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Thailandina and *Neothailandina* and their family Thailandinidae salvaged: a valid taxonomic group of peculiar Permian fusuline Foraminifera

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The fusuline genera *Thailandina* Toriyama and Kanmera, 1968 and *Neothailandina* Toriyama and Kanmera, 1968 were established by Toriyama and Kanmera (1968) based on material from the Khao Phlong Phrab section of the Permian Rat Buri Limestone in central Thailand that is currently assigned to the Khao Khad Formation of the Saraburi Group (Ueno and Charoentitirat, 2011). These fusuline genera are peculiar in having parachomata and replaced tests by secondary mineralization. Moreover, *Neothailandina* was described to have a test with transverse septula, considered to be characteristic for Neoschwagerinidae. Based on these remarkable test features, Toriyama and Kanmera (1968) newly introduced the subfamily Thailandininae to accommodate these two new genera and assigned it to the Neoschwagerinidae, despite the lack of septula in *Thailandina*. Later, Kobayashi et al. (2010) argued that *Thailandina* and *Neothailandina* are just a mixed grouping of several known genera of schwagerinids, verbeekinids, and neoschwagerinids that are too altered by recrystallization to be recognizable, and rejected the taxonomic validity of these two genera as well as Thailandininae.

The Khao Phlong Phrab section represents one of the standard late Cisuralian−Guadalupian (late early−middle Permian) fusuline successions in the eastern Paleotethys (Zhang and Wang, 2018) and contains not only *Thailandina* and *Neothailandina* but also abundant schwagerinid, verbeekinid, and neoschwagerinid fusulines (Toriyama, 1975; Fig. 1). I investigated the original specimens described by Toriyama and Kanmera (1968) and Toriyama (1975) from the section that are housed in the Department of Earth and Planetary Sciences of Kyushu University, Japan. I found that most of the grounds for Kobayashi et al.'s (2010) arguments to regard the thailandinin genera as taxonomically invalid are not supported by observations on these specimens as explained in the account that follows. In this taxonomic note, I propose that *Thailandina* and *Neothailandina*, and their family Thailandinidae, should be retained as valid taxonomic groups.

Kobayashi et al. (2010) noted, while referring to a similar opinion by Rauzer-Chernousova et al. (1996), that *Thailandina buravasi* Toriyama and Kanmera, 1968 (Figs. 2.1–2.5, 3.13), the type species of the genus, merely represents replaced specimens of the genus *Misellina* Schenck and Thompson, 1940. In fact, *Thailandina* usually occurs together with several different species of *Misellina* (Figs. 1, 3.1–3.3, 3.9, 3.13), e.g., *Misellina* cf. *Misellina termieri* (Deprat, 1915) and *Misellina confragaspira* Leven, 1967, and also occurs with the somewhat similar *Armenina saraburiensis* (Toriyama and Kanmera in Toriyama, 1975) (Fig. 3.8) and *Maklaya saraburiensis* Kanmera and Toriyama, 1968 (Fig. 3.4). But, *T. buravasi* consistently has an ∼1.5−2 times larger test in axial length than coexisting *Misellina*, *Armenina*, and *Maklaya* spp. *Thailandina hongnusonthiae* Toriyama and Kanmera, 1968 (Fig. 2.7) and *T.* sp. A (Fig. 2.6) have even larger tests, which are definitely out of the size range of known *Misellina* spp. These observations conclude that *Thailandina* cannot be regarded as recrystallized specimens of coexisting *Misellina*, or even of the similar *Armenina* Miklukho-Maklay, 1955 and *Maklaya* Kanmera and Toriyama, 1968. Moreover, Kobayashi et al. (2010) thought that the apparent large to giant proloculi in thailandinin specimens are the mere result of recrystallization of (smaller) proloculi and the early few volutions of the test and thus, do not show the original size of the proloculus. However, this observation does not seem reasonable. As illustrated in Figures 2.1–2.3, 2.5–2.7, and 3.13, a circular wall seen in the central part of *Thailandina* makes a distinct boundary with the inner hollow space, which is filled with mosaic calcite crystals that are similar to sparry calcite cement surrounding fusuline tests in the same limestone sample. Additionally, there is no vestige of test structure inside the circular wall. These observations lead to an interpretation that the large spherical 'openings' in the central part of *Thailandina* tests could never be a replaced relict of small proloculi plus a few inner whorls, but indeed represent the proloculus. *Neothailandina* has even larger proloculi (Fig. 2.8–2.12, 2.16, 2.17) and, as in *Thailandina*, these specimens also have a sharp prolocular wall separating the inner hollow space and outer coiled chambers, although in some specimens (Fig. 2.8, 2.17), the wall becomes slightly vague. It is interesting to note that there is a somewhat irregular, large, first coiled chamber that surrounds the large proloculus in some *Neothailandina* specimens (Fig. 2.9, 2.11) and this resembles the circumproloculus chamber described by Thompson (1964, fig. 283). Thus, the large central 'openings' in both *Thailandina* and *Neothailandina* are not made by the selective recrystallization of the inner part of the tests, but are considered as innate morphology of these fusulines, i.e., the proloculus.

