

# MIDDLE AND LATE PERMIAN FORAMINIFERS FROM THE CHICHIBU BELT, TAKACHIHO AREA, KYUSHU, JAPAN: IMPLICATIONS FOR FAUNAL EVENTS

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**ABSTRACT**—The middle and late Permian to Triassic sequence of carbonate rocks in the Takachiho area, central Kyushu, Japan, originated as a Panthalassan seamount and formed parts of far-traveled accreted terranes. This succession is divided into the Permian Guadalupian Iwato and Lopingian Mitai formations, and the Triassic Kamura Formation. The Iwato Formation is further into three zones, the *Neoschwagerina*, *Yabeina higoensis*, and *Neoendothyra permica* zones in ascending order; the Mitai Formation includes the *Nanlingella suzukii* Zone. Biotic turnovers are recorded twice in the Iwato and Mitai formations. The first and more remarkable biotic event is the total disappearance of fusulines at the top of the *Yabeina higoensis* Zone. The *Neoendothyra permica* Zone is characterized by black fine-grained micritic limestones having only sparse non-fusuline foraminifers. The second biotic event is the first appearance of Wuchiapingian fusulines by which the *Nanlingella suzukii* Zone is defined. The Capitanian–Wuchiapingian boundary is drawn between the *Neoendothyra permica* and *Nanlingella suzukii* zones. Above this boundary both the numbers of individual foraminifers and diversity of species gradually increase. The turnovers recorded in the Takachiho area were the result of late Capitanian–Wuchiapingian environmental changes which were sufficient to cause the disappearance of large, multi-chambered fusulines and allow the new appearance of an ‘ultimate’ Paleozoic foraminiferal assemblage. Ten species of foraminifers, including *Yabeina higoensis* and *Yabeina Columbiana*, are described.

## INTRODUCTION

THE TAKACHIHO area is of special interest for the study of middle-late Permian and Triassic faunas and strata because it contains sufficient evidence to provide the basis for study of the “Kamura event” at the end Guadalupian in the mid-oceanic (Panthalassan) Faunal Realm (Ota et al., 2000; Isozaki et al., 2007). No previous detailed descriptions of the foraminifers in the Takachiho area exist, perhaps because the preservation of this fauna has been variously affected by deformation during tectonic transport and by low-grade metamorphism. Preservation of the foraminifer wall microstructure is less than ideal. Ota et al. (2000) illustrated 12 specimens of fusulines (“*Lepidolina* cf. *shiraiwensis*,” *Nanlingella* cf. *meridionalis*, “*Palaefusulina*” sp., and three other species). The present study examines the Takachiho middle and late Permian foraminifers in more detail, and reexamines the “Kamura event” in light of new data and through a reassignment of a number of earlier species identifications.

Upper middle Permian (Capitanian) through upper Permian (Lopingian), and Middle Triassic (Anisian) limestones in Japan may be lithologically subdivided into two main groups based on the presence or absence of detrital quartz grains and intercalations of seams of siliciclastic rocks (Kobayashi, 1996, 1997, 1999, 2001b, 2002, 2005; Kobayashi et al., 2005, 2007, 2009). In addition to significant lithologic differences, spatiotemporal distribution of these limestones and foraminiferal fauna help constrain interpretations of the paleogeography and tectonic evolution of the pre-Cretaceous of Japan (Kobayashi, 1986, 1999, 2003). These studies suggest the limestones in the Maizuru, Kurosegawa, and South Kitakami belts were originally deposited on shelves underlain by granitic basement (Kobayashi, 1997, 1999, 2002, 2003).

On the other hand, limestones without detrital quartz grains and siliciclastic seams in the Chichibu and Mino-Tamba belts originated in seamounts concentrated in the Panthalassan

domain. After breaking up, pieces of these terrains moved in various directions and accreted to the Mesozoic subduction belts of the present-day circum-Pacific. Those that moved westward and closer to the Cathaysian (South Chinese) Continent are now exposed as fault-bounded tectonic blocks chaotically embedded in the Jurassic to Lower Cretaceous siliciclastic rocks of Japan (Kobayashi, 1999, 2004; Kobayashi et al., 2007, 2010).

The Permian–Triassic depositional history of the Panthalassan-originated seamount is most accurately deciphered from carbonate rocks of the Takachiho area, central Kyushu. Although the Wuchiapingian–Changhsingian boundary is uncertain, nearly continuous successions from the Capitanian (upper Guadalupian) to Wuchiapingian (lower Lopingian) and from the Changhsingian (upper Lopingian) to Induan (lower Triassic) have been carefully studied in the area (Kanmera and Nakazawa, 1973; Sano and Nakashima, 1997; Ota et al., 2000). They record the end-Guadalupian biotic event (Stanley and Yang, 1994; Ota and Isozaki, 2006; Clapham et al., 2009) and the deep-sea anoxic (oxygen-depleted) event across the Permian–Triassic (Isozaki, 1997; Isozaki et al. 2007).

The end-Guadalupian mass extinction considered by Ota et al. (2000) was based on fusuline biostratigraphy of the Iwato and Mitai formations. However, the age of the uppermost part of the Iwato Formation has been unresolved. The age and biostratigraphic correlation of the lower part of Mitai Formation have been debated by Kanmera and Nakazawa (1973) and Sano and Nakashima (1997) versus Ota et al. (2000) and Ota and Isozaki (2006).

The biostratigraphy of the Iwato and Mitai formations are examined here with detailed descriptive work on the middle and late Permian foraminifers. This paper describes the stratigraphy, foraminiferal biostratigraphy, faunal composition, and correlation of both formations, including connections with the end-Guadalupian biotic crisis. Ten species of

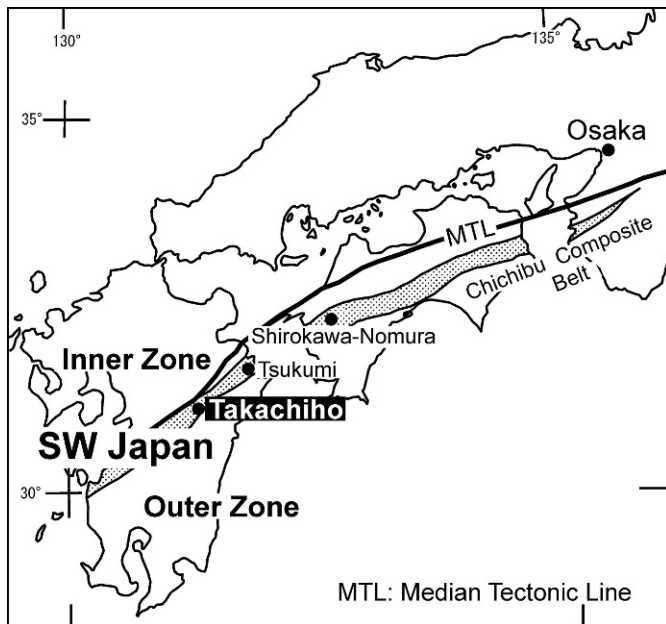


FIGURE 1—Index map of the Takachiho area in Outer Zone of Southwest Japan. Chichibu Composite Belt is subdivided into Northern, Middle, and Southern Chichibu belts. The Middle Chichibu Belt is also called the Kurosegawa Belt. Lopingian limestones in Shirokawa-Nomura and Tsukumi areas (Kobayashi, 2004) are located in the Southern Chichibu Belt along with those in the Takachiho area.

