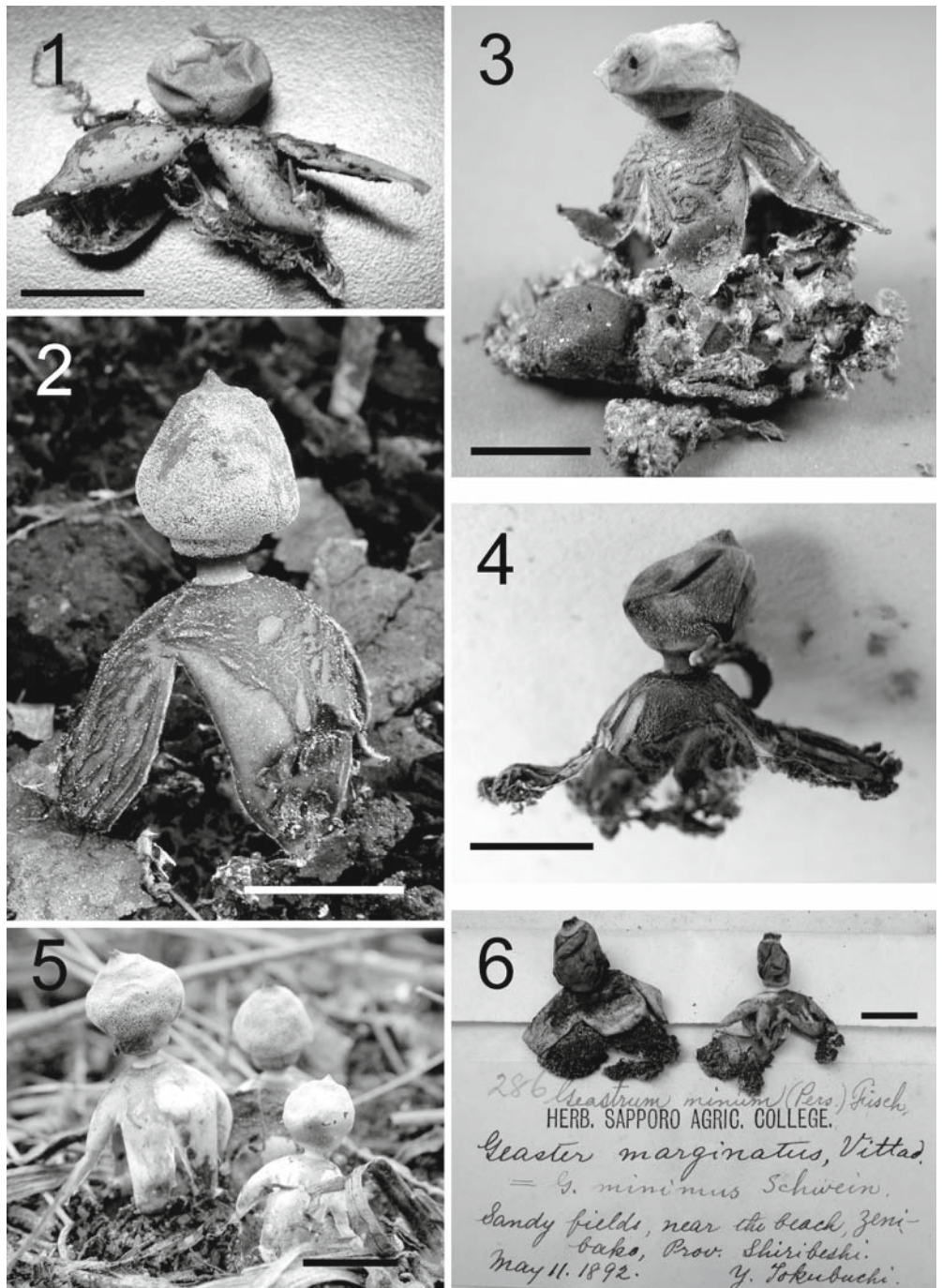
Japanese name: Ibo-hime-tsuchiguri (newly named).

Remarks: *Geastrum berkeleyi* is well characterized by arched, nonhygroscopic exoperidial rays, conspicuously roughened endoperidium with minute, irregular verrucae, and distinctly plicate, conical peristome. Morphological characteristics of the specimens examined are in good agreement with the previous descriptions of *G. berkeleyi* (Masee 1889; Calonge 1981, 1998; Kotlaba and Pouzer 1987; Sunhede 1989; Pegler et al. 1995).

*Geastrum campestre* Morgan, *G. kotlaba* V.J. Staněk, and *G. pouzarii* V.J. Staněk are other species having a plicate, conical peristome and roughened endoperidia (Sunhede 1989). However, *G. campestre* and *G. pouzarii* are clearly distinguished from *G. berkeleyi* by their hygroscopic rays of the exoperidia and smaller basidiomata than *G. berkeleyi* [*G. campestre*: 8–29 mm in diameter; *G. pouzarii*: 9–30 mm (Sunhede 1989)]. *Geastrum kotlaba* is also distinguishable from *G. berkeleyi* by its strongly hygroscopic rays of the exoperidium and the nonstipitate endoperidial bodies (Staněk 1958; Dörfelt et al. 1979; Sunhede 1989; Calonge 1998; Sakamoto and Kasuya 2008). *Geastrum hieronymi* P. Henn. and *G. pseudolimbatum* Hollós are also morphologically similar to *G. berkeleyi* in having nonhygroscopic rays of exoperidia, short-stipitate endoperidial bodies, and roughened endoperidia (Coker and Couch 1928; Long and Stouffer 1948; Sunhede 1989; Leite et al. 2007). However, those two species clearly differ from *G. berkeleyi* by their nonplicate, flat to mammiform, fibrillose peristomes.