As for some *Neothailandina* (Fig. 2.8, 2.10, 2.15–2.18), Kobayashi et al. (2010) considered that they are probably referable to recrystallized *Parafusulina*-like schwagerinids. In this regard, they probably mistook regularly arranged semicircular

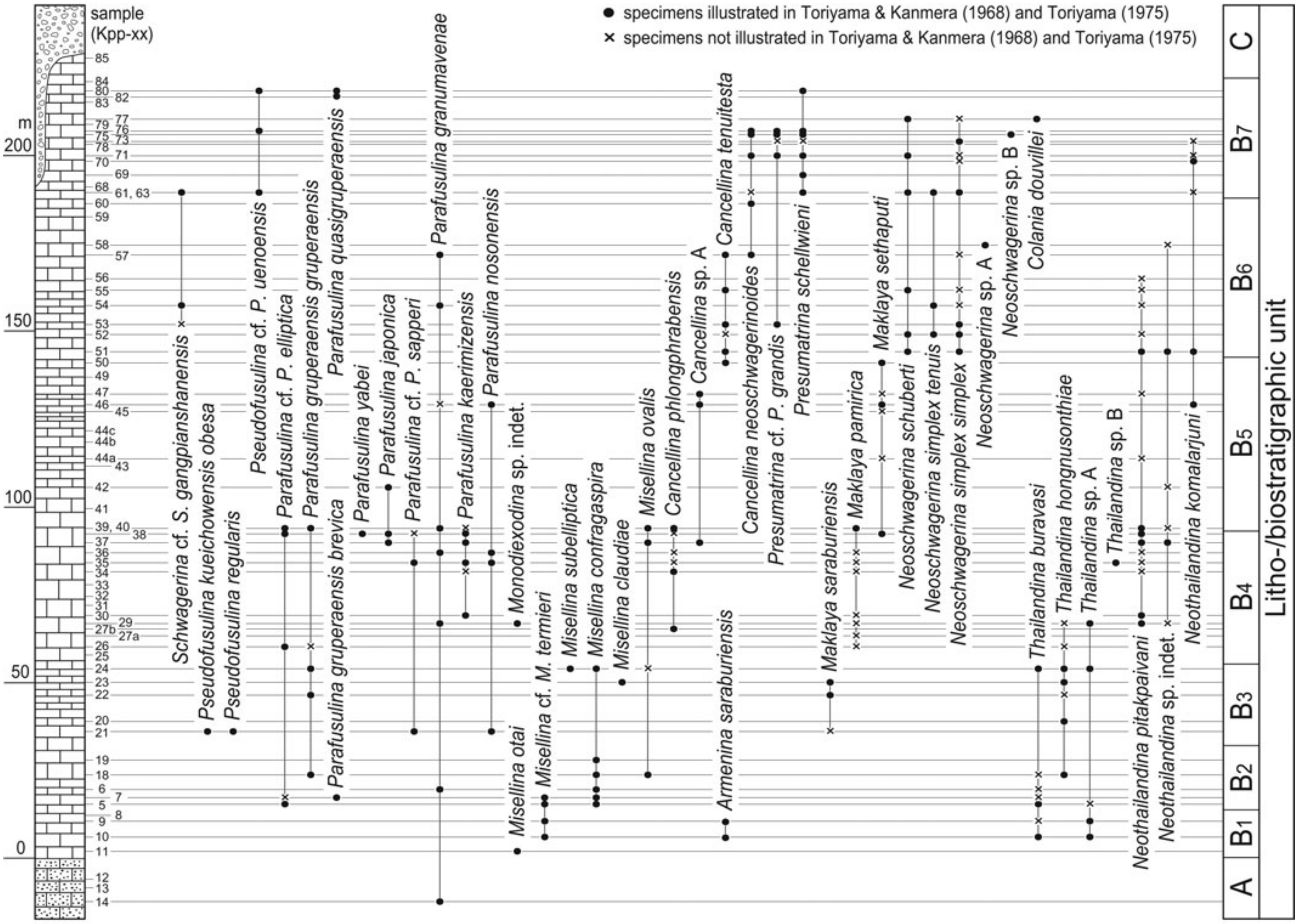

Figure 1. Stratigraphic ranges of *Thailandina*, *Neothailandina*, and associated major fusulines (schwagerinids, verbeekinids, and neoschwagerinids) in the Khao Phlong Phrab section of central Thailand (modified from Toriyama, 1975). Litho-/bioiostratigraphic units, A: mostly crystalline limestone, B_1–B_7: limestone, B_1: *Misellina otai-Misellina* cf. *Misselina termieri* Biozone, B_2: *Misellina confragaspira* Biozone, B_3: *Maklaya saraburiensis* Biozone, B_4: *Maklaya pamirica* Biozone, B_5: *Maklaya sethaputi* Biozone, B_6: *Neoschwagerina simplex* Biozone, B_7: *Presumatrina schellwieni* Biozone, C: limestone conglomerate. Taxa include: *Armenina saraburiensis* (Toriyama and Kanmera in Toriyama, 1975); *Cancellina neoschwagerinoides* (Deprat, 1913); *Cancellina phlongphrabensis* Toriyama and Kanmera in Toriyama, 1975; *Cancellina tenuitesta* Kanmera, 1963; *Colania douvillei* (Ozawa, 1922); *Maklaya pamirica* (Leven, 1967); *Maklaya saraburiensis* Kanmera and Toriyama, 1968; *Maklaya sethaputi* Kanmera and Toriyama, 1968; *Misellina claudiae* (Deprat, 1912); *Misellina confragaspira* Leven, 1967; *Misellina