foraminifers are described, including *Yabeina higoensis* Kobayashi, 2001b and *Yabeina columbiana* (Dawson, 1879) which is synonymous with *Lepidolina* cf. *shiraiwensis* (Ozawa, 1925) by Ota et al. (2000) and Ota and Isozaki (2006). All limestone thin sections from the Takachiho area are retained in the collection of the Earth Science Division, Museum of Nature and Human Activities, Hyogo, Japan (Fumio Kobayashi Collection).

#### GEOLOGIC SETTING AND HISTORICAL REVIEW

The Permian–Triassic sequence of carbonate rocks in the Takachiho area is situated in the northern part of the Southern Chichibu Belt, Outer Zone of Southwest Japan, as well as those in the Tsukumi and Shirokawa-Nomura areas (Fig. 1). The stratigraphy, lithology, and foraminiferal faunas closely resemble each other among these areas (Kanmera and Nakazawa, 1973; Working Group on the Permian–Triassic Systems, 1975; Kobayashi, 2004).

The Permian–Triassic limestone in the Takachiho area was originally divided into two units based on color: dark gray and light gray limestone (Saito et al., 1958). Middle Permian fusulines, *Neoschwagerina megaspherica* Deprat, 1913, *Neoschwagerina margaritae* Deprat, 1913, and *Yabeina* cf. *katoii* (Ozawa, 1927) were reported from the dark gray limestone. The light gray limestone was named as the Kamura Formation from the Scytian (Early Triassic) bivalves. Both the dark gray and light gray limestones were thought to be intercalated within mudstone, sandstone, and chert of unnamed Paleozoic formations. Subsequently, Kambe (1963) proposed the Iwato Formation for these rocks except for those assignable to the Kamura Formation and described Scytian bivalves and cephalopods from the Kamura Formation.

Kanmera and Nakazawa (1973) founded the Mitai Formation (40 to 50 m thick) based on the late Permian fusulines from limestones formerly assigned to the lower part of the Kamura Formation. They showed that the Mitai Formation is remarkably dolomitized especially in its upper part, is in fault-bounded

contact with the Iwato Formation and is disconformably overlain by the Kamura Formation, which is about 20 m thick. They reported *Codonofusiella kueichowensis* Sheng, 1963, *Reichelina changhsingensis* Sheng and Chang, 1958, and *Palaeofusulina* sp. comparable to *P. sinensis* Sheng, 1955 from the lower part of the Mitai Formation, and *Staffella* sp. and *Codonofusiella* sp. from the upper part. These fusulines were not described or illustrated but, based on their occurrence the lower part of the Mitai Formation, were correlated to the lower Changhsingian. The middle and upper parts of the Mitai Formation were assigned to the middle Changhsingian. However, Rui et al. (1984) correlated the lower and middle parts of the Mitai Formation to the Wuchiapingian and the upper part to the Changhsingian.

Based on conodont biostratigraphy Watanabe et al. (1979) determined that the Kamura Formation ranges from the Smithian (early Olenekian) to Norian and contains two disconformities. Koike (1996) recognized the presence of the Griesbachian (lower Induan) in the basal part of the Kamura Formation based on conodonts such as *Hindeodus parvus* (Kozur and Pjatakova, 1976).

Although the study of Sano and Nakashima (1997) was focused on the facies analysis of limestones of the Mitai and Kamura formations, they listed four species of *Palaeofusulina* (*P. ex. gr. fusiformis* Sheng, 1955, *P. ellipsoidalis* Sheng, 1963, *P. simplicata* Sheng, 1963 and *P. sp.*) and others from the lower part of the Kamura Formation, and *Staffella* sp. and *Nankinella* sp. from the upper part. Based on these fusulines, they assigned a Changhsingian age for the Mitai Formation as did Kanmera and Nakazawa (1973).

Ota et al. (2000) first illustrated one specimen (*Lepidolina* cf. *shiraiwensis*) from the Iwato Formation and 11 specimens of five species (*Nanlingella* cf. *meridionalis* Rui and Sheng, 1981, *Codonofusiella kwangsiana* Sheng, 1963, *Codonofusiella* cf. *paradoxica* Dunbar and Skinner, 1937, *Reichelina media* Miklukho-Maklay, 1954, *Palaeofusulina* sp.) from the Mitai Formation. They recognized the conformable relation between the Iwato and Mitai formations and subdivided the Iwato Formation into the lower *Lepidolina* Zone and the upper “barren interval” and the Mitai Formation into the lower *Codonofusiella-Reichelina* Zone and the upper *Palaeofusulina* Zone. The *Lepidolina* Zone and the barren interval were correlated to the upper Maokouan (Capitanian), the *Codonofusiella-Reichelina* Zone to the Wuchiapingian, and the *Palaeofusulina* Zone to the Changhsingian. Ota et al. (2000) thought that the *Palaeofusulina* Zone sections studied by Kanmera and Nakazawa (1973) entirely correspond to the Mitai Formation in the and that the limestones comparable to the *Codonofusiella-Reichelina* Zone are not developed in the sections studied by Kanmera and Nakazawa (1973) and Sano and Nakashima (1997). The description of stratigraphy and biostratigraphy of Iwato and Mitai formations summarized in Ota and Isozaki (2006) is essentially the same as that in Ota et al. (2000).

Global environment change before the end-Permian mass extinction, as emphasized by Ota et al. (2000), was supported by Guadalupian to Lopingian carbon isotope profiles, which indicated a “Kamura event” (Isozaki et al., 2007). On the other hand, the paleontologic data are insufficient for determining the age of the “barren interval” of the uppermost Iwato Formation.