Hitherto, the three species of *Geastrum* having a plicate peristome, i.e., *G. elegans* Vittad. (= *G. badium* Pers.), *G. pectinatum* Pers., and *G. schmidlii* Vittad. (= *G. nanum* Pers.), are known from Japan (Imai 1936; Ito 1959; Yoshimi and Hongo 1989). However, *G. berkeleyi* is distinctively

**Figs. 1–6.** Mature basidiomata of *Geastrum* species. **1** *G. berkeleyi* (TNS-F-16966). **2** *G. fornicatum* in natural habitat (TNS-F-18202). **3** *G. fornicatum* (TNS-F-18203). **4** *G. minimum* (TNS-F-243735). **5** *G. quadrifidum* in natural habitat (TNS-F-18206). **6** Authentic specimen of “*Geastrum minus*” auct. non (Pers.) G. Cunn.: Imai (SAPA 1109). Bars 1–3 1.5 cm; 4 7 mm; 5, 6 6 mm



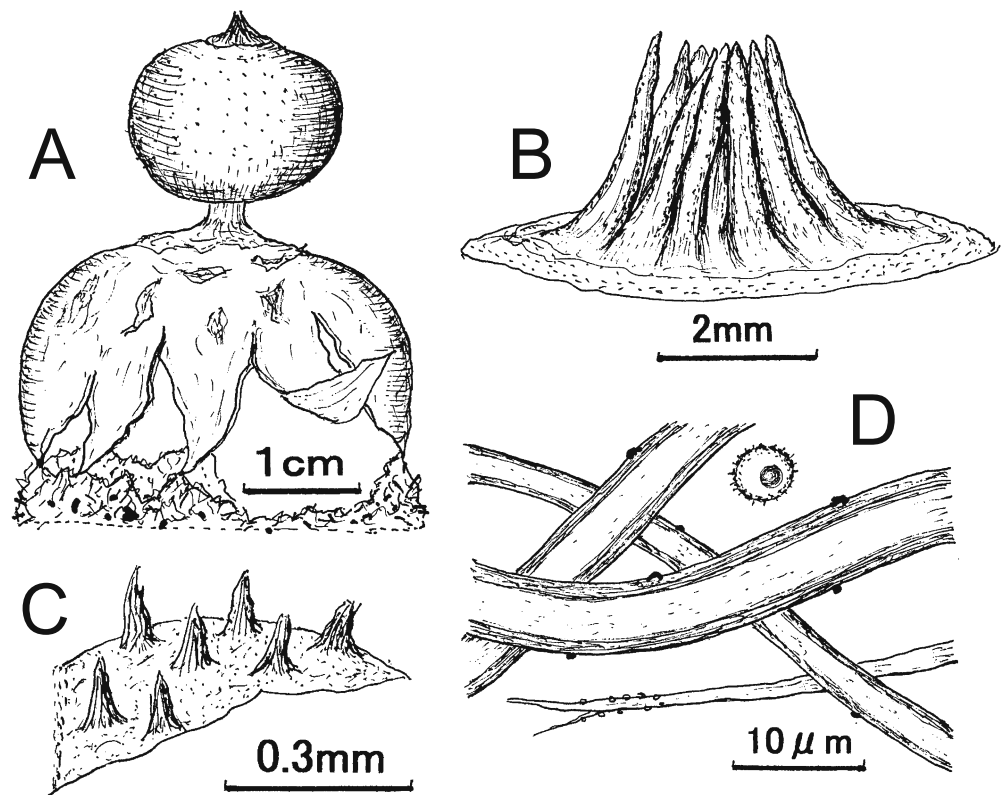
separated from those three species by its roughened, pale brown to brown endoperidium.

*Geastrum fornicatum* (Huds.) Hook., Fl. Londinensis 4:575, 1821. Figs. 2, 3, 10, 11, 16, 17

Basidiomata hypogeous to subhypogeous, globose to subglobose when young, about 10–20 mm in diameter, surface encrusted with debris, yellowish brown to brown. Expanded basidiomata 25–50 mm across, fornicate, exoperidium splitting into 3–6 rays that become often almost straight and vertical, with incurved margins attached to the mycelial

layer, nonhygroscopic, although sometimes partly curled back when dry. Mycelial layer well developed, cup shaped, whitish, with plant debris and soil particles. Fibrous layer papery, pale brown, brown to reddish brown. Pseudoparenchymatous layer whitish at first, later becoming pale brown to brown, tending to fragment and peel off in several patches. Endoperidial body stipitate, subglobose to ovoid, 7–20 mm in diameter, with a distinct or indistinct apophysis. Stalk short, 1–2 mm long, pale brown to grayish brown. Endoperidium pale brown to grayish brown, finely puberulent and pruinose, with whitish crystalline material, except for a smooth, circular area surrounding the peristome. Peri-

**Fig. 7.** *Geastrum berkeleyi* (TNS-F-16965). **A** Mature basidioma. **B** Plicate peristome. **C** Spinules on the endoperidial body. **D** Capillitial hyphae and basidiospore. Bars **A** 1 cm; **B** 2 mm; **C** 0.3 mm; **D** 10  $\mu$ m



stome surface fibrillose, conspicuously distinct, 1–2.5 mm long, paler than endoperidium. Columella conical, cylindrical to clavate. Mature gleba brown to dark brown.

