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Source: Paleontological Research, 20(4) : 394-406

Published By: The Palaeontological Society of Japan

URL: https://doi.org/10.2517/2016PR013

Paleontological Research, vol. 20, no. 4, pp. 394–406, October 1, 2016

doi:10.2517/2016PR013

Morphologic variation and microspheric forms of *Parafusulina japonica* from Tamanouchi, Itsukaichi-Ome area, west Tokyo, Japan

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Received November 19, 2015; Revised manuscript accepted February 21, 2016

Abstract. **Specimens of *Parafusulina japonica* (Gümbel), middle Permian (late Wordian) Fusulinoidea from a small, exotic limestone block within the Middle Jurassic Kamiyozawa Formation exposed at Tamanouchi, west Tokyo, Japan, show considerable morphologic variation and include microspheric forms. The megalospheric specimens vary greatly in the shape and size of their tests, expansion of their tests, and in the shape and size of their proloculi. Two microspheric specimens are about twice the size of the megalospheric specimens and show early whorls to be schubertellid-like. The presence or absence of an initial one or two endothyroid whorl is not established. The shape of septal folds seems distinctive as they have slightly wider, flattened or slightly rounded dome-shaped tops both in megalospheric and microspheric forms. Cuniculi are absent in early whorls and quite poorly developed in later whorls where they are low inconspicuous features, suggesting a relatively early evolutionary stage in the *Parafusulina* lineage. The features of the megalospheric specimens have led some authors to place this species in the genus *Parafusulina* (*Skinnerella*) or even as a separate genus, *Skinnerella*. However, the microspheric specimens are much more typical of the genus *Parafusulina* (*Parafusulina*), and so *P. japonica* will be placed in the unsubdivided genus *Parafusulina*.**

Key words: Kanto Mountains, limestone block, microspheric forms, middle Permian, morphologic variation, *Parafusulina japonica*

Introduction

Late Paleozoic foraminifers are common in many limestone blocks and fragments in younger sediments in the Itsukaichi-Ome area, southeastern part of the Kanto Mountains, Tokyo, Japan (Kobayashi, 2005). Among them, one exposed at the river floor north of Tamanouchi, at the southeastern end of the mountains, contains many middle Permian (Wordian) fusulines of *Parafusulina*, *Neoschwagerina*, *Chusenella*, *Rauserella*, and others.

After Kobayashi's (2005) initial description of the fusulinid faunas, more than 100 additional limestone thin sections have been prepared to further examine the morphologic variation of *Parafusulina japonica* (Gümbel, 1874) and to compare them with those from the Nabeyama Formation in the Kuzu area, Ashio Mountains (Kobayashi, 2006) and the Akasaka Limestone (Kobayashi, 2011). Microspheric forms of *P. japonica*, though very rare, are newly recognized in these thin sections from Tamanouchi. Dimorphism is very conspicuous in North American *Parafusulina* (e.g. Dunbar and Skinner, 1937). On the other hand, it is uncommon in evolved schwagerinids from the Tethyan regions except for *Eopolydiexodina* from Iran (Kobayashi and Ishii, 2003). In Japan, it is exclusively known in *Parafusulina japonica* from the Kuzu area (Kobayashi, 2006). The juvenile stage of the microspheric tests of these two and other fusuline genera are completely omitted in the megalospheric tests.

Confirmation of microspheric forms of *Parafusulina japonica* is important taxonomically, since the test size of microspheric forms is two times larger than that of megalospheric ones in *Parafusulina* (e.g. Dunbar and Skinner, 1937), whereas these two forms are about the same size in *Skinnerella* (e.g. Skinner, 1971a). Characters of the juvenile stage of the fusuline test have a special bearing on the subject of dimorphism and evolution as suggested by many workers (e.g. Dunbar, 1963). However, the rea-

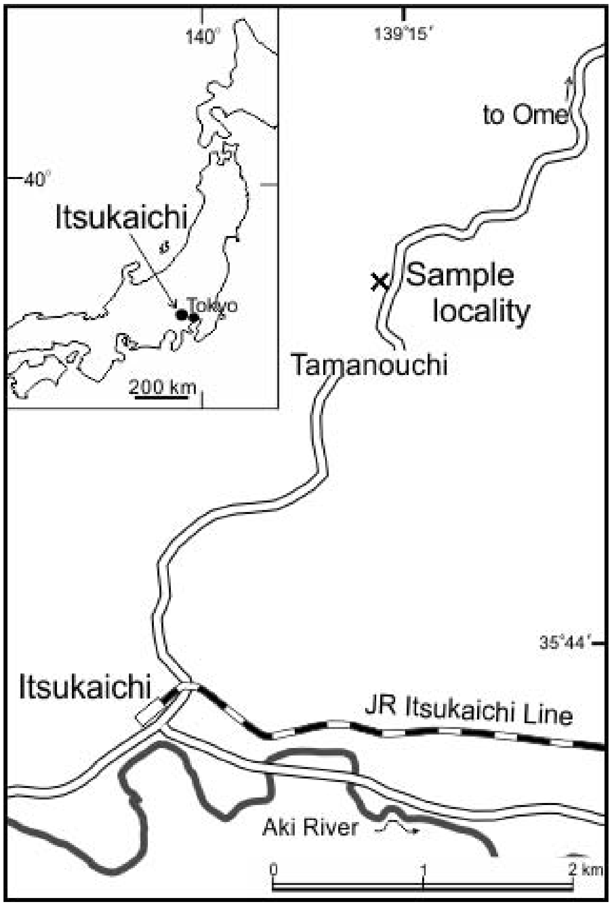

Figure 1. Map showing the sample locality north of Tamanouchi, Itsukaichi-Ome area, west Tokyo, Japan.

Figure 2. Fusuline packstone/grainstone containing many specimens of *Parafusulina japonica* and others. Scale bar is 5 mm.

son for these similarities and dissimilarities of fusuline test size, and details on their biological implications, are left largely unresolved.

Coogan (1960) subdivided *Parafusulina* into four subgenera, but did not delve deeply into the dimorphism of *Parafusulina*. Based mainly on the poorly developed cuniculi, Coogan (1960) assigned *Parafusulina japonica* to *Parafusulina* (*Skinnerella*), along with *Parafusulina yabei* Hanzawa, 1942, rather than to *Parafusulina* (*Parafusulina*). Both are characteristic species in the various Permian exotic boulders found within the Jurassic terranes of Japan. Kobayashi (2006) thought that these two similar species are better assigned to *Parafusulina* but recognized a need for future taxonomic studies.

The main purpose of this paper is to describe the morphologic variation of *Parafusulina japonica* and to announce the occurrence of its microspheric forms from Tamanouchi. The taxonomic problems of *Parafusulina* and *Skinnerella* are reviewed and discussed, and *P. japonica* is systematically described. All limestone thin sections from Tamanouchi are kept in the collection of the Earth Science Division, Museum of Nature and Human Activities, Hyogo, Japan (Fumio Kobayashi Collection).