#### STRATIGRAPHY

Two stratigraphic sections in this study were selected to establish the foraminiferal biostratigraphy of the Iwato and Mitai formations (Fig. 2). One of the two, Section A, occurs

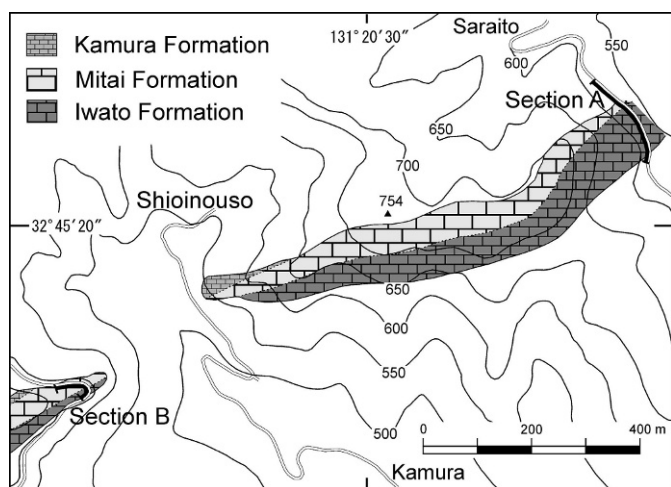


FIGURE 2—Map showing the location of two sections studied and the distribution of limestones of Iwato, Mitai, and Kamura formations based on Watanabe et al. (1979).

along the Saraito logging road and crosses at a high angle to exposed limestones of both formations that generally strike ENE to WSW. It was selected because it is the thickest section of the Iwato limestone exposed near Shioinouso and it corresponds to a portion of the section measured by Kambe (1963, fig. 3). The other section, Section B, was selected because it is the same as one studied by Ota et al. (2000, fig. 3) and it yielded abundant foraminifers in the Mitai Formation. The prefix “SLR” is used for samples from Section A and “Mi” is for those from Section B.

**Section A.**—The limestone of the Iwato Formation is massive, dark gray to black, strikes variably from N20E to EW, dips steeply to almost vertically N or S, and is in fault contact with the Mitai Formation. It is estimated to be up to 40 m in thickness, taking into account faults of various sizes and the wedge-shaped tectonic intercalation of Jurassic sandstone in its middle section (Figs. 3, 4).

The basal part consists of limestone conglomerate (6 m thick) and is in fault contact with the strongly dolomitized and recrystallized upper limestone (about 20 m thick). The limestone conglomerate is composed of breccias mostly composed of limestone and less commonly of chert and sandstone. The matrix within the breccias consists of mudstones. The stratigraphic interval from sample SLR-12 to -14 is composed of wackestone and packstone with bioclasts of many recrystallized algae and few foraminifers, ostracodes, gastropods, and bivalves. Overlying limestones (including SLR-15 to -17, -19, -20) are frequently cut by minor faults and consist of bioclastic packstone (Fig. 5.1) rich in fusulines, crinoids and algae, peloidal packstone/wackestone, and wackestone. Some fossils are recrystallized and deformed. Limestones in a fault contact with the Mitai Formation are mostly recrystallized and dolomitized. Some of the limestones are strongly deformed but highly fossiliferous (Fig. 5.2). Their lighter color is due to recrystallization and dolomitization.

The Mitai Formation is 14 m in thickness in this section. It consists primarily of light gray dolostone with some recrystallized and dolomitized limestone. A weakly recrystallized limestone suggests it was originally a fossiliferous packstone/wackestone.

**Section B.**—Black to dark gray limestones of the Iwato Formation are subdivided into two parts (Fig. 6). In the lower part (4 m thick), *Yabeina* is abundant in three levels (Mi-A–Mi-C) and rare in its uppermost level (Mi-D). Rocks

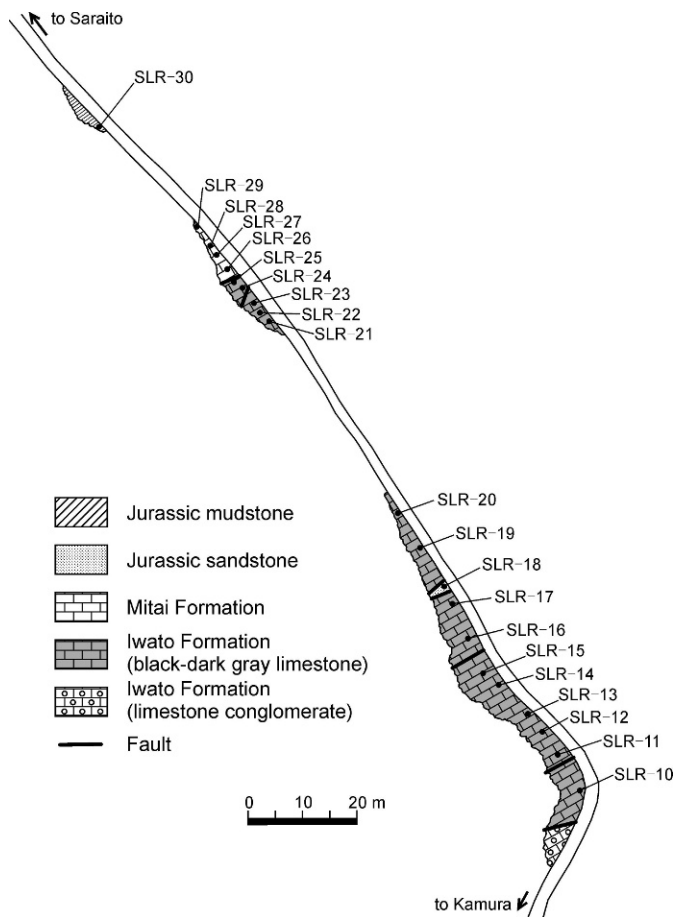


FIGURE 3—Route map of Section A along the Saraito logging road showing sample points and major faults.

underlying these fossiliferous limestones are not exposed due to the construction work of logging road. *Yabeina* is completely absent in the upper part (11 m thick). These limestones (15 m thick) correspond to the uppermost part of the limestone of the Iwato Formation that is not exposed in Section A.

The lower limestone of the Iwato Formation consists either of a fusuline packstone with abundant *Yabeina* (Fig. 5.3) or a bioclastic packstone with rare *Yabeina* (Fig. 5.4). Other fossils contained in the lower limestone are small foraminifers, thick-shelled bivalves, green algae, cyanobacteria, crinoids, gastropods, bryozoans, ostracodes, and calcisponges.

The upper limestone of the Iwato Formation is completely barren of *Yabeina* and other fusulines. Limestones are composed of peloidal wackestone (Fig. 7.1), bioclastic wackestone, algal wackestone (Fig. 7.2), wackestone, and lime-mudstone. Its basal part consists of wackestone with numerous microproblematica (Fig. 7.3). Its middle and upper parts are partly brecciated; some are weakly recrystallized. Larger fossil fragments are poorly preserved or completely absent but small-sized foraminifers, mostly small hemigordiopsids, are present but rare in some levels. Its uppermost part (about 1 to 1.5 m thick) is dark gray and partly brecciated, and is comprised of bioclastic wackestone (Mi-44) more fossiliferous than the underlying ones.