Mycelial layer consisting of 1–1.5  $\mu$ m thick, thin-walled, hyaline to cream, smooth filamentous hyphae. Pseudoparenchymatous layer consisting of thin-walled, hyaline to pale brown, bladder-like hyphae 5.5–15  $\mu$ m thick. Peristome consisting of thick-walled, pale brown, smooth to minutely verrucose, nonbranched, 4–6.5  $\mu$ m thick filamentous hyphae. Hyphae of the columella 1.5–7.5  $\mu$ m thick, filamentous, thick walled, hyaline to pale yellowish brown. Hyphae of the capillitium yellowish brown, thick walled, 4–5.5  $\mu$ m thick, tapered gradually toward subacute tips, rarely dichotomously branched, surface smooth or minutely encrusted. Basidia not seen. Basidiospores globose, minutely verrucose, thick walled, yellowish brown to dark brown, 3–4.5  $\mu$ m in diameter (mean = 4  $\mu$ m) excluding ornaments, 4.5–5  $\mu$ m in diameter (mean = 4.7  $\mu$ m) including ornaments, verrucae to 0.5  $\mu$ m high, basal apiculus prominent.

Habitat: Solitary or scattered on rich soil in broad-leaved forests.

Distribution: Japan (Tokyo, Saitama, Mie and Hyogo), Europe (Calonge 1981, 1998; Sunhede 1989; Pegler et al. 1995), North America (Long and Stouffer 1948), and Latin America (Esqueda et al. 2003; Leite et al. 2007).

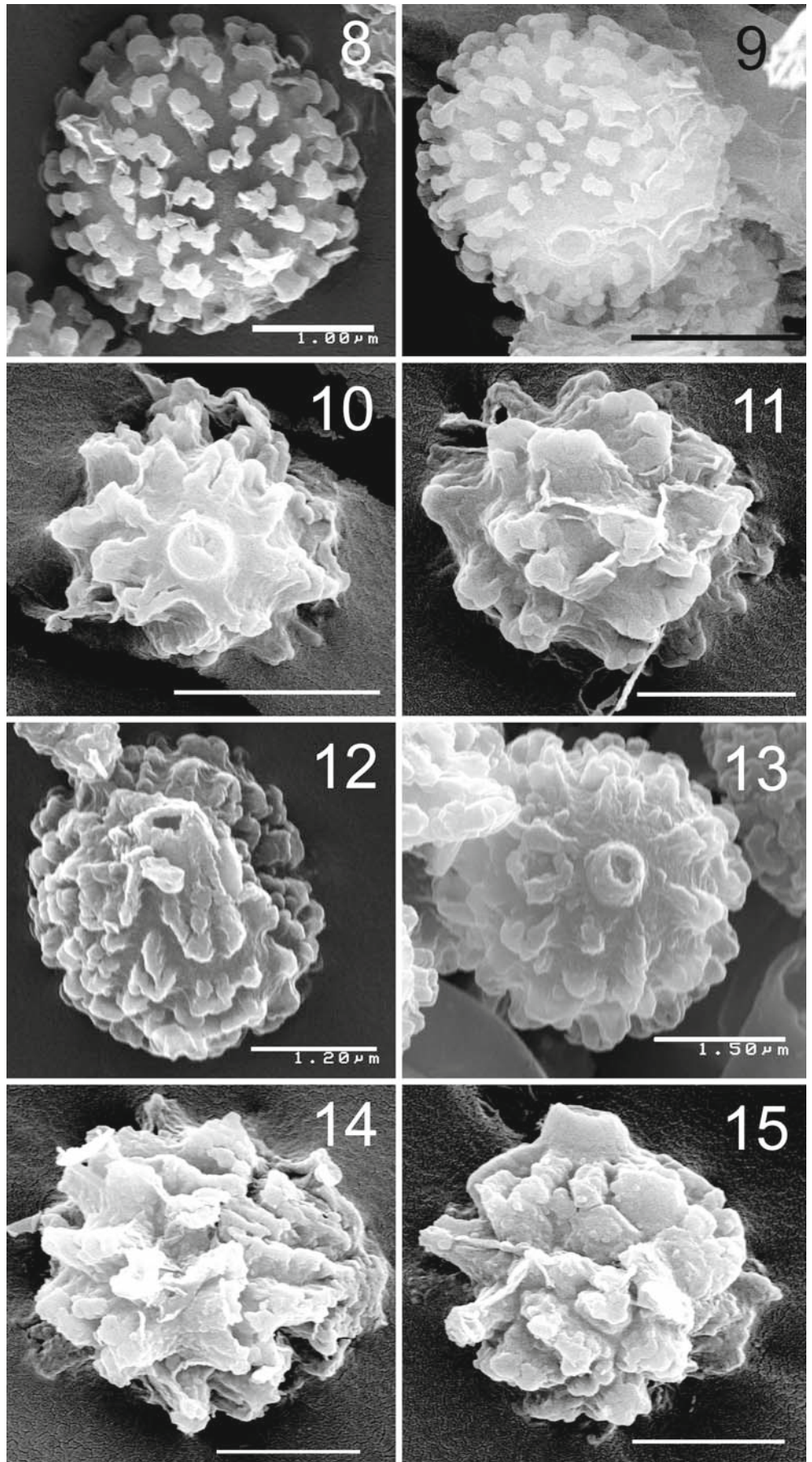
Specimens examined: Japan, Metropolitan Tokyo, Bunkyo-ku, Honkomagome, Rikugien, March 27, 1993, coll. H. Nakayama, TNS-F-18194; same place, April 4, 1993, coll. H. Nakayama, TNS-F-18195; same place, November 27, 1993, coll. H. Nakayama, TNS-F-18196; same place, December 5, 1993, coll. H. Nakayama, TNS-F-18197; same