Material, fauna, and age

Material studied in this paper is from a limestone sample (Kobayashi M-136) collected just north of Tamanouchi, Itsukaichi-Ome area, Tokyo (Figure 1). The sample locality is from the same locality described by Kobayashi (2005, Loc. 47). This limestone is an exotic block in the Middle Jurassic Kamiyozawa Formation, and is a fusuline packstone/grainstone (Figure 2) with smaller amounts of bioclasts of algae, bryozoans, crinoids, brachiopods, and rugose corals. From 31 thin sections at the locality, Kobayashi (2005) listed nine species of foraminifers: *Climacammina valvulinoides* Lange, 1925, *Palaeotextularia* sp., *Endothyra* sp., *Tetrataxis conica* Ehrenberg, 1854, *Abadehella coniformis* Okimura and Ishii in Okimura *et al*., 1975, *Rauserella* sp., *Chusenella sinensis* Sheng, 1963, *Parafusulina japonica*, and *Neoschwagerina margaritae* Deprat, 1913.

The foraminifers are mostly fusulines and *Parafusulina japonica* is dominant. A few non-fusulines found in association with *P. japonica* are illustrated in Figure 3. Newly recognized foraminifers are *Parafusulina* sp., *Dunbarula oviformis* Kobayashi, 2006, *Spireitlina* sp., and an indeterminable foraminifer with a hyaline wall. A rare *Parafusulina* sp. is discriminated from *P. japonica* in its almost cylindrical test and much more broadly rounded poles. *Dunbarula oviformis* closely resembles type specimens from the Kuzu area (Kobayashi, 2006). *Neoschwagerina margaritae* in Kobayashi (2005) is

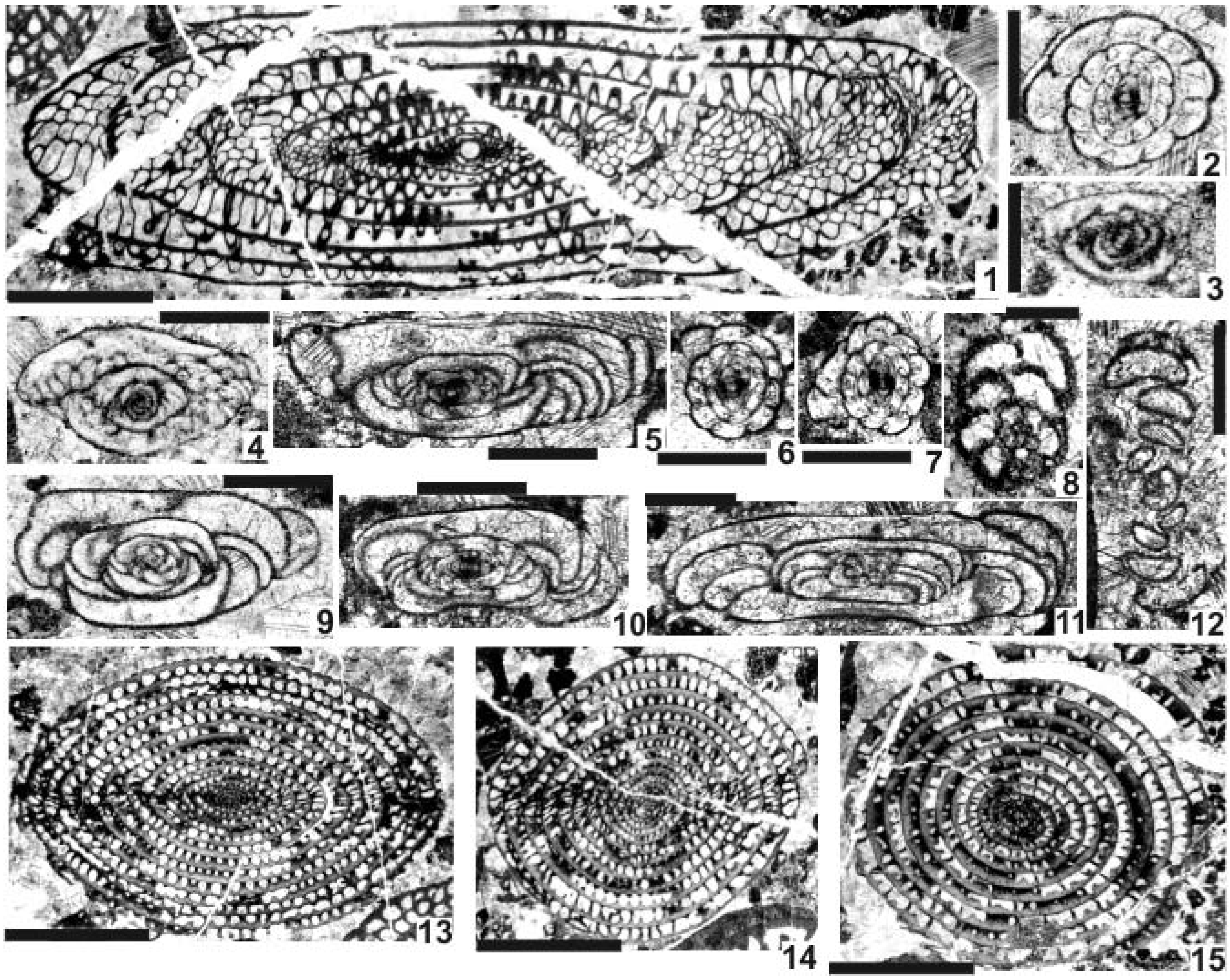

Figure 3. Some foraminifers associated with *Parafusulina japonica* Gümbel in sample M-136. **1,** *Parafusulina* sp., D2-036988; **2, 5–7, 9–11,** *Rauserella staffi* Skinner and Wilde; 2, D2-036954; 5, D2-036969; 6, D2-036920; 7, D2-036899; 9, D2-036977; 10, D2-036909; 11, D2-036980; **3, 4,** *Dunbarula oviformis* Kobayashi; 3, D2-036997; 4, D20-36926; **8,** *Spireitlina* sp., D2-036986; **12,** Indeterminable foraminifer, D2-036987; **13–15,** *Neoschwagerina colaniae* Ozawa; 13, D2-036915; 14, D2-036972; 15, D2-036972. Scale bar of 2 mm is for 1, 13–15; of 0.5 mm for 2–7, 9, 10–12; and of 0.2 mm for 8.

reassigned in this paper to *N. colaniae* Ozawa, 1927 based on reexamination of topotypes of the latter from the Akasaka Limestone (Kobayashi, 2011). An unnamed species of *Rauserella* in Kobayashi (2005) is herein identified as *R. staffi* Skinner and Wilde (1966), which they originally described from collections from the middle Permian of Sicily.

Parafusulina japonica is dominant in the lower Wordian *Neoschwagerina craticulifera* Zone in the Akasaka Limestone (Kobayashi, 2011). This zone correlates with the *Parafusulina tochigiensis* Zone in the Kuzu area (Kobayashi, 2006). *Parafusulina japonica* ranges upwards into the upper Wordian *N. colaniae* Zone in the Akasaka Limestone (Kobayashi, 2011). Thus, *P. japonica* from Tamanouchi is thought to be as old as *P. japonica* from the *N. colamiae* Zone at Akasaka and somewhat younger than *P. japonica* at Kuzu.