ovalis* (Deprat, 1915); *Misellina otai* Sakaguchi and Sugano, 1966; *Misellina subelliptica* (Deprat, 1915); *Misellina* cf. *Misellina termieri* (Deprat, 1915); *Neoschwagerina schuberti* Kochansky-Devidé, 1958; *Neoschwagerina simplex simplex* Ozawa, 1927; *Neoschwagerina simplex tenuis* Toriyama and Kanmera in Toriyama, 1975; *Neothailandina komalarjuni* Toriyama and Kanmera, 1968; *Neothailandina pitakpaivani* Toriyama and Kanmera, 1968; *Parafusulina* cf. *Parafusulina elliptica* Sheng, 1963; *Parafusulina granumavenae* (Roemer, 1880); *Parafusulina gruperaensis brevica* Sheng, 1963; *Parafusulina gruperaensis gruperaensis* Thompson and Miller, 1944; *Parafusulina japonica* (Gümbel, 1874); *Parafusulina kaerimizensis* (Ozawa, 1925); *Parafusulina nosonensis* Thompson and Wheeler in Thompson, Wheeler, and Hazzard, 1946; *Parafusulina quasigruperaensis* Sheng, 1963; *Parafusulina* cf. *Parafusulina sapperi* (Staff, 1912); *Parafusulina yabei* Hanzawa, 1942; *Presumatrina* cf. *Presumatrina grandis* Leven, 1967; *Presumatrina schellwieni* (Deprat, 1913); *Pseudofusulina kueichowensis obesa* Sheng, 1963; *Pseudofusulina regularis* (Schellwien, 1898); *Pseudofusulina* cf. *Pseudofusulina uenoensis* Kobayashi, 1957; *Schwagerina* cf. *Schwagerina. gangpianshanensis* Sheng, 1965; *Thailandina buravasi* Toriyama and Kanmera, 1968; *Thailandina hongnusonthiae* Toriyama and Kanmera, 1968.