place, January 19, 1994, coll. H. Nakayama, TNS-F-18198; same place, February 19, 1994, coll. H. Nakayama, TNS-F-18199; same place, September 15, 1994, coll. H. Nakayama, TNS-F-175038; same place, November 19, 1994, coll. H. Nakayama, TNS-F-18200; same place, March 6, 1996, coll. H. Nakayama, TNS-F-18201; same place, March 31, 1996, coll. H. Nakayama, TNS-F-18202; Saitama Pref., Saitama-shi, Minuma-ku, December 23, 2006, coll. G. Yokoyama, TNS-F-18203; Mie Pref., Ise-shi, Yamada, Ise-jingu Geku, October 1924, coll. Uega, TNS-F-200512; Hyogo Pref., Kobe-shi, Kita-ku, Yamada-cho, May 16, 2004, coll. M. Nabe, TNS-F-18204. United States, California, Alameda County, Berkeley, University of California campus, January 15, 1979, coll. I. Tarves, TNS-F-6348.

Japanese name: Taiko-hime-tsuchiguri (newly named).

Remarks: Japanese specimens of *G. fornicatum* are macroscopically and microscopically nearly identical with a specimen collected from the United States (TNS-F-6348) and the earlier descriptions of this species (Long and Stouffer 1948; Calonge 1981, 1998; Sunhede 1989; Pegler et al. 1995; Leite et al. 2007), with the exception of peristome morphology. A studied North American specimen (TNS-F-6348) has indistinct, fimbriate peristome. Moreover, several authors (Long and Stouffer 1948; Calonge 1981, 1998; Sunhede 1989; Leite et al. 2007) described a peristome of *G. fornicatum* as indistinctly delimited, mammiform to fimbriate. In the studied Japanese materials, we recognized a peristome to be well delimited, fibrillose. However, all other morphological features were identical with those of *G. fornicatum*. Therefore, we think that the morphology of the peristome of this species is variable.

**Figs. 8–15.** Basidiospores of *Geastrum* species. **8, 9** *G. berkeleyi* (TNS-F-16966). **10, 11** *G. fornicatum* (TNS-F-18202). **12, 13** *G. minimum* (TNS-F-13034). **14** *G. quadrifidum* (TNS-F-18156). **15** Authentic specimen of “*G. minus*” (SAPA 1109). Bars **8** 1  $\mu\text{m}$ ; **9, 11, 13, 14** 1.5  $\mu\text{m}$ ; **10** 2.31  $\mu\text{m}$ ; **12** 1.2  $\mu\text{m}$ ; **15** 1.67  $\mu\text{m}$



*Geastrum dissimile* Bottomley is morphologically similar to *G. fornicatum* in having fornicate, mostly 4–5, rays of exoperidium and pale brown to grayish brown, conspicuously puberulent endoperidium with distinct apophysis (Bottomley 1948). However, *G. dissimile* is clearly distinguished from *G. fornicatum* by its silky, fimbriate, smooth peristome. *Geastrum leptospermum* Atk. & Coker, *G. quadrifidum*, and *G. welwitschii* Mont. are also morphologically similar to *G. fornicatum* in having fornicate, mostly 3–6 rays, of exoperidia and a cup-shaped mycelial layer. However, *G. leptospermum* and *G. quadrifidum* are well separated from *G. fornicatum* by their whitish fibrous layer and smaller basidiomata than the latter [*G. leptospermum*: 5–10 mm in diameter; *G. quadrifidum*: 9–25 mm (Coker and Couch 1928; Sunhede 1989)]. Further, basidiospores of *G. quadrifidum* are larger (4.5–6 µm in diameter) than those of *G. fornicatum*. *Geastrum welwitschii* is clearly different from *G. fornicatum* by its epigeal mycelial cup with a felted or tufted outer surface (Sunhede 1989; Calonge 1998).