The dark gray limestone of the uppermost part of the Iwato Formation is conformably overlain by gray limestone in the basal part of the Mitai Formation (0.5 to 1 m thick) consisting of peloidal packstone/grainstone and peloidal algal wackestone

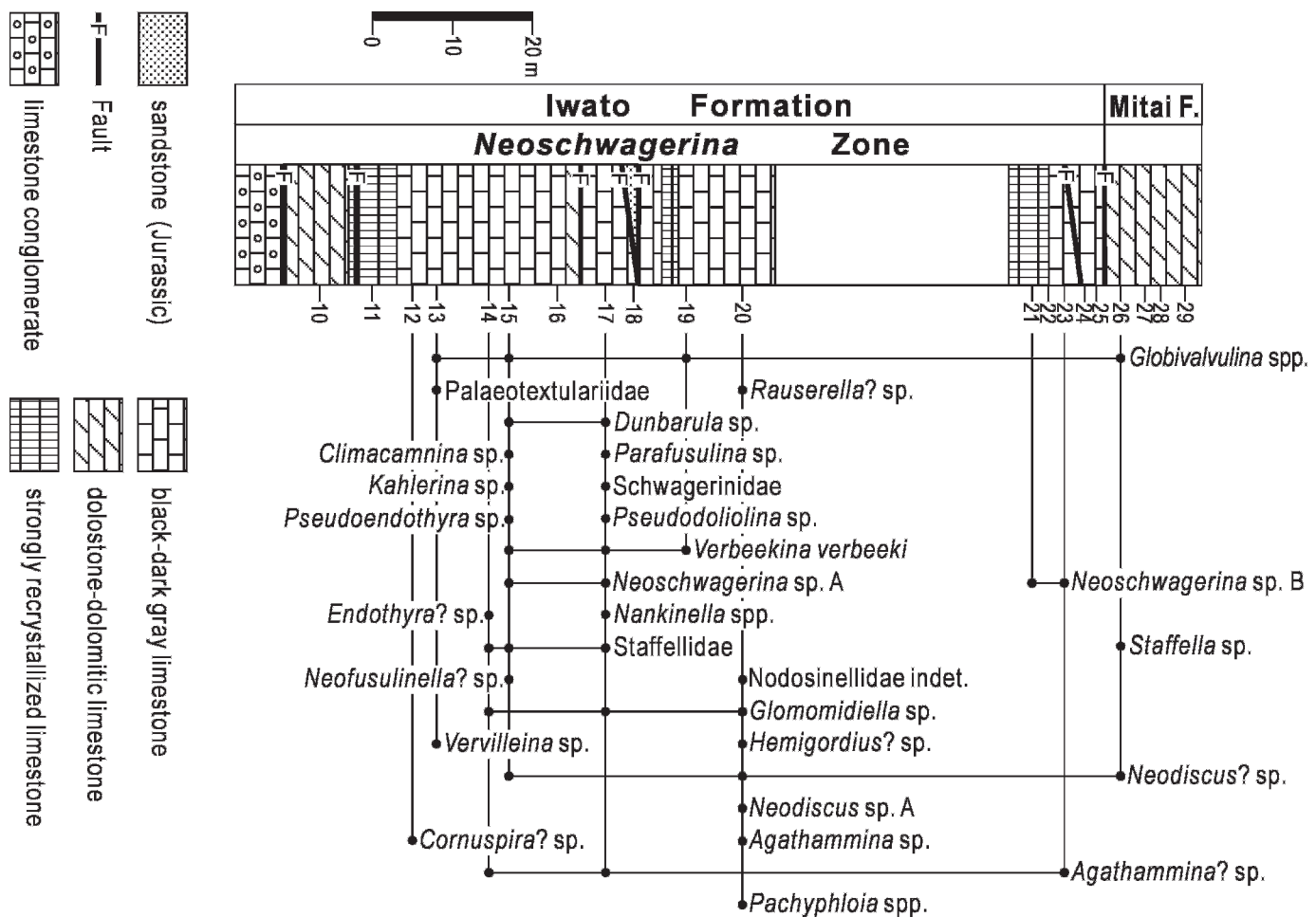


FIGURE 4—Stratigraphic column, stratigraphic distribution of foraminifers, and biostratigraphic zonation of the Iwato and Mitai formations in Section A. The sample prefix (SLR) is omitted in the column.

(Fig. 5.5). The gray limestone in the basal part grades upward to more light-colored and more fossiliferous. Overlying this is 17.5 m of the Mitai Formation which is exclusively light gray to gray and generally fossiliferous limestone.

The limestone showing alternating bands of darker and lighter parts is characteristic in the limestone of Mi-40 to -42 and Mi-F. Fossil fragments and pelloids are dominant in the darker part and few and sporadic in the lighter part (Fig. 5.6). Similar limestones showing discontinuous and irregular bands are prevailing in the lower part of the Mitai Formation. Middle and upper parts of the formation are partly more or less dolomitized (Fig. 5.9). The whitish appearance of the limestone is due to an unusually high degree of dolomitization. The degree of dolomitization becomes conspicuous upwards, with the uppermost part remarkably dolomitized (Mi-21, -23).

Significant differences of limestone lithology and fossil content by horizons are obscured throughout the Mitai Formation in Section B except the basal part. Most limestones are composed of grainstone, grainstone/packstone, packstone, and wackestone, which contain many bioclasts and commonly pelloids (Fig. 5.7, 5.8). Bioclasts are predominantly composed of green algae, problematical algae, foraminifers, and crinoids but also include gastropods, bivalves, ostracodes, rugose corals, bryozoans, brachiopods, and calcisponges.

The Mitai Formation is fault bounded with Jurassic mudstones containing blocks of gray limestone and gray to dark gray chert. The upper part of the Mitai Formation is

considered to be absent in Section B because of decreased thickness of limestone, dolostone and remarkably dolomitized limestone in this section compared with other sections studied by Kanmera and Nakazawa (1973) and Sano and Nakashima (1997).

#### BIOSTRATIGRAPHY

Based on foraminifers distinguished from ten stratigraphic levels in Section A and 36 levels in Section B, the Iwato and Mitai formations are biostratigraphically subdivided into four zones in ascending order: the *Neoschwagerina*, *Yabeina higoensis*, and *Neoendothyra permica* zones in the Iwato Formation, and the *Nanlingella suzuki* Zone in the Mitai Formation.