structures seen in the lower part of chambers in the outer volutions of *Neothailandina* for septal loops in schwagerinids. In fact, there are a number of schwagerinid species, including those of *Parafusulina* Dunbar and Skinner, 1931, co-occurring with *Neothailandina* in the Khao Phlong Phrab section (Fig. 1). However, most associated *Parafusulina* spp. have elongate fusiform and cylindrical tests exemplified by *Parafusulina japonica* (Gümbel, 1874) (Fig. 3.12), and are fundamentally different in gross test morphology from thailandinids. Especially, *Neothailandina komalarjuni* Toriyama and Kanmera, 1968 (Fig. 2.17, 2.18), with its gigantic test, is not comparable to any schwagerinids from the section. There are a few species of *Parafusulina* and *Pseudofusulina* Dunbar and Skinner, 1931 that have fusiform or short cylindrical tests (e.g., *Pseudofusulina kueichowensis obesa* Sheng, 1963; Fig. 3.11). But, they have different internal test structures from thailandinids and so, these schwagerinids would not look like thailandinids even if they exhibited recrystallization. Kobayashi et al. (2010) also stated that some of *Neothailandina* (including the specimen illustrated in Fig. 2.14) are possibly recrystallized Neoschwagerinidae because vague, recrystallized partitions are preserved that probably correspond to transverse and axial septula. As shown in Fig. 1, there are a number of neoschwagerinid species from the Khao Phlong Phrab section and Toriyama