Morphologic variation in *Parafusulina japonica*

Forty-three axial and six sagittal sections are illustrated at the same magnification to visually compare the ranges of variation (Figure 4) of their measurements (Table 1), such as proloculus size, length, width, form ratio of the tests, wall thickness, and septal counts in the seventh whorl of the test (Figure 5). These include mea-

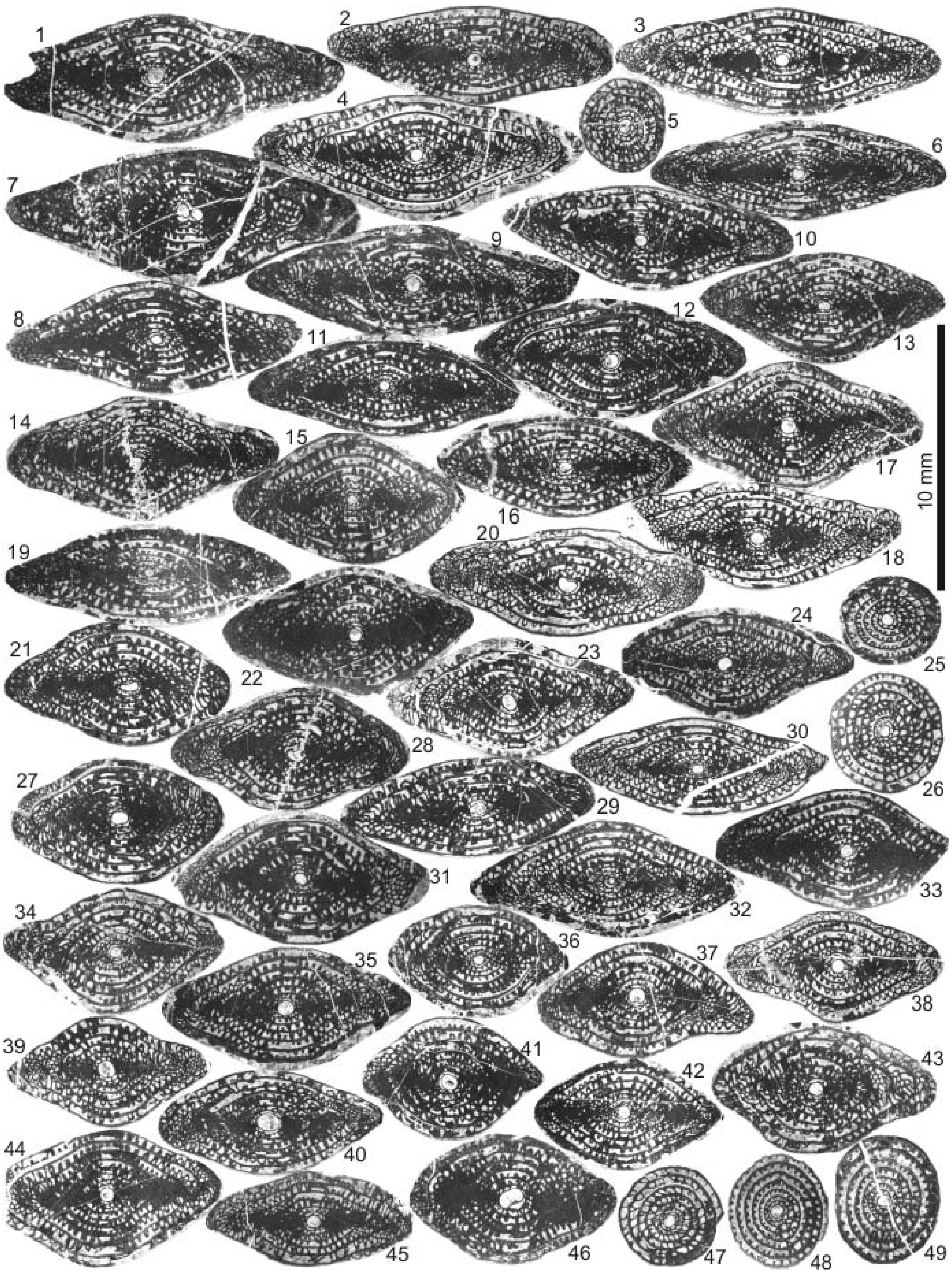

Figure 4. Megalospheric forms of *Parafusulina japonica* in sample M-136. **1–4, 6–24, 27–46,** axial sections; **5, 25, 26, 47–49,** sagittal sections; 1, D2-036989; 2, D2-036993; 3, D2-036934; 4, D2-036986; 5, D2-037006; 6, D2-036921; 7, D2-036917; 8, D2-037001; 9, D2-036989; 10, D2-036948; 11, D2-036905; 12, D2-036959; 13, D2-036966; 14, D2-036968; 15, D2-036950; 16, D2-036947; 17, D2-036900; 18, D2-036963; 19, D2-036964; 20, D2-036983; 21, D2-036977; 22, D2-036945; 23, D2-036961; 24, D2-036933; 25, D2-037005; 26, D2-036924; 27, D2-036925; 28, D2-036944; 29, D2-036938; 30, D2-036941; 31, D2-036952; 32, D2-036932; 33, D2-036953; 34, D2-036995; 35, D2-036991; 36, D2-036992; 37, D2-036997; 38, D2-036982; 39, D2-036910; 40, D2-036980; 41, D2-036960; 42, D2-036973; 43, D2-037000; 44, D2-036976; 45, D2-036913; 46, D2-036931; 47, D2-036904; 48, D2-036909; 49, D2-037002. Scale bar is for all.

surements of 74 specimens prepared for this study and ten others illustrated in Kobayashi (2005). The frequency distributions of the proloculi, length, width, form ratio, and wall thickness are shown in histograms (Figure 6). The septal count is not shown because of the small number of individuals.

Shape and size of proloculi.—Proloculi range from subspherical, ellipsoidal, subellipsoidal, to (rarely) subrectangular. A few specimens contain two proloculi (Figure 4.7). The size of proloculi differs greatly among megalospheric and microspheric forms. Also, the measured value of a proloculus does not always represent its actual size depending on whether the slide is cut exactly through the center of the proloculus or is slightly off-center. Even in the same specimen, the proloculus may be an ellipsoid or irregular and not spheroid. Longer diameters of proloculi range from 0.31 to 0.96 mm, averaging 0.55 mm in the 85 megalospheric forms measured.

Shape and size of tests, and number of whorls.—The test of *Parafusulina japonica* in megalospheric forms ranges from elongate to inflated fusiform with broadly arched periphery and broadly rounded to bluntly pointed poles (Figures 4, 7). Lateral slopes are generally straight but in some specimens may be slightly concave or convex. The width of inner whorls gradually increases to the third to fourth whorl, and then tends to be more or less constant, so that the form ratio of the test is fairly well established by the third or fourth whorls. The test is thought to have reached its mature stage at least in the seventh whorl. Length, width, and form ratio of the test of each specimen are not shown in Table 1 because the exact numbers are uncertain inasmuch as the outermost part of the tests in many specimens is often abraded. Fusuline tests tend to be abraded by many processes, such as waves, physical activities of other organisms, some sedimentary processes, and even by diagenesis and tectonic activity. For these reasons, it is unusual for a fossil fusuline test to have escaped without some abrasion and, most often, one to several outer whorls are broken and have been damaged or removed. In this study (rather arbitrarily) the seventh whorl is used to represent the beginning of the 'mature growth' stage of a megalospheric test in the genus *Parafusulina*, realizing that the test may have grown several more whorls.