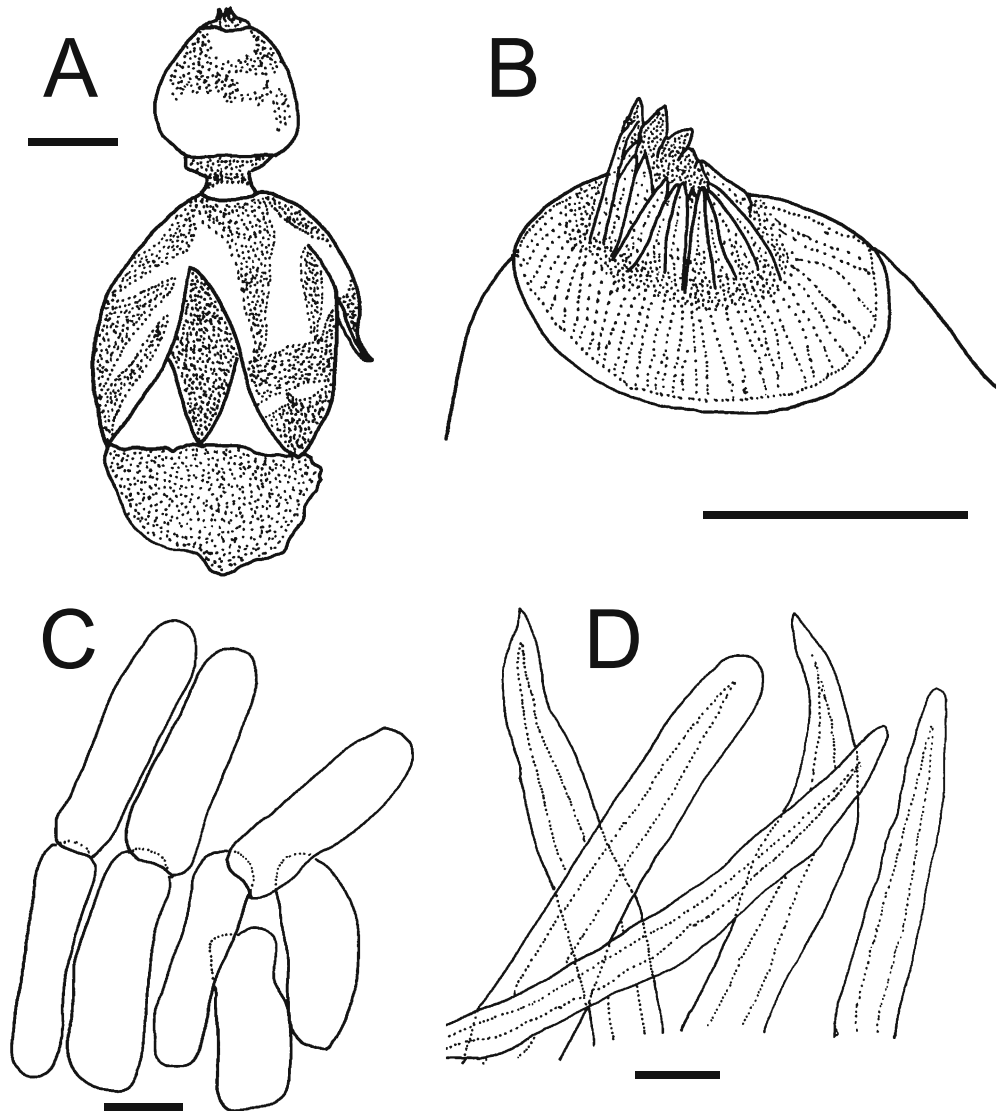
*Geastrum minimum* Schwein., Schriften Nat. Ges. Leipzig 1:58, 1822. Figs. 4, 12, 13, 18

= *Geaster marginatum* Vittad., Monogr. Lycoperd.: 19, 1842.

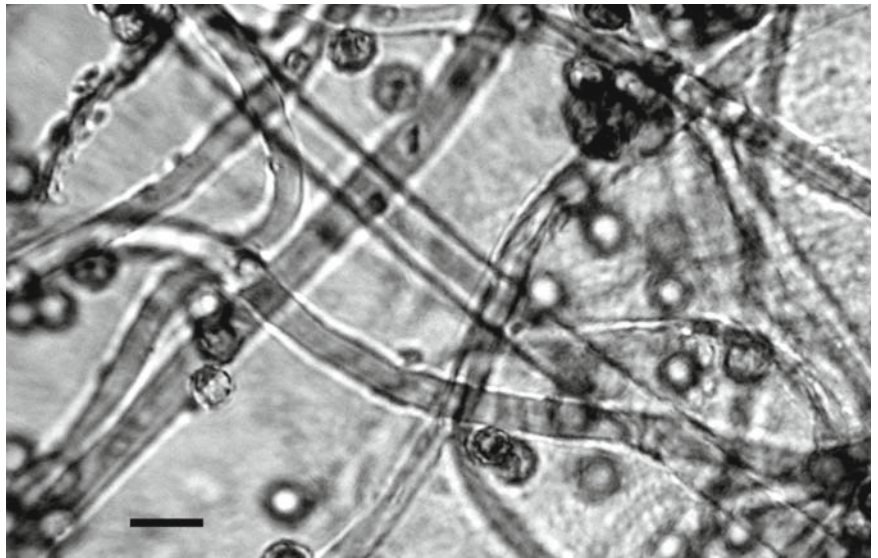
= *Geaster cesatii* Rabenh., Bot. Zeitung 9:628, 1851.

Basidiomata hypogeous to subhypogeous, globose to subglobose when young, about 10–15 mm in diameter, surface encrusted with debris, whitish to pale brown. Expanded basidiomata 20–35 mm across, exoperidium splitting into 4–9 rays that sometimes become arched or curved downward, nonhygroscopic although sometimes partly curled back when dry. Mycelial layer well developed, whitish, persistent, with plant debris and soil particles, attached to the fibrous layer for a long time, without forming a mycelial cup. Fibrous layer papery, white, cream to pale brown, outer side covered by the mycelial layer. Pseudoparenchymatous layer whitish at first, later becoming brown to dark brown, sometimes forming a collar-like patch around

**Fig. 16.** *Geastrum fornicatum* (TNS-F-18202).  
**A** Mature basidioma.  
**B** Fibrillose peristome.  
**C** Pseudoparenchymatous cells.  
**D** Hyphae of peristome.  
 Bars **A** 1.5 cm; **B** 1 mm;  
**C** 7 µm; **D** 5.5 µm



**Fig. 17.** Capillitial hyphae of *Geastrum fornicatum* (TNS-F-18202). Bar 5  $\mu\text{m}$



the stalk. Endoperidial body stipitate, depressed globose to subglobose, 5–10 mm in diameter, often with an indistinct apophysis. Stalk short, 1–2 mm long, pale brown to grayish brown. Endoperidium pale brown to grayish brown, almost smooth when old, but usually pruinose with whitish crystalline material in fresh basidiomata except for a smooth, circular area surrounding the peristome. Peristome surface fibrillose, distinct, 1–1.5 mm long. Columella cylindrical to clavate, sometimes indistinct. Mature gleba olivaceous brown to brown.