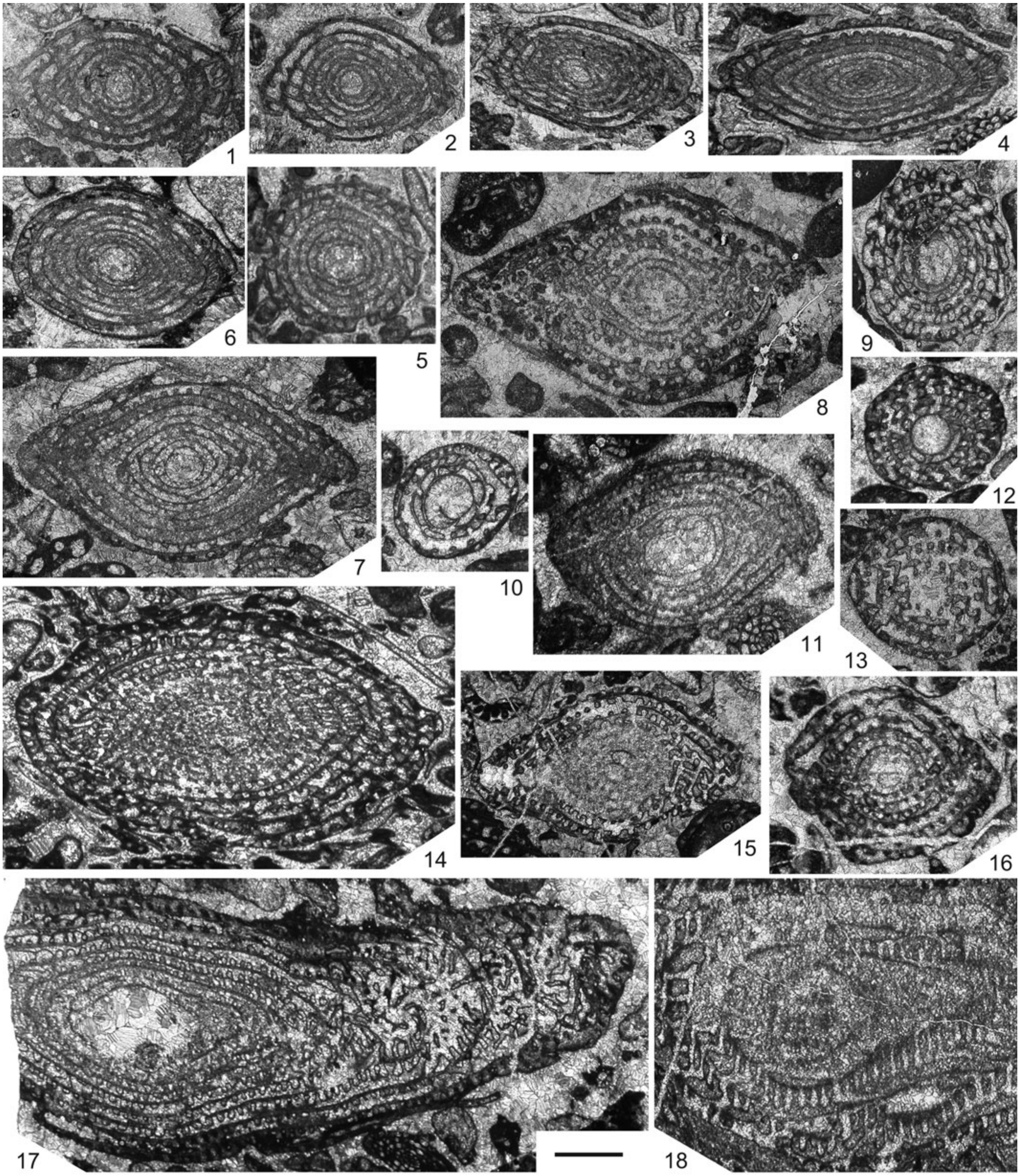

Figure 2. *Thailandina* and *Neothailandina* reported by Toriyama and Kanmera (1968) from the Khao Phlong Phrab section of central Thailand. Original photomicrographs from Toriyama and Kanmera's (1968) thin sections; plate and figure numbers in parentheses denote those by Toriyama and Kanmera (1968). (**1–5**): *Thailandina buravasi* Toriyama and Kanmera, 1968: (**1**) axial section of holotype (GK.D14009; pl. 6, fig. 1), Kpp-5; (**2, 3**) axial sections (pl. 6, figs. 5, 7), Kpp-5 and Kpp-24; (**4**) axial section of microspheric specimen (pl. 6, fig 8), Kpp-5; (**5**) sagittal section (pl. 6, fig. 13), Kpp-5; (**6**) *Thailandina* sp. A, axial section (pl. 6, fig. 16), Kpp-10; (**7**) *Thailandina hongnusonthiae* Toriyama and Kanmera, 1968: axial section of holotype (GK.D13712a; pl. 7, fig. 1), Kpp-20; (**8–16**) *Neothailandina pitakpaivani* Toriyama and Kanmera, 1968: (**8**) axial section of holotype (GK.D13074a; pl. 7, fig. 9), Kpp-39; (**9, 10, 12**) sagittal sections (pl. 8, figs. 4, 5, 7), Kpp-30 and Kpp-39; (**11, 15, 16**) axial sections (pl. 7, figs. 10, 12, 14), Kpp-29, Kpp-37, and Kpp-51; (**13**) tangential section (pl. 7, fig. 19), Kpp-39; (**14**) oblique section (pl. 7, fig. 17), Kpp-29; (**17, 18**): *Neothailandina komalarjuni* Toriyama and Kanmera, 1968: (**17**) axial section (pl. 8, fig. 12), Kpp-51; (**18**) tangential section (pl. 8, fig. 14), Kpp-46. Scale bar = 1 mm (applicable to all specimens).