Length of the seventh whorl is correctly measured only in the axial section of a specimen having a straight axis of coiling (Figure 5). Width of the seventh whorl is exactly measured in the sagittal section by the distance between at the 7 1/2th and at the end of the seventh whorl (= start of the eighth whorl) (Figure 5). In the axial section, however, it is actually done by the distance ranging either between more than the seventh and more than 7 1/2 or between less than 7 1/2 and less than the eighth whorl (Figure 5). By the seventh whorl, the test's form ratio (length/width) has become fairly well established and, although this ratio does continue to change as the test adds additional chambers, it usually remains a reliable feature for comparison of shape between conspecific specimens. Chamber height in the outermost whorl may be lower than in the preceding whorl as in some specimens of *Parafusulina shimotsukensis* Kobayashi, 2006 (Kobayashi, 2006, figs. 9.1 and 9.2). In this paper, the length and width at the seventh whorl are used to compare the test size instead of using the outermost test that might be present (Table 1, Figure 6). Length and width of corresponding whorls differ from specimen to specimen, depending on size and shape of the proloculus, and degree of roundness of the test. Length of the seventh whorl is especially variable, ranging from 6.54 to 12.36 mm in 52 specimens, and does not show a marked peak of frequency like that of proloculus size.

Thickness of wall.—Spiral wall consists of a tectum and alveolar keriotheca throughout the test of megalospheric forms. Thickness of the wall increases gradually to the fourth or fifth whorl, and then becomes more or less constant. The thickness ranges from 0.072 to 0.148 mm in the seventh whorl (Figure 6) at the tunnel region in the axial section and near the end of the seventh whorl in the sagittal section (Figure 5).

Septal counts.—The test is divided into numerous chambers by the septa. Septa are gently inclined anteriorly and variable in thickness due to the presence or absence of secondary deposits and their strength in the tunnel regions as well as the thickness of the wall. Septal counts per whorl are exactly measured from the starting point to the end point of each whorl, and range from 33 to 39 in the seventh whorl (Figure 5, Table 1). They increase ontogenetically and are variable in corresponding whorls, being 7 to 9, 14 to 20, 21 to 25, 27 to 30, 28 to 33, 32 to 36, and 33 to 39 from the first to the seventh whorl in 12 specimens. Septal counts are 9, 19, 24, 27, 28, 34, and 39 in the specimen with 7.1 whorls that is illustrated in Figure 4.48 (= Figure 7.3).

Septal folding.—Septa are strongly folded throughout the test, especially in polar regions. In axial sections, septal folds are rather regular, rounded to rectangular, and generally more than half as high as chambers and some reach the top of the chamber. Some are mushroom-shaped in outline as described by Skinner (1971a, p. 3). Strongly folded adjacent septa result in numerous, various-shaped chamberlets on and above the chamber floor in polar regions of the test. Morphologic features of septal folds are similar in general among the illustrated axial sections. Local absence of septal folds is due to loss by partial recrystallization (e.g. Figures 7.4, 7.20). Poor development or absence of cuniculi even in outer whorls

Table 1. Measurements of *Parafusulina japonica* in 86 Tamanouchi specimens in Kobayashi (2005) and this paper. They include number of whorls (Whorl), longer diameter of proloculus (*P*), and length (*7th L*), width (*7th W*), form ratio (*7th R*), thickness of wall (*7th Wall*), and septal counts (*7th S*) in the seventh whorl. An asterisk shows the specimen not illustrated in Figure 4.

Specimen no.	Figure	Whorl	*P*	*7th L*	*7th W*	*7th R*	*7th Wall*	*7th S*
D2-001475	8.1	7	0.68	8.45	4.81	1.76	0.101	–
D2-001471	8.2	8.5	0.60	7.72	3.99	1.93	0.106	–
D2-001478	8.3	6.3	0.65	–	–	–	–	–
D2-001474	8.4	6.5	0.57	–	–	–	–	–
D2-001476	8.5	6	0.92	–	–	–	–	–
D2-001469	8.6	7	0.59	9.27	4.30	2.16	0.085	–
D2-001482	8.7	7	0.62	11.30	4.25?	2.66	0.086	–
D2-001470	8.8	7.5	0.67	8.94	4.78	1.87	0.102	–
D2-001473	8.9	7	0.73	10.38	4.33	2.40	0.118	–
D2-001472	8.10	7.5	0.49	10.77	4.19	2.57	0.119	–
D2-036989	4.1	8	0.71	10.85	4.15	2.61	0.098	–
D2-036993	4.2	7	0.53	12.36	4.02	3.07	0.096	–
D2-036934	4.3	7	0.55	12.24	4.06	3.01	0.094	–
D2-036914	*	5.5	0.48	–	–	–	–	–
D2-036917	4.7	8	0.52	?	4.40	–	0.096	–
D2-036960	4.41	6.5	0.59	–	–	–	–	–
D2-036986	4.4	8	0.53	10.82	4.04	2.68	0.092	–
D2-036991	4.35	7	0.64	9.45	4.70	2.01	?	–
D2-036983	4.20	6.5	0.74	–	–	–	–	–
D2-037001	4.8	7.5	0.46	10.10?	3.95	2.56	0.102	–
D2-036959	4.12	8	0.57	8.49	3.86	2.20	0.094	–
D2-036989	4.9	7.5	0.59	11.11	3.88	2.86	0.090	–
D2-036952	4.31	7.5	0.49	9.25	4.67	1.98	0.099	–
D2-036941	4.30	7.5	0.46	8.85?	3.68	2.40	0.101	–
D2-036964	4.19	7	0.37	10.80?	3.85?	2.81	?	–
D2-036992	4.36	7.5	0.39	6.70?	3.84	1.74	0.098	–
D2-036968	4.14	7.5	0.47	?	?	–	0.093	–
D2-036945	4.22	8.5	0.49	7.15	3.95	1.81	0.086	–
D2-036926	*	7	0.59	10.45?	3.64	2.87	0.072	–
D2-036974	*	8	0.68	?	3.48	–	0.100	–
D2-036947	4.16	7	0.50	9.70	3.85	2.52	0.090	–
D2-036987	*	8	0.49	?	3.43	–	0.094	–
D2-036995	4.34	8	0.42	6.54	4.04	1.62	0.104	–
D2-036944	4.28	7.5	?	–	–	–	0.103	–
D2-036932	4.32	6.5	0.61	–	–	–	–	–
D2-036919	*	7	0.31	7.15	4.09	1.75	0.104	–
D2-036973	4.42	8	0.50	6.83	3.70	1.85	0.114	–
D2-036928	*	8	0.36	9.05	3.84	2.36	0.122	–
D2-036976	4.44	8.5	0.56	7.02	3.96	1.77	0.112	–
D2-036921	4.6	7.5	0.47	10.46	3.49	3.00	0.097	–
D2-036961	4.23	7	0.69	9.30?	4.63	2.01	0.087	–
D2-036996	*	6.5	0.63	–	–	–	–	–
D2-037000	4.43	7.5	0.57	8.49	4.71	1.80	0.104	–
D2-036925	4.27	8	0.65	7.44	4.06	1.83	0.097	–
D2-036933	4.24	7	0.57	8.90?	4.25?	2.09	?	–
D2-036966	4.13	8	0.46	8.36	3.54	2.36	0.090	–
D2-036941	4.30	8	0.44	7.62	4.18	1.82	0.114	–
D2-036937	*	7	0.43	6.61?	4.16	1.59	0.103	–
D2-036979	*	7	0.54	?	4.05?	–	0.102	–
D2-036963	4.18	7	0.58	10.75?	3.98	2.70	0.081	–
D2-036977	4.21	7.5	0.67	8.05	4.39	1.83	0.118	–
D2-036905	4.11	7.5	0.41	10.10	3.61	2.80	0.096	–
D2-036948	4.10	7.5	0.48	10.76?	3.68	2.92	0.098	–
D2-036900	4.17	8	0.60	8.88	4.34	2.05	0.103	–
D2-036984	*	7.5	0.39	9.79?	3.97	2.47	0.102	–
D2-036960	*	6.5	0.65	–	–	–	–	–
D2-036940	*	7	0.50	9.15	3.91	2.34	0.106	–
D2-036953	4.33	7.5	0.49	9.99?	4.23	2.36	0.103	–
D2-036938	4.29	7	0.67	9.80	3.66	2.68	0.088	–
D2-036975	*	6.5	0.61	–	–	–	–	–
D2-036980	4.40	7	0.76	8.52	3.96	2.15	0.082	–
D2-036929	*	7.5	0.57	8.37	3.42	2.45	0.094	–
D2-036971	*	7	0.43	8.95?	3.36?	2.66	0.099	–
D2-036942	*	7.5	0.51	8.90?	3.75	2.37	0.099	–
D2-036997	4.37	6.5	0.61	–	–	–	–	–
D2-036931	4.46	7	0.96	7.96?	4.94?	1.61	0.105	–
D2-036910	4.39	6.5	0.69	–	–	–	–	–
D2-036990	*	7	0.66	8.70?	3.90?	2.23	0.104	–
D2-036998	*	7.5	0.63	6.84?	4.26	1.61	0.100	–
D2-036936	*	6.5	0.50	–	–	–	–	–
D2-036985	*	6.5	0.58	–	–	–	–	–
D2-036981	4.38	6.5	0.53	–	–	–	–	–
D2-036946	*	7	0.72	8.45?	4.30?	1.97	0.101	–
D2-036913	4.45	6	0.52	–	–	–	–	–
D2-036904	4.47	6.5	0.50	–	–	–	–	–
D2-036920	*	6.8	0.56	–	4.22	–	0.103	37?
D2-036899	*	7.3	0.58	–	4.52	–	0.097	33
D2-036909	4.48	7.1	0.55	–	3.76	–	0.106	39
D2-036907	*	?	0.54	–	–	–	–	–
D2-036924	4.26	7.2	0.48	–	4.09	–	0.106	38
D2-036969	*	7	0.63	–	4.07	–	0.098	39?
D2-037007	*	7.2	0.47	–	4.44	–	0.102	?
D2-037005	4.25	5.7?	0.47	–	–	–	–	–
D2-037006	4.5	5.8	0.58	–	–	–	–	–
D2-037002	4.49	6.8	0.51	–	–	–	0.148	–
D2-036899	*	7.3	0.59	–	4.84	–	0.078	33
Mean value		7.2	0.56	9.12	4.06	2.26	0.100	35.8