*Neoschwagerina zone definition.*—Total stratigraphic interval of the Iwato Formation exposed in Section A, including its lower and uppermost parts barren in foraminifers.

*Faunal characteristics.*—This zone is marked by *Neoschwagerina* sp. A, *Neoschwagerina* sp. B, and *Verbeekina verbeeki* (Geinitz, 1876) which are not found in Section B of the Iwato Formation. Two fusuline genera of *Kahlerina* and *Dunbarula* restricted to the middle Permian are associated with them. Non-fusuline foraminifers are not present for age determination within this zone (Fig. 4).

*Age and correlation.*—Assigned to the middle Gualalupian (Wordian), based on the evolutionary stage of two indeterminate neoschwagerinids. More precise correlation is impossible

due to the absence of an identifiable species of *Neoschwagerina*.

*Remarks.*—Biostratigraphic subdivision of the formation is difficult because of numerous faults and sporadic occurrences of foraminifers. Nonetheless, the Iwato Formation in Section A is assigned to the *Neoschwagerina* Zone.

*Yabeina higoensis zone definition.*—The upper limit of this zone is defined by the last occurrence of the zonal species in the Iwato Formation in Section B. Its lower limit is indeterminate due to a lack of exposures along the logging road but it is apparently biostratigraphically above the *Neoschwagerina* Zone in Section A.

*Faunal characteristics.*—Representative fusulines from this zone are *Yabeina higoensis* and *Yabeina columbiana*. Both are recognized in Mi-A and the latter species is absent in Mi-B, -C and -D. All fusuline species identified in this zone are not observed in the Mitai Formation. *Dunbarula* and *Codonofusiella* are absent in this zone and various forms of small miliolinids (e.g., *Glomomidiella* sp. A, *Hemigordius* spp.) are dominant among non-fusuline foraminifers in this zone.

*Age and correlation.*—This zone is Capitanian (Midian) and is correlated to the *Yabeina globosa* Zone and the *Lepidolina shiraiwensis* Zone, which are widely distributed in Japan. It is comparable to the “*Lepidolina* Zone” designated for the same stratigraphic interval of this section by Ota et al. (2000).

*Remarks.*—*Lepidolina* cf. *shiraiwensis*, named by Ota et al. (2000, fig. 6.1) for one incomplete specimen, is different from the types from the Akiyoshi Limestone, which were described by Ozawa (1925) as having a smaller proloculus. It is reassigned to *Yabeina columbiana*, showing broad morphologic variation of the present material (Fig. 11.1–11.4, 11.7, 11.8), as well as western North American ones (Kobayashi et al., 2007). Moreover, almost all specimens that were referred to as “*Lepidolina* cf. *shiraiwensis*” in Ota et al. (2000, fig. 4) are probably transferred to *Yabeina higoensis* or *Y. columbiana*, since their stratigraphic levels are nearly the same as those of the two species of *Yabeina* in this study.

More well-preserved specimens of *Yabeina columbiana* than those in Mi-A are obtained from a black limestone erratic (sample Shioinouso) collected on the eastern hillside about 120 m apart from Mi-A. Limestone lithology and faunal composition are very similar between the erratic and Mi-A. Specimens apparently referable to *Yabeina columbiana* are not known from Japan (Kobayashi, 2010, p. 85) but this species is the most widespread and dominant in the Capitanian limestones in western North America (Kobayashi et al., 2007).

*Yabeina higoensis* was proposed from the *Lepidolina kumaensis* Zone of the Kuma Formation (Kobayashi, 2001b) and later reported by Kobayashi (2006b) from the Capitanian limestone blocks of the Chichibu Belt in Kaize in association with *Yabeina kaizensis* (Huzimoto, 1936). *Yabeina globosa* (Yabe, 1906), very common in the Jurassic accretionary complexes of Japan and coeval with *Y. kaizensis*, *Lepidolina shiraiwensis*, and *L. kumaensis* Kanmera, 1954 (Kobayashi et al., 2007), is absent in the studied sections of the Iwato Formation as well as in limestone blocks of Kaize. Other large fusulines such as other neoschwagerinids (e.g., *Yabeina katoi* (Ozawa, 1927), *Gifuelloides larga* (Morikawa and Suzuki, 1961), *Neoschwagerina minoensis* Deprat, 1914), schwagerinids and verbeekinids are absent in the *Yabeina higoensis* Zone along Section B. They are common in the Capitanian limestones in Jurassic to Cretaceous accretionary complexes of Japan (Morikawa and Suzuki, 1961; Kobayashi, 1986, 2007) and western North America (Thompson et al., 1950; Skinner and Wilde, 1966).

*Neoendothyra permica zone definition.*—Stratigraphic interval barren of fusulines ranging from immediately above the *Yabeina higoensis* Zone to the *Nanlingella suzukii* Zone, including the stratigraphic range of *Neoendothyra permica* (Lin, 1978).

*Faunal characteristics.*—Fusulines are completely absent in this zone. Non-fusuline foraminifers, however, are recognized in eight levels, though they are very rare throughout the zone. They become relatively abundant and diverse in the gray limestone (Mi-43) of the uppermost part of this zone where *Paraglobivalvulina* sp. first occurs. There are no age-diagnostic taxa in this zone. *Glomomidiella* sp. A is the most common among non-fusuline foraminifers. It occurs more commonly in the *Yabeina higoensis* Zone and is also rarely found in the lower part of the *Nanlingella suzukii* Zone. Taxa restricted to this zone are *Neoendothyra permica*, *Septaglobivalvulina?* sp., *Hemigordius* sp. C, *Brunsiella?* sp., *Geinitzina?* sp., *Glomomidiella* sp. B, and *Glomomidiella?* sp. (Figs. 6, 7).

*Age and correlation.*—This zone is provisionally regarded as Capitanian because it lacks definitive Wuchiapingian elements.

*Remarks.*—This zone is nearly identical with the “barren interval” conformably overlying the “*Lepidolina* Zone” by Ota et al. (2000) and Ota and Isozaki (2006). The zonal species, *Neoendothyra permica* was originally described from the Changhsingian of Guangxi (Lin, 1978). In Japan, this species is reported from the Changhsingian of the Iwai-Kanyo area (Kobayashi, 1997) and the Capitanian Kamiyasse Formation (Kobayashi et al., 2009). The exact age of this zone remains uncertain. Conodonts, an index of more precise correlation, have not been reported from the Iwato and Mitai formations, despite of their common occurrence throughout the Triassic Kamura Formation (Watanabe et al., 1979).