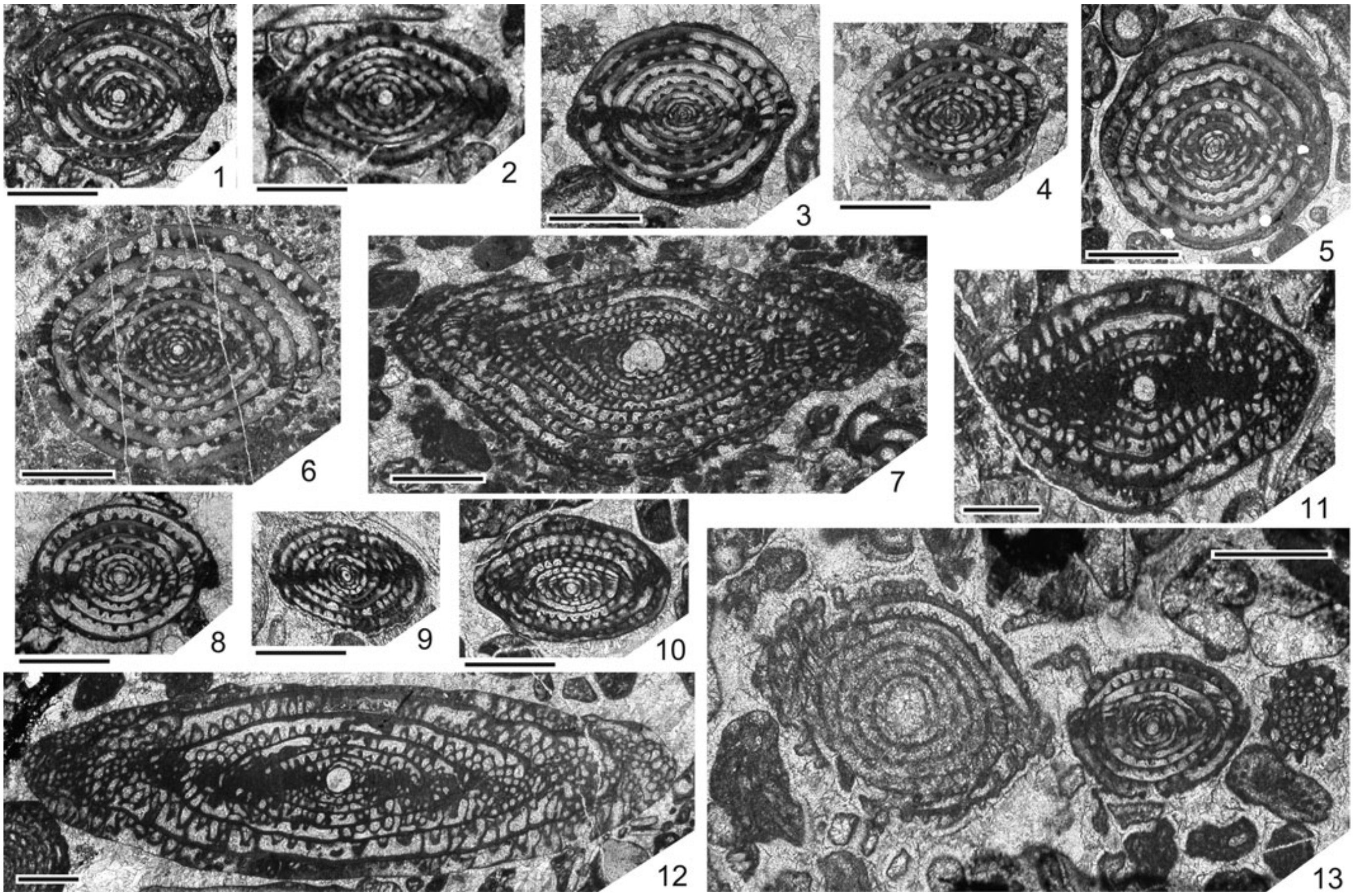

Figure 3. Major schwagerinid, verbeekinid, and neoschwagerinid fusulines associated with *Thailandina* and *Neothailandina* from the Khao Phlong Phrab section of central Thailand, as reported by Toriyama (1975). Original photomicrographs from Toriyama's (1975) thin sections; plate and figure numbers in parentheses in (**1–12**) denote those by Toriyama (1975). (**1**) *Misellina* cf. *Misellina termieri* (Deprat, 1915), axial section (pl. 12, fig. 7), Kpp-9; (**2**) *Misellina confragaspira* Leven, 1967, axial section (pl. 12, fig. 11), Kpp-5; (**3**) *Misellina claudiae* (Deprat, 1912), axial section (pl. 13, fig. 1), Kpp-23; (**4**) *Maklaya saraburiensis* Kanmera and Toriyama, 1968, axial section (pl. 18, fig. 21), Kpp-22; (**5**) *Maklaya pamirica* (Leven, 1967), axial section (pl. 18, fig. 16), Kpp-39; (**6**) *Neoschwagerina simplex simplex* Ozawa, 1927, axial section (pl. 19, fig. 26), Kpp-52; (**7**) *Colania douvillei* (Ozawa, 1922), axial section (pl. 20, fig. 23), Kpp-77; (**8**) *Armenina saraburiensis* (Toriyama and Kanmera in Toriyama, 1975), axial section (pl. 13, fig. 16), Kpp-9; (**9**) *Misellina subelliptica* (Deprat, 1915), axial section (pl. 12, fig. 3), Kpp-24; (**10**) *Cancellina phlongphrabensis* Toriyama and Kanmera in Toriyama, 1975, axial section (pl. 16, fig. 18), Kpp-34; (**11**) *Pseudofusulina kueichowensis obesa* Sheng, 1963, axial section (pl. 2, fig. 5), Kpp-21; (**12**) *Parafusulina