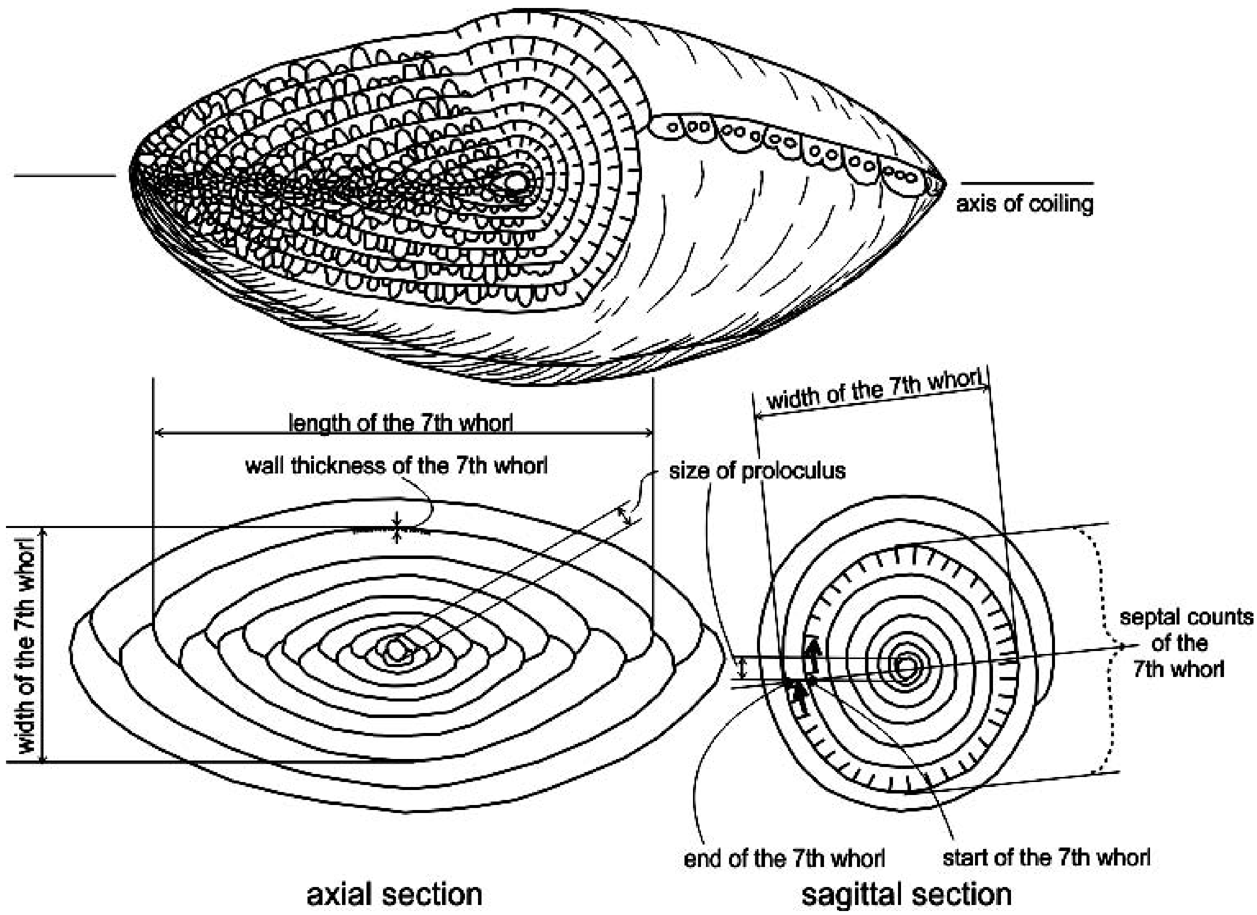

Figure 5. External view and inner structure (mode of coiling and septal folding) of the test in the megalospheric form of *Parafusulina japonica*, showing the scheme of measurements of the size of proloculus and those of length, width, thickness of wall, and septal counts in the seventh whorl of axial and sagittal sections of the test.

is also common in the material studied (Figures 7.7, 7.8). It is not possible to divide the present specimens by slight differences in the shape of the septal folds.

Advanced development of cuniculi is one of the diagnostic characters of *Parafusulina*, especially in many North American species. Cuniculi are very well developed and prominent features in all whorls after the first two or three whorls of *P. wordensis* Dunbar and Skinner, 1931, the type species of *Parafusulina*, according to C. A. Ross (pers. comm., 2013). Among the species from Japan, cuniculi are relatively well developed in *P. kaerimizensis* (Ozawa, 1925) that was assigned to *Parafusulina* (*Parafusulina*) by Kanmera (1963), though much poorer in comparison with some species of *Parafusulina* from North America (e.g. Dunbar and Skinner, 1937, pl. 72, fig. 3; pl. 73, fig. 10).