*Nanlingella suzukii zone definition.*—The base of this zone is defined by the first appearance of the zonal species. The uppermost part of the Mitai Formation in Section B consisting of dolostone to remarkably dolomitized limestone barren in foraminifers is included in this zone (Fig. 6).

*Faunal characteristics.*—Foraminifers become more abundant and diverse in the gray limestone (Mi-42) at the base of the *Nanlingella suzukii* Zone than in the gray limestone (Mi-43), which is referable to the uppermost part of the *Neoendothyra permica* Zone and the basal part of the Mitai Formation. Characteristic and dominant species in this zone are *Nanlingella suzukii* (Igo and Igo, 1977) and *Nankinella kuzuensis* Igo and Igo, 1977. They occur throughout most of the zone along with *Codonofusiella kwangiana* and *Reichelina media*. Other fusulines recognized are *Staffella* sp., *Staffella?* sp., and *Sphaerulina* sp. These fusulines are never found in the *Yabeina higoensis* Zone. *Palaeofusulina* is totally absent in Section B. Non-fusuline foraminifers are more diversified than fusulines but inferior to fusulines in their abundance. *Fronidina* sp., *Multidiscus* sp., and *Neodiscus* sp. B are confined to this zone. *Agathammina asymmetricus* (Han, 1982) is nearly restricted to this zone. *Dagmarita* spp. and *Paraglobivalvulina* sp. are more dominant than in the underlying zones, though all are rare in this zone.

*Age and correlation.*—This zone is Wuchiapingian and correlates to the *Codonofusiella* Zone of the Tethyan regions (Kobayashi, 1999) based on the occurrence of *Nanlingella suzukii* and *Codonofusiella kwangiana*.

*Remarks.*—The lower part of the Mitai Formation in other sections, where *Codonofusiella kueichowensis*, *Reichelina changhsingensis* and *Palaeofusulina* sp. were formerly reported, is probably Wuchiapingian in age as reported by Rui et al. (1984) rather than lower Changhsingian as thought by others (Kanmera and Nakazawa, 1973; Sano and Nakashima, 1997).

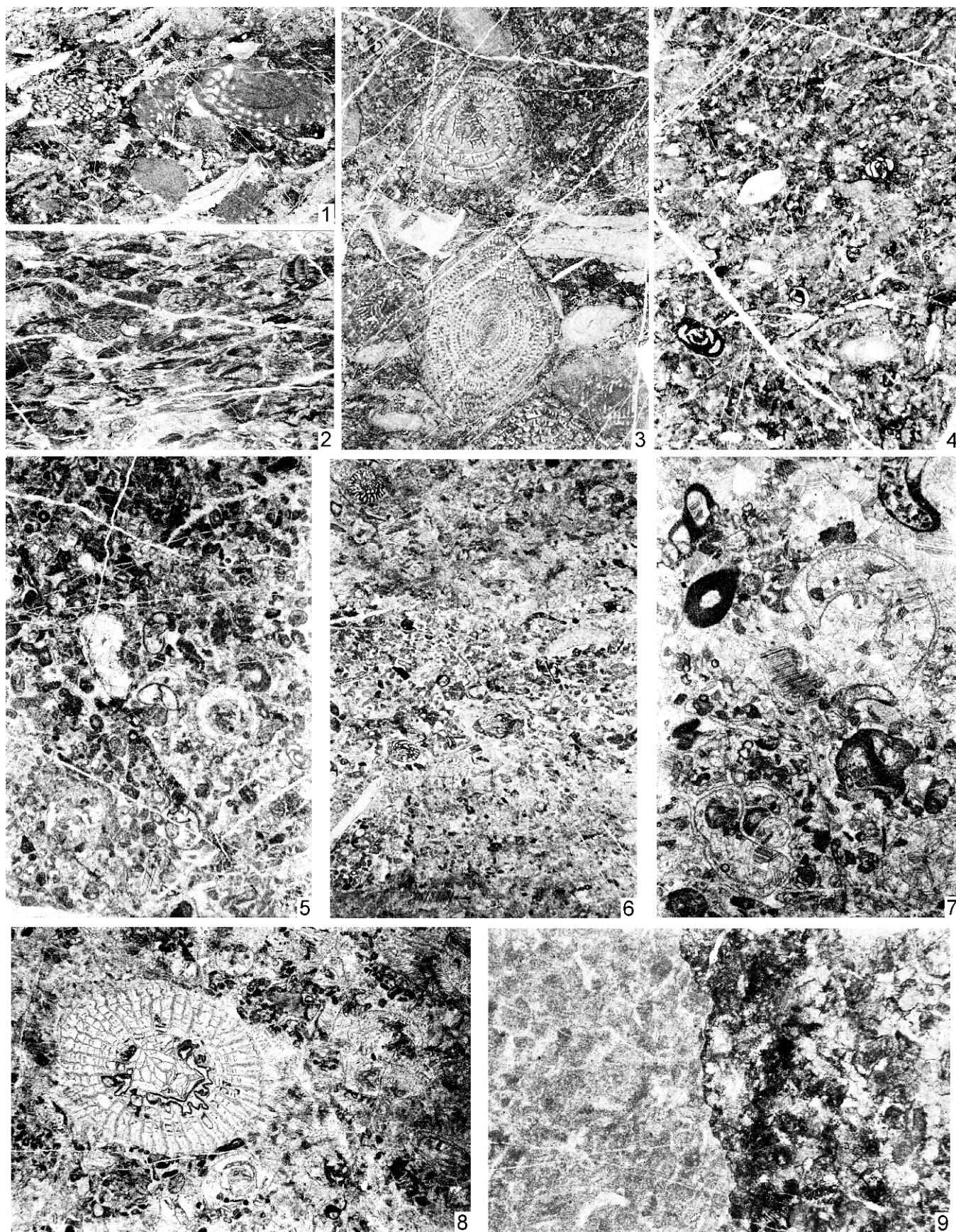


FIGURE 5—Photomicrographs of limestone in the Iwato and Mitai formations. 1, 2, Section A: 1, bioclastic packstone with many fragments of fusulines, SLR-17,  $\times 10$ ; 2, weakly recrystallized bioclastic grainstone with many deformed fossil fragments, SLR-23,  $\times 10$ ; 3–9, Section B: 3, fusuline packstone with many fusulines, thick-shelled bivalves, and small bioclasts of other fossils, Mi-C,  $\times 7$ ; 4, bioclastic packstone, Mi-D, uppermost part of