Pseudoparenchymatous layer consisting of thin-walled, hyaline to pale brown, bladder-like hyphae 10–40  $\mu\text{m}$  thick. Hyphae of the columella 1.5–10  $\mu\text{m}$  thick, hyaline to pale yellowish brown, thick walled. Hyphae of the capillitium yellowish brown, thick walled, 2–8  $\mu\text{m}$  thick, tapered gradually toward subacute tips, rarely dichotomously branched, surface smooth or encrusted. Basidia not seen. Basidiospores globose, densely verrucose, thick walled, olivaceous brown to dark brown, 4–5.5  $\mu\text{m}$  in diameter (mean = 4.5  $\mu\text{m}$ ) excluding ornaments, 4.5–6  $\mu\text{m}$  in diameter (mean = 5.5  $\mu\text{m}$ ) including ornaments, verrucae to 0.5  $\mu\text{m}$  high, basal apiculus prominent.

Habitat: Solitary or scattered on sandy soil.

Distribution: Japan (Tokyo and Aichi), China (Zhou et al. 2007), Europe (Calonge 1981, 1998; Sunhede 1989; Pegler et al. 1995), North Africa (Kasuya and Smaoui 2008), North America (Lloyd 1902; Long and Stouffer 1948), and Latin America (Esqueda et al. 2003).

Specimens examined: Japan, Metropolitan Tokyo, Nishitama-gun, Hinohara-mura, Ozawa, October 21, 2001, coll. K. Maruyama, TNS-F-13034; Aichi Pref., Tahara-shi, Irako Cape, April 1, 1987, coll. S. Yoshimi, TNS-F-243735.

Japanese name: Sunaji-hime-tsuehiguri (newly named).

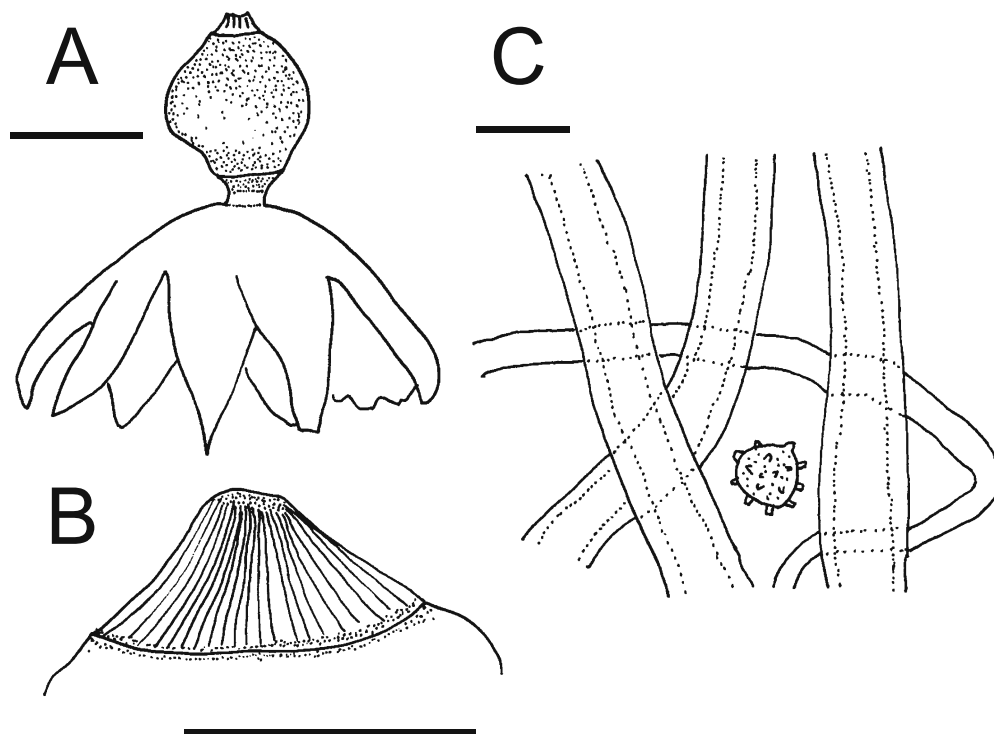
Remarks: The Japanese specimens of *G. minimum* are well characterized by nonfornicate, nonhygroscopic, white

to pale brown exoperidial rays, whitish mycelial layer persistently attached to the fibrous layer, and well-delimited, fibrillose peristomes. Morphological characteristics of the specimens examined are in good agreement with previous descriptions of *G. minimum* (Long and Stouffer 1948; Calonge 1981, 1998; Sunhede 1989; Pegler et al. 1995; Kasuya and Smaoui 2008). Therefore, we have identified the Japanese material as *G. minimum*.

*Geastrum quadrifidum* is morphologically very similar to *G. minimum* in its characteristics of basidiomata, especially of endoperidial bodies, peristomes, and basidiospores. However, *G. minimum* is clearly distinguished from *G. quadrifidum* by nonfornicate, 4–9 exoperidial rays, and mycelial layer attached to fibrous layer for a long time, without forming a mycelial cup. Morphological and ecological characteristics of *G. arenarius* Lloyd are very close to *G. minimum* in their nonfornicate exoperidial rays, whitish mycelial layer persistently attached to the fibrous layer, and well-delimited, fibrillose peristomes (Long and Stouffer 1948; Oteino 1966). Moreover, those two species usually grow on sandy soil. Nevertheless, *G. arenarius* has hygroscopic rays of the exoperidium and a nonstalked endoperidial body whereas *G. minimum* has nonhygroscopic rays and a distinct stalk. The basidiospores of *G. arenarius* are smaller (3.8–4.7  $\mu\text{m}$  in diameter; Oteino 1966) than those of *G. minimum*.