Axial filling.—Axial regions of the test are filled with dense, dark calcareous materials (axial filling) in many specimens. The amount of axial filling gradually changes within a specimen and from specimen to specimen and is almost absent in some specimens. In the outermost whorls, axial filling is not developed in most specimens.

The internal features of these tests under consideration may change gradually from specimen to specimen. These relative wide ranges of character variation also appear in other collections of *Parafusulina japonica* such as in Kuzu and Akasaka materials. Accordingly, these broad individual differences are intrapopulational variations that are intraspecific variation within a single species and do not have subspecies or species significance.

Review of the taxa *Parafusulina* vs. *Skinnerella*

Coogan (1960) subdivided *Parafusulina* into *Parafusulina* (*Parafusulina*), *Parafusulina* (*Skinnerella*), *Parafusulina* (*Eoparafusulina*), and *Parafusulina* (*Mon-*

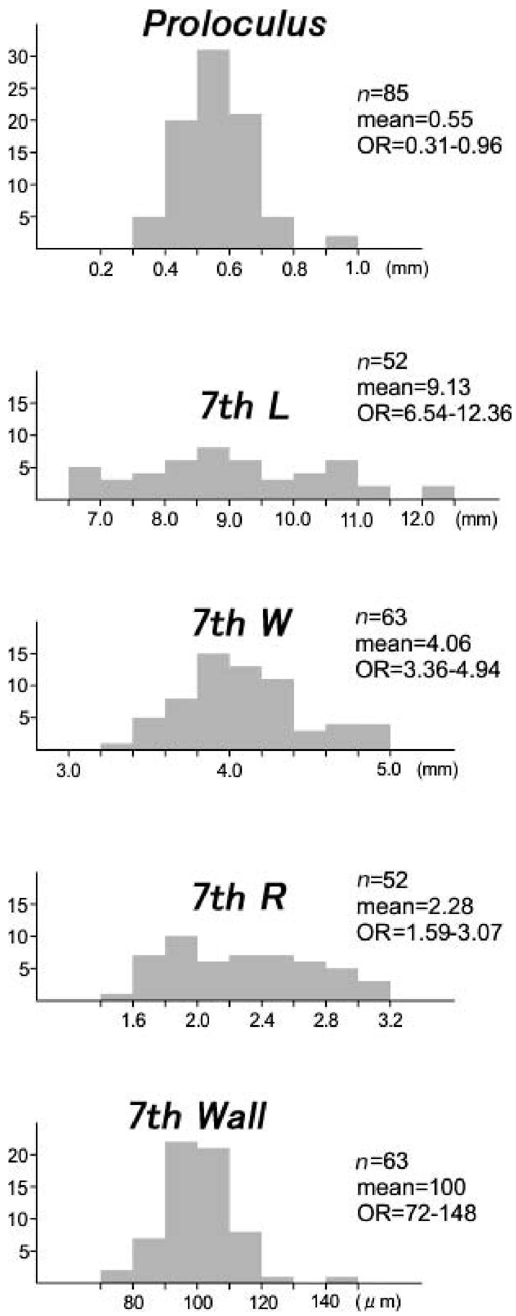

Figure 6. Frequency distribution histograms and statistical values [number of specimens (*n*), mean value, and observed range (OR)] of longer diameter of proloculus, and length, width, form ratio, and thickness of wall in the seventh whorl of megalospheric forms of *Parafusulina japonica* in Tamanouchi (M-136).

odiexodina). *Parafusulina* (*Skinnerella*) was distinguished from *Parafusulina* (*Parafusulina*) based mainly on weaker development of cuniculi, which are restricted to outer few whorls in *Parafusulina* (*Skinnerella*). *Parafusulina japonica* and *P. yabei*, described from Japan were reassigned to *Parafusulina* (*Skinnerella*) along with nine other species and two subspecies of *P. japonica* by Coogan (1960). Kanmera (1963) thought that *Parafusulina* (*Skinnerella*) had more inflated fusiform inner whorls than *Parafusulina* (*Parafusulina*) but that the two subgenera are not easily distinguished from one another based on the weak development of cuniculi.

Skinner (1971a) redefined *Parafusulina* (*Skinnerella*) and showed that septal folds in axial sections of *Parafusulina* (*Skinnerella*) are commonly squared off across the tops so that the tops are wider than at the base. He also believed megalospheric and microspheric forms were about the same size in *Parafusulina* (*Skinnerella*). These features are quite different in *Parafusulina* (*Parafusulina*) and are well described and illustrated by three new species of *Parafusulina* (*Skinnerella*) proposed by Skinner (1971a). Septa are more regularly folded and test size of microspheric forms is two times larger than in megalospheric *Parafusulina* (*Parafusulina*), especially in North American ones (e.g. Dunber *et al*., 1935; Dunbar and Skinner, 1937; Dunbar, 1953; Coogan, 1960; Stevens, 1995). Skinner (1971a; b) thought that *Parafusulina* (*Skinnerella*) evolved from species of *Schwagerina* such as *S. crassitectoria* Dunbar and Skinner, 1937 and *S. guembeli* Dunbar and Skinner, 1937 in late Wolfcampian or early Leonardian.

Vachard (in Vachard *et al*., 1997) considered that *Skinnerella* deserved generic rank. He thought that it originated in the Texas-Mexico-Guatemala region in the early to middle Leonardian and later migrated to the Tethyan regions in the Kubergandian (late Kungurian to early Roadian). Some authors, such as Kobayashi and Ishii (2003) and Leven (2009) also recognized *Skinnerella* as a genus based on the characteristics of the septal folds in their western Tethyan materials, which are closely similar to *Parafusulina* (*Skinnerella*) as redefined by Skinner (1971a).

Microspheric individuals in Japan

Occurrence of microspheric form[s] of *Parafusulina* in Japan has been confirmed in *P. japonica* from the Nabeyama Formation, Kuzu area (Kobayashi, 2006) and in this paper. There may be few microspheric forms of *P.* (*Skinnerella*) *sensu* Skinner, 1971a in the Tethyan regions. The tightly coiled inner whorls of the Kuzu specimen consist of a minute proloculus about 0.05 mm in diameter, succeeded by one and a half endothyroid whorls. They are succeeded by three and one-half elongate, fusiform schubertellid-like whorls. The actual size and number of whorls and the shape and form of septal folds in the outer part of the test in the microspheric form