japonica* (Gümbel, 1874), axial section (pl. 5, fig. 4), Kpp-38; (**13**) *Thailandina buravasi* (left) and *Misellina* cf. *Misellina termieri* (right) showing two different modes of preservation in the same thin section, Kpp-5; this photomicrograph has almost the same field of view as that shown by Toriyama and Kanmera (1968, pl. 8, fig. 15)—note that the proloculus and the chambers of *T. buravasi* are filled with sparry calcite cement that has a similar nature to that seen in interstitial spaces between grains in this limestone. Scale bars = 1 mm.

(1975) illustrated somewhat large neoschwagerinid specimens, e.g., *Neoschwagerina simplex simplex* Ozawa, 1927 (Fig. 3.6) and *Colania douvillei* (Ozawa, 1922) (Fig. 3.7). However, the specimens of *Neothailandina pitakpaivani* Toriyama and Kanmera, 1968, which Kobayashi et al. (2010) considered to be replaced Neoschwagerinidae, occurred in samples Kpp-29 and Kpp-37 from the *Maklaya pamirica* Biozone (B_4) (Fig. 1). In this interval, neoschwagerinids consist of *Maklaya pamirica* (Leven, 1967) (Fig. 3.5), *Cancellina phlongphrabensis* Toriyama and Kanmera in Toriyama, 1975 (Fig. 3.10), and *Cancellina* sp. A, and all of these species are much smaller than *Neothailandina pitakpaivani*. Thus, it is not likely that *Neothailandina* resulted from simple recrystallization of coexisting neoschwagerinids in the B_4 biostratigraphic interval where the relevant *Neothailandina pitakpaivani* specimens were obtained.