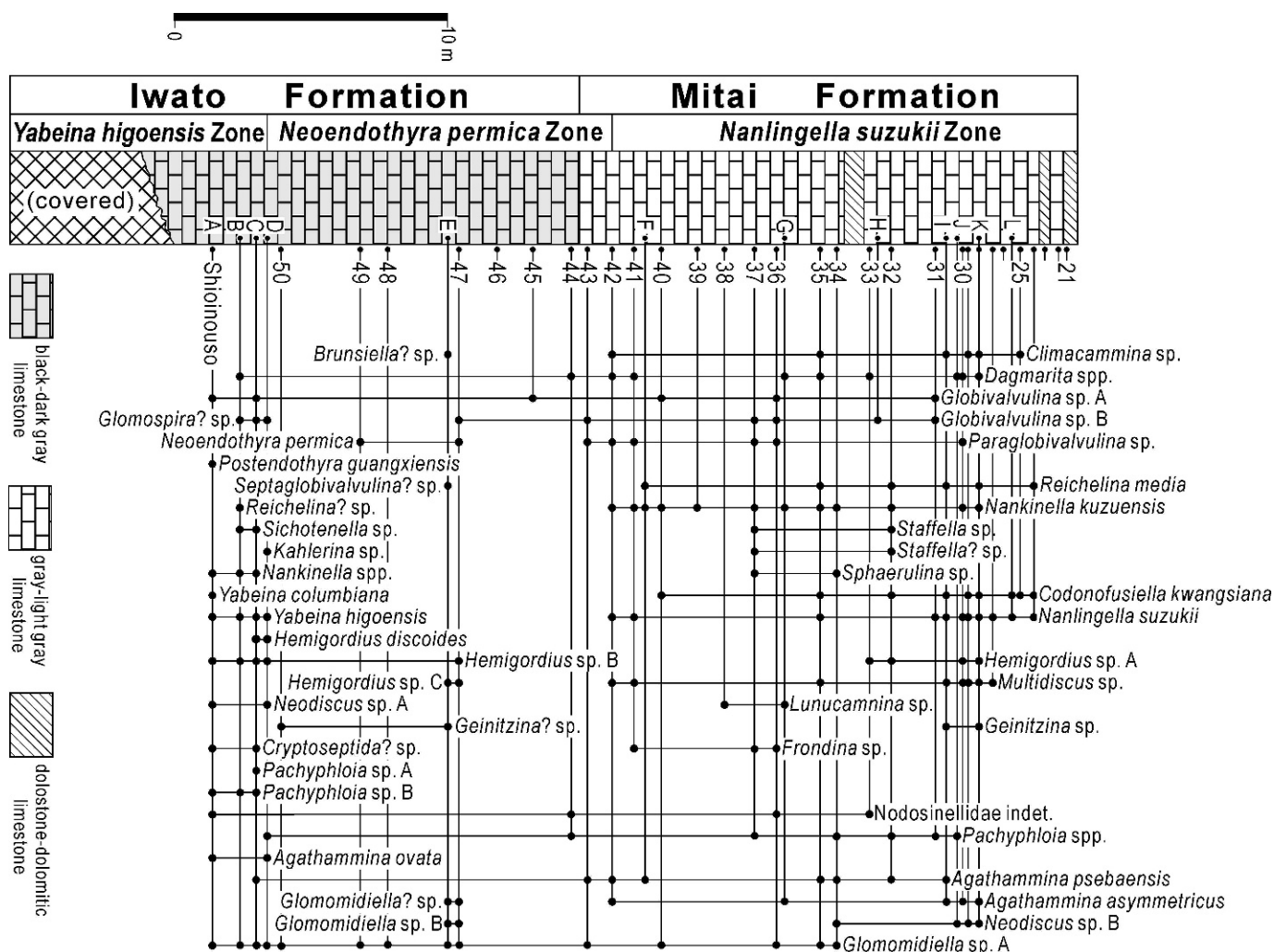


FIGURE 6—Stratigraphic column, stratigraphic distribution of foraminifers, and biostratigraphic zonation of the Iwato and Mitai formations in Section B. The prefix (Mi) of a sample is omitted in the column. The point Shioinouso in the column shows the presumable stratigraphic level of the erratic limestone sample of Shioinouso.

Specimens compared with *Nanlingella meridionalis* from Section B (Ota et al., 2000) more closely resemble *Nanlingella suzukii* than the types of *N. meridionalis*, and are reassigned based on the morphologic variation of *Nanlingella suzukii* in Kuzu (unpublished data by the author), Akasaka (Kobayashi, 2011), and the present materials. “*Palaeofusulina*” sp. in Ota et al. (2000) is referable to a form of *Nanlingella suzukii* with a relatively large proloculus. Other specimens showing a primitive *Palaeofusulina*-like appearance from this zone are also identical with *Nanlingella suzukii*. Therefore, the Mitai Formation in Section B cannot be subdivided into the lower *Codonofusiella*-*Reichelina* Zone and the upper “*Palaeofusulina*” Zone as suggested by Ota et al. (2000). The “Changhsingian *Palaeofusulina* Zone” in Ota et al. (2000) was canceled and reassigned into the Wuchiapingian *Codonofusiella*-*Reichelina* Zone in Isozaki and Ota (2001), Ota and Isozaki (2006), and

Isozaki et al. (2007) without supporting arguments. There is no biostratigraphic evidence suggesting that the uppermost part of the formation in Section B might range into the Changhsingian as assumed by Ota and Isozaki (2006).

AGE AND CORRELATION OF THE UPPER PART OF THE MITAI FORMATION

The Wuchiapingian age of the *Nanlingella suzukii* Zone in Section B is based on the biostratigraphy of South China: 1) the Wuchiapingian is represented biostratigraphically by the *Codonofusiella* Zone; 2) *Palaeofusulina* is the best marker of the Changhsingian; 3) *Codonofusiella* became extinct near the middle or late Changhsingian; and 4) *Codonofusiella* that are present in the *Palaeofusulina* Zone are of limited value for age determination (Rui, 1979; Rui and Sheng, 1981). Furthermore, *Nanlingella* is not confined to the Changhsingian and

←  
the *Yabeina higoensis* Zone, fusulines entirely disappeared immediately above the level of this sample, ×14; 5, peloidal algal packstone, Mi-43, basal part of the Mitai Formation, ×14; 6, horizontally laminated limestone consisting of alternating bands of darker and lighter parts, peloids and bioclasts are dominant in the darker part (central part), and few in the lighter part (both sides of the central part) in the original sample, Mi-42, ×7; 7, algal gastropod grainstone, Mi-29, ×14; 8, weakly dolomitized, peloidal bioclastic packstone with rugosa (*Waagenophyllum*), Mi-28, ×7; 9, weakly dolomitized limestone (right half) bounded with remarkably dolomitized limestone (left half), Mi-H, ×21. Photomicrographs from the upper part of the Iwato Formation (*Glomomidiella* sp. Zone) are shown in Figure 7.