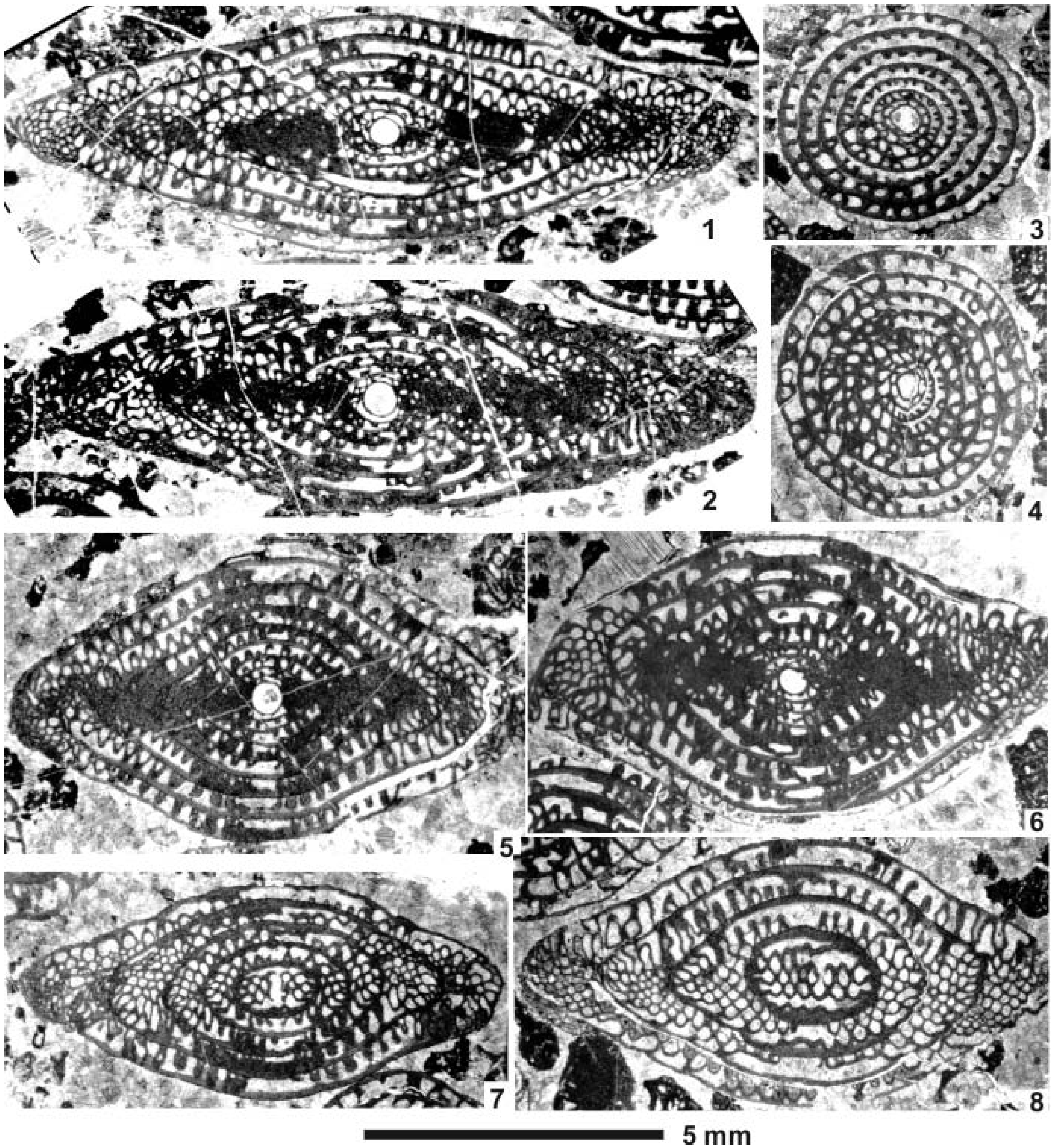

Figure 7. Two axial sections of elongate form (**1, 2**), two axial sections of inflated form (**5, 6**), two sagittal sections (**3, 4**), and two tangential sections (**7, 8**) of *Parafusulina japonica*. 1, D2-036934 (= Figure 4.3); 2, D2-036989 (= Figure 4.9); 3, D2-036909 (= Figure 4.48); 4, D2-036924 (= Figure 4.26); 5, D2-036976 (= Figure 4.44); 6, D2-036952 (= Figure 4.31); 7, D2-036958; 8, D2-036933. Scale bar is for all.

of *P. japonica* from Kuzu is not known because the outer whorls have been abraded off. Kobayashi (2006) placed *P. japonica* from Kuzu in *Parafusulina* and left open the question of a possible assignment to a subgenus to future taxonomic studies.

Original features of septal folds at the tunnel region of the test of *Parafusulina japonica* are almost erased due to secondary replacement of mosaic calcite in the two microspheric specimens from Tamanouchi. These two specimens are thought to be megalospheric counterparts of *Parafusulina japonica* and not those of *Parafusulina* sp. based on the entirety of septal folding, presence of phrenotheca, and better developed axial filling. The occurrence of *Parafusulina* sp. is only less than one percent of *P. japonica* in the sample studied. Septal folds of the two microspheric forms of *P. japonica* are closer to those of *Parafusulina* (*Skinnerella*) than to *Parafusulina* (*Parafusulina*). However, both microspheric tests are much more elongate, more than two times as long, than the megalospheric forms, which is similar to forms in *Parafusulina* (*Parafusulina*), so that the question of a subgeneric placement remains.

In the Tethyan fusuline faunas, the relative test size of microspheric forms compared to megalospheric forms appears to divide species in two groups, those having alternation of generations that are about the same size and those having contrasting sizes that differ by two times or more larger. In Permian Tethyan fusulines, for example, *Quasifusulina nimia* Kochansky-Devidé, 1959 (Kobayashi and Altiner, 2008), *Eopolydiexodina persica* (Kahler, 1933) (Kobayashi and Ishii, 2003), and many species of *Lepidolina* and *Colania* (e.g. Gubler, 1935; Ozawa, 1970) are consistently twice as long (often much more) as the megalospheric individuals, which is also true of *Parafusulina* and *Polydiexodina* in North America (e.g. Dunbar and Skinner, 1937). *Monodiexodina kattaensis* (Schwager, 1887) (Douglass, 1970), *Dutkevichia splendida* (Bensh, 1962) (Leven and Shcherbovich, 1978) and *Eoparafusulina brevis* Kobayashi and Altiner, 2008 (Kobayashi and Altiner, 2008) are always less than twice as long as the megalospheric individuals. Based on Ross (1964, p. 314) and Skinner (1971a; b), species of *Skinnerina* also belong to this latter group. This may lead to the speculation that the earlier fusuline genera in an evolutionary lineage have consistently shorter microspheric individuals whereas the later ones develop the more extreme lengths in their microspheric individuals. This pattern may be also in large part an artifact of the geographic and stratigraphic distribution of early and middle Permian fusuline faunas.

Characters of the juvenile stage of fusuline test have a special bearing on the subject of dimorphism and evolution as suggested by many workers (e.g. Dunbar, 1963), but the reason for these similarities and dissimilarities, and details on their biological implications are left largely unresolved. Microspheric individuals are much rarer than megalospheric counterparts, some by 1 in 10, some by 1 in 20, and in the case of middle Permian Tethyan fusulines from Japan, perhaps 1 in 100, or even rarer. Moreover, many other previously illustrated individuals may belong to either the megalospheric or microspheric form of a species based on the size of the proloculus and size and complexity of the test; i.e., both the megalospheric and microspheric forms, if present, have not been identified in the 19 specimens of *Gifuelloides larga* (Morikawa and Suzuki, 1961) or in the 17 specimens of *Yabeina globosa* (Yabe, 1906) both of which were described and illustrated by Kobayashi (2011) from the Akasaka Limestone. However, there are no reports from either the Permian Tethyan regions or North and South America of schwagerinids having both septal folds typical in *Parafusulina* (*Skinnerella*) and much larger microspheric than megalospheric tests as in the present Tamanouchi example. This remains an unresolved problem. Further information on dimorphism of fusulines referable to *Parafusulina* and *Skinnerella*, especially from the Tethyan regions, is necessary before a classification and an evolutionary history of these advanced forms of schwagerinids can be constructed.