The above-mentioned various lines of evidence lead to a conclusion that *Thailandina* and *Neothailandina* are not mere taphotaxa (Lucas, 2001) formed in the course of diagenesis, but are indeed existing taxonomic entities that can be characterized by recrystallized tests probably originally of aragonite (e.g., Fig. 3.13) and parachomata (e.g., Fig. 2.1, 2.16). Moreover, *Neothailandina* has partitions of the chambers, which correspond to transverse septula (Fig. 2.13, 2.15, 2.18). The supposed original aragonitic test mineralogy in Thailandinidae suggests a close phylogenetic relationship to the existing fusuline family Staffellidae (Vachard et al., 2010), but the development of parachomata and transverse septula is disparate from that family. In view of the higher taxonomy of the fusulines, therefore, *Thailandina* and *Neothailandina* should be considered as forming a distinct family that constitutes a small collateral clade of Staffellidae in the superfamily Staffelloidea of the order Fusulinida.

In conclusion, contrary to Kobayashi et al.'s (2010) arguments, *Thailandina* and *Neothailandina*, and the higher taxon Thailandinidae to include these genera, should be retained as taxonomically valid and included in the Staffelloidea in fusuline systematics. Kobayashi et al. (2010) assumed, while referring to a notable photomicrograph by Toriyama and Kanmera (1968, pl. 8, fig. 15) showing *Thailandina* with a recrystallized test in close association with well-preserved *Misellina* (Fig. 3.13), that it appears to be an exceptional example of (selective) metamorphic recrystallization. However, my thorough observation of Toriyama and Kanmera's (1968) and Toriyama's (1975) Khao Phlong Phrab material concludes that this case can be of universal application to all of the co-occurrences of thailandinids and other microgranular fusulines from the section. In those samples, all tests of Thailandinidae are invariably recrystallized whereas microgranular species are always well preserved. Kobayashi et al. (2010) further argued that sedimentary reworking of specimens at a disconformity can also potentially produce a mixture of specimens in different preservation states. As noted above, however, the internal spaces (proloculus and chambers) of thailandinid tests are filled with the same type of cement found in the interstitial spaces between grains in the host limestone (Fig. 3.13). That interpretation is, therefore, rejected for the Khao Phlong Phrab thailandinids. Kobayashi et al. (2010, fig. 1) illustrated schwagerinid, neoschwagerinid, and verbeekinid fusuline specimens from the Akasaka Limestone of central Japan that represent several different states of contact metamorphic alteration from partial recrystallization to complete degradation of tests. Using this example, they intended to demonstrate that thailandinids were made by a similar metamorphic process affected on other microgranular fusulines. But, those illustrated fusulines show an essentially different recrystallization appearance from thailandinid specimens in the Khao Phlong Phrab section (e.g., Fig. 3.13). Recrystallization of the latter is due probably to the mineralogical change from aragonite to calcite in their tests, which occurred during early diagenesis. It is a different content from contact metamorphism.

A similar occurrence in the mixture of recrystallized *Thailandina* and well-preserved microgranular fusulines (verbeekinids and neoschwagerinids) was also reported by Zhou and Liengjarern (2007) from the Nong Pong Formation of the Saraburi Group, located ~40 km east of Khao Phlong Phrab. In that area, *Thailandina* shows identical test features to those from the Khao Phlong Phrab section, representing a slightly recrystallized appearance, whereas associated verbeekinids and neoschwagerinids retain their original microgranular test walls. This occurrence gives additional supporting evidence that thailandinids are not mere accidental products made by local metamorphism on particular limestones containing *Misellina*, *Parafusulina*-like schwagerinids, and other neoschwagerinids, but they comprise a valid taxonomic group characterized by inherent aragonitic test mineralogy.

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