*Geastrum leptospermum* and *G. welwitschii* also have similar morphological characters to *G. minimum* in having small basidiomata, whitish exoperidia, and fibrillose peristomes. However, *G. leptospermum* and *G. welwitschii* are well separated from *G. minimum* by their fornicate, mostly 3–6, rays of the exoperidia, and the mycelial layer easily loosening from the fibrous layer and forming a mycelial cup (Coker and Couch 1928; Sunhede 1989). Further, *G. leptospermum* has smaller basidiospores (2–3  $\mu\text{m}$  in diameter; Coker and Couch 1928) than *G. minimum*.

**Fig. 18.** *Geastrum minimum* (TNS-F-243735). **A** Mature basidioma. **B** Fibrillose peristome. **C** Capillitial hyphae and basidiospore. Bars **A** 6 mm; **B** 1 mm; **C** 5  $\mu$ m



### Reexamination of *Geastrum minus* in Japan

“*Geastrum minus*” auct. non (Pers.) G. Cunn.: Imai, Bot. Mag. Tokyo 50:216, 1936. Figs. 5, 6, 14, 15, 19

Specimen examined: Japan, Hokkaido, Shiribeshi Prov., Otaru-shi, Zenibako, on sandy soil near seashore, May 11, 1892, coll. Y. Tokubuchi, SAPA 1109.

This material represents *Geastrum quadrifidum* DC. ex Pers. (Syn. Meth. Fung.: 133, 1801). Information from other Japanese collections (see “Other specimens examined,” indicated below) are also incorporated in the description given next.

Basidiomata hypogeous to subhypogeous, subglobose when young, about 10–15 mm in diameter, surface encrusted with debris, yellowish brown to pale brown. Expanded basidiomata 12–25 mm across, fornicate, exoperidium splitting into 3–5 rays that become often almost straight and vertical, with incurved margins attached to the mycelial layer, nonhygroscopic although sometimes partly curled back when dry. Mycelial layer well developed, whitish, with plant debris and sand, easily loosening from the fibrous layer and forming a mycelial cup. Fibrous layer thin, papery, white, cream to pale brown. Pseudoparenchymatous layer whitish at first, later becoming pale brown to gray brown, tending to fragment and peel off in several patches. Endoperidial body stipitate, subglobose to ovoid, 5–10 mm in diameter, with an apophysis. Stalk short, 0.5–3 mm long, pale brown to gray brown. Endoperidium pale brown to gray brown, conspicuously pruinose with whitish crystalline material except for a smooth, circular area surrounding the peristome. Peristome surface fibrillose, distinct, raised,

1–3 mm across. Columella cylindrical to clavate, indistinct. Mature gleba brown to dark brown.

Pseudoparenchymatous layer consisting of thin-walled, hyaline to pale brown, bladder-like hyphae 10–25  $\mu$ m thick. Columella hyphae 1–5.5  $\mu$ m in diameter, thick walled, hyaline to pale yellowish brown. Hyphae of the capillitium yellowish brown, thick walled, 2–6  $\mu$ m in diameter, tapered gradually toward subacute tips, rarely dichotomously branched, surface smooth or minutely encrusted. Basidia not seen. Basidiospores globose, verrucose, thick walled, yellowish brown to dark brown, 4.5–5.5  $\mu$ m in diameter (mean = 5  $\mu$ m) excluding ornaments, 5–6  $\mu$ m in diameter (mean = 5.4  $\mu$ m) including ornaments, verrucae to 0.5  $\mu$ m high, basal apiculus prominent.

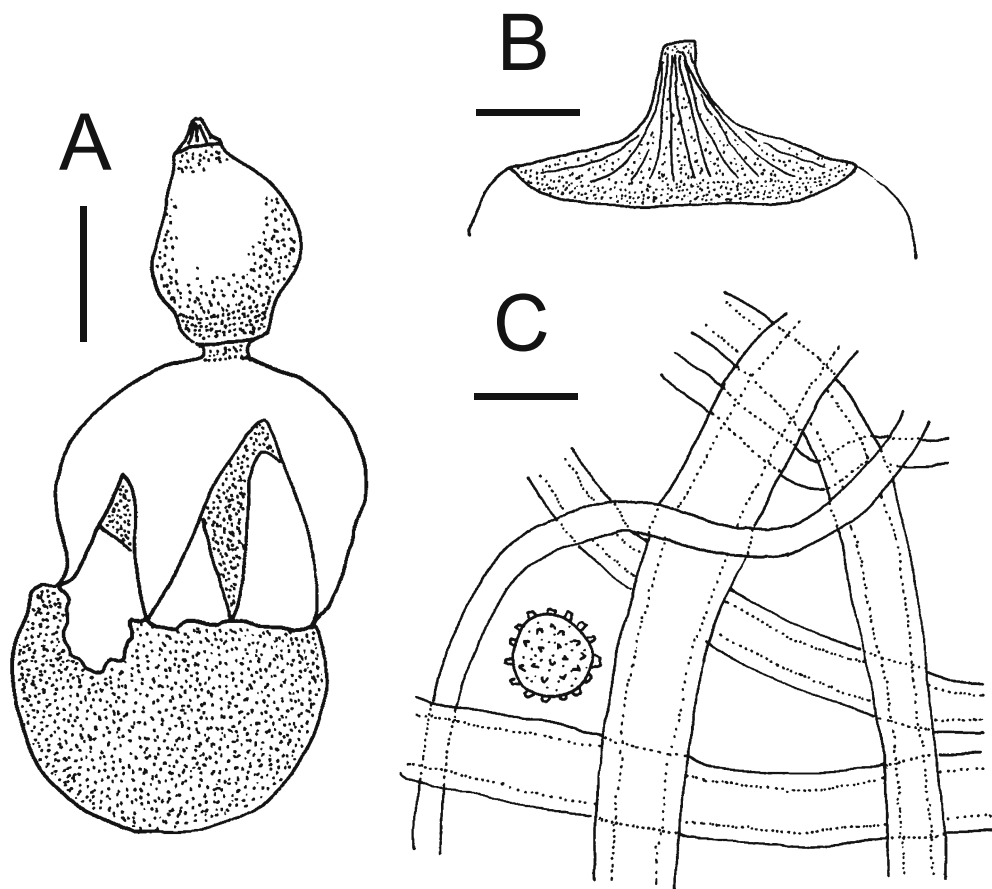
Habitat: Solitary, scattered, or gregarious on sandy soil near seashore or in coniferous woods.