Parafusulina japonica in the Tamonouchi material has septal folds typical to those of *Parafusulina* (*Skinnerella*). Based on its test size, however it appears to belong to *Parafusulina* (*Parafusulina*). Accordingly, generic assignment of species *japonica* to *Parafusulina* (*Skinnerella*) *sensu* Skinner, 1971a, needs further consideration from both the taxonomic and evolutionary points of view. In this paper, the species *japonica* is assigned to *Parafusulina*, which is treated as an undivided genus of evolved schwagerinids (see also Kobayashi, 2006; 2011) and is not subdivided into subgenera.

Systematic paleontology

Order Foraminiferida Eichwald, 1830
Suborder Fusulina Wedekind, 1937
Superfamily Fusulinoidea von Möller, 1878
Family Schwagerinidae Dunbar and Henbest, 1930
Genus ***Parafusulina*** Dunbar and Skinner, 1931

Parafusulina japonica (Gümbel, 1874)

Figures 4, 7, 8

Fusulina japonica Gümbel, 1874, p. 479; Gümbel *in* Schwager, 1883, p. 121, pl. 15, figs. 1–11; Deprat, 1913, p. 7, pl. 1, figs. 1–9.
Schwagerina furoni var. *tamonouchiensis* Sakagami, 1956, p. 262, pl. 37, figs. 4–12.
Parafusulina japonica (Gümbel) Kobayashi, 2005, p. 427, figs. 8.1–8.10; Kobayashi, 2006, p. 47, figs. 12.1–12.25; Kobayashi, 2011, p. 470, pl. 15, figs. 9–15; pl. 16, figs. 1–27.

Type locality.—Akasaka Limestone, Ogaki City, Gifu Prefecture, Japan.

Diagnosis.—Shape and size of the proloculus and the

Figure 8. Microspheric forms of *Parafusulina japonica*. **1,** D2-036939; **2,** D2-36992. Scale bar of 3 mm is for 1a and 2a, and of 1 mm is for 1b and 2b.

test are highly variable in megalospheric forms. Microspheric tests, though very rare, are about twice the length of megalospheric tests. Septal folds are high, reaching nearly to the top of the chamber as is typical of *Parafusulina* (*Skinnerella*). Cuniculi absent or are poorly developed only in outer whorls.

Description of megalospheric forms.—Test elongate to inflated fusiform with broadly arched periphery, mostly straight lateral slopes, and straight axis of coiling. Mature test with seven to eight and a half whorls, more than 6 mm in length and more than 3.6 mm in width, and about 1.6 to 3.1 in form ratio. Proloculus spherical, subspherical, ellipsoidal, often irregular, rarely rectangular, and 0.31 to 0.96 mm in its longer diameter. Test increasing more in length than in width in inner three to four whorls, then the form ratio is more or less constant in outer whorls.

Septa strongly folded throughout the test. Septal folds rather regular, rounded to rectangular, more than half as high as chambers, and some in polar regions reaching the top of chambers. Septal counts 7 to 9, 14 to 20, 21 to 25, 27 to 30, 28 to 33, 32 to 36, and 33 to 39 from the first to the seventh whorl in 12 specimens. Combination of strongly folded septa results in numerous, various-sized, various-shaped chamberlets on and above the chamber floor in polar regions. Cuniculi poorly developed only in outer whorls of the test or absent. Phrenotheca weakly developed in middle and outer whorls in some specimens.

Wall composed of a tectum and alveolar keriotheca; ranges from 0.072 to 0.148 mm in thickness and averaging 0.100 mm in 63 specimens. Rudimentary chomata present only on surface of the proloculus. Tunnel low, not well developed. Axial filling well developed in axial regions in earlier whorls and rare to almost absent in the outer one or two whorls.

Description of microspheric forms.—Two microspheric forms and a few doubtful ones of *Parafusulina japonica* were newly recognized in 109 thin sections prepared for this study. They are not centered and not completely preserved due to secondary mineralization, some abrasion, and partial gaps in the completeness of the test. One specimen illustrated in Figure 8.1 consists of more than ten whorls and is more than 3 mm in width with a length of more than 28 mm. The other, shown in Figure 8.2, has more than ten whorls and is more than 3.5 mm in width. Both specimens have highly elongate cylindrical tests, much longer, possibly more than two times longer, than the longest megalospheric form of this species. Their periphery is straight and the poles are broadly rounded. Loosely concave-convex periphery is possibly due to weak deformation in the median part of the test.

Distinct embryonic whorls are similar to those of the Kuzu specimen (Kobayashi, 2006, fig. 12.21), although the presence or absence of an endothyroid whorl is unknown. These tests are highly elongate fusiform in shape with pointed poles and appear to be schubertellid-like except for the folded septa. Thickness of the wall in the outer whorls is variable depending on the degree of secondary replacement of mosaic calcite, and partly shows a thinner appearance than in the preceding whorls.

Septal folds, phrenotheca, and axial filling are similar to those of megalospheric forms. Appearance of weaker septal folds in the median part of the test is apparently due to recrystallization, and seems to result from a broad, asymmetric, not straight passage referable to the tunnel.

Discussion.—Diagnostic test characters were clearly described and nine illustrations of this species given by Deprat (1914) based on the topotype specimens from the Akasaka Limestone. However, they have been interpreted and recognized in various ways by workers. Some workers erroneously identified or compared the lower to middle Permian schwagerinids with this species, as discussed in Kobayashi (2011). *Schwagerina furoni* var. *tamonouchiensis* proposed by Sakagami (1956) from the same limestone as the present one is only one such example. Sakagami did not notice the abrasion of the outer test in his two axial sections. Based on shape and size of the proloculus and the mode of axial filling, he suggested its similarity to *S. furoni* Thompson, 1946 from the Bamian Limestone, Afghanistan (Thompson, 1946). However, these two specimens and the other nine sections in the Sakagami (1956) collection are reassigned to *P. japonica*.

Rarely associated with *P. japonica* is an unnamed species of *Parafusulina* (Figure 3.1) with an almost cylindrical test, much more broadly rounded poles, and weaker axial filling. It has also septal folds typical of those of *Parafusulina* (*Skinnerella*).

Two microspheric specimens illustrated are megalospheric counterparts of *Parafusulina japonica* and not of *Parafusulina* sp., as indicated above. All of the megalospheric forms of *P. japonica* from Tamanouchi, Kuzu (Kobayashi, 2006), and Akasaka (Kobayashi, 2011) show similar test characters. The proloculi are somewhat larger in the Tamanouchi specimens than in the other two localities. This difference is thought to indicate a younger age of the Tamonouchi specimens, which is from the *Neoschwagerina colaniae* Zone (upper Wordian), whereas the Akasaka sample (Ak-70) and Kuzu sample (Ka-28) are from the *N. craticulifera* Zone (lower Wordian) as indicated by Kobayashi (2011).

Occurrence.—Abundant in fusuline packstone/grainstone. Microspheric forms are very rare, occurring in a ratio of one in several hundreds of megalospheric forms.

Acknowledgments

I am deeply grateful to Charles A. Ross for his careful examination and refining of the English throughout the pages of the original and revised manuscript and for his helpful and constructive comments. Thanks are also due to Calvin H. Stevens and an anonymous reviewer for their helpful comments and suggestions.

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