Distribution: Japan (Hokkaido, Ibaraki, Chiba, Niigata, Mie, and Ehime), Europe (Calonge 1981, 1998; Sunhede 1989; Pegler et al. 1995), North America (Long and Stouffer 1948), and Latin America (Esqueda et al. 2003).

Other specimens examined: Hokkaido, Ishikari Prov., Ishikari-shi, Atsuta-ku, Muenhama, October 15, 2006, coll. C. Takehashi, TNS-F-18156; Ibaraki Pref., Hitachi-shi, Juuou-machi, Ijihama, January 25, 2004, coll. H. Sato, TNS-F-18205; Ibaraki Pref., Naka-gun, Tokai-mura, Toyooka, November 23, 2004, coll. H. Sato, INM-2-54838; same place, November 23, 2004, coll. K. Yoshida, INM-2-54839; same place, April 17, 2005, coll. T. Kasuya, INM-2-54840; Ibaraki Pref., Naka-gun, Tokai-mura, Muramatsu, April 17, 2005, coll. T. Kasuya, INM-2-54841; Ibaraki Pref., Hitachinaka-shi, Hitachi Kaihin Park, February 29, 2004, coll. H. Sakamoto, TNS-F-18217; same place, April 11, 2004, coll. H. Sakamoto, TNS-F-18206; same place, October 24, 2004,



**Fig. 19.** *Geastrum quadrifidum*. **A** Mature basidioma (TNS-F-18220). **B** Fibrillose peristome (TNS-F-18220). **C** Capillitial hyphae and basidiospore (TNS-F-18156). Bars **A** 7 mm; **B** 0.5 mm; **C** 5  $\mu$ m



coll. H. Sakamoto, TNS-F-18207; same place, December 26, 2004, coll. H. Sakamoto, TNS-F-18208; same place, January 23, 2005, coll. H. Sakamoto, TNS-F-18209; same place, March 13, 2005, coll. H. Sakamoto, TNS-F-18210; same place, November 13, 2005, coll. I. Asai, TNS-F-18211; same place, January 8, 2006, coll. H. Sakamoto, TNS-F-18212; Chiba Pref., Sammu-shi, Hasunuma, December 3, 2005, coll. H. Sakamoto, TNS-F-18214; Niigata Pref., Nagaokashi, Teradomari, November 2, 2003, coll. H. Sakamoto, TNS-F-18215; same place, November 5, 2005, coll. H. Sakamoto, TNS-F-18216; Mie Pref., Minamimuro-gun, Kihochi, Ida, October 9, 2003, coll. M. Taniguchi, TNS-F-18213; Ehime Pref., Ozu-shi, Hijikawa-cho, Yamatosaka, July 3, 2004, coll. T. Kasuya, TNS-F-16964.

Japanese name: Hime-kammuri-tsuhiguri (Imai 1936).

Remarks: Imai's authentic specimen, "SAPA 1109" (Imai 1936), is in good condition and characterized by typically fornicate, nonhygroscopic exoperidial rays, cupulate mycelial layer, pruinose endoperidium with crystalline material, and well-delimited, fibrillose peristome. These features clearly suggest that Imai's authentic material represents *G. quadrifidum*. Also, morphological characteristics of the other specimens examined are in good agreement with the previous descriptions of *G. quadrifidum* (Long and Stouffer 1948; Calonge 1981, 1998; Sunhede 1989; Pegler et al. 1995). According to the report by Imai (1936), *G. quadrifidum* was occasionally recorded from Japan under the name *G. minus* (Ito 1959; Yoshimi and Hongo 1989).

However, detailed macroscopic and microscopic features of this species were hitherto not described in Japan.

*Geastrum quadrifidum* is similar to *G. fornicatum*, *G. minimum*, *G. dissimile*, *G. leptospermum*, and *G. welwitschii* in its basidiome morphology, especially in its exoperidial rays, endoperidial body, and peristome. For comparison to *G. fornicatum* and *G. minimum*, see remarks under those two species, respectively. *Geastrum dissimile* is clearly distinguished from *G. quadrifidum* by its often sulcate or silky fimbriate, smooth peristome, and slightly smaller basidiospores (4–5  $\mu$ m in diameter; Bottomley 1948) than those of *G. quadrifidum*. *Geastrum leptospermum* can be separated from *G. quadrifidum* by its smaller basidiospores (2–3  $\mu$ m in diameter; Coker and Couch 1928). Further, *G. welwitschii* clearly differs from *G. quadrifidum* by its epigeal mycelial cup with a felted or tufted outer surface and indistinctly delimited peristome (Sunhede 1989; Calonge 1998).

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