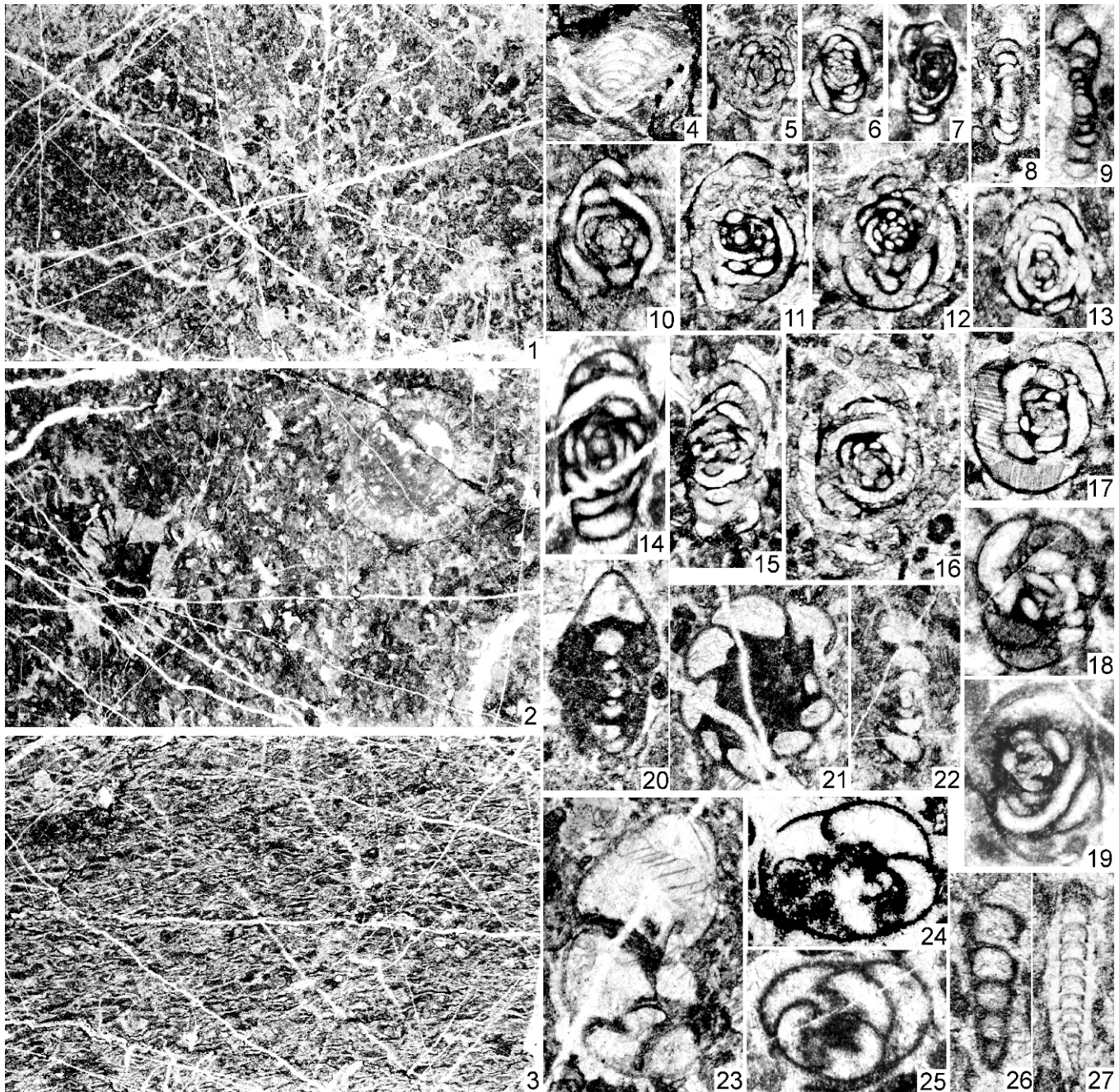


FIGURE 7—Photomicrographs of limestone and foraminifers in the upper part of the Iwato Formation (stratigraphic interval with no fusulines, *Glomomidiella* sp. Zone). 1, pelloidal wackestone, Mi-49,  $\times 14$ ; 2, algal wackestone, Mi-E,  $\times 14$ ; 3, wackestone containing numerous microproblematica,  $\times 21$ ; 4, *Geinitzina*? sp., D2-040659, Mi-50,  $\times 70$ ; 5–7, *Glomomidiella*? sp.: 5, D2-040171, Mi-47,  $\times 50$ ; 6, D2-030305, Mi-E,  $\times 70$ ; 7, D2-030301, Mi-E,  $\times 70$ ; 8, *Hemigordius* sp. B, D2-040181, Mi-47,  $\times 70$ ; 9, *Brunstiella*? sp., D2-030302, Mi-E,  $\times 70$ ; 10–13, 16, 17, *Glomomidiella* sp. A,  $\times 70$ : 10, D2-030301, Mi-E; 11, D2-040181, Mi-47; 12, D2-040170, Mi-47; 13, D2-040171, Mi-47; 16, D2-040172, Mi-47; 17, D2-040174, Mi-47; 14, 15, *Hemigordius* sp. C: 14, D2-030308, Mi-E,  $\times 70$ ; 15, D2-040169, Mi-47,  $\times 70$ ; 18, 19, *Glomomidiella* sp. B, Mi-E,  $\times 70$ : 18, D2-030304; 19, D2-030310; 20, 21, 22, *Neoendothyra permica* (Lin): 20, D2-040173, Mi-47,  $\times 70$ ; 21, D2-040176, Mi-47,  $\times 50$ ; 22, D2-040193, Mi-49,  $\times 70$ ; 23, *Globivalvulina* sp. B, D2-040180, Mi-47,  $\times 70$ ; 24, 25, *Septaglobivalvulina*? sp., D2-030307, Mi-E,  $\times 70$ ; 26, *Dagmarita* spp., D2-040152, Mi-44,  $\times 70$ ; 27, *Pachyphloia* spp., D2-040149, Mi-44,  $\times 70$ .

ranges down into the Wuchiapingian as does the non-fusuline foraminifer *Colaniella* in the Tethyan regions (Kobayashi, 1999). This age determination of the *Nanlingella suzukii* Zone in Section B supports a conformable relation between the Iwato and Mitai formations.

However, the age and correlation of the previously studied upper part of the Mitai Formation remains uncertain. As mentioned above, Kanmera and Nakazawa (1973) correlated the upper part of the formation to the middle Changhsingian

based on occurrences of *Staffella* sp. and *Codonofusiella* sp. and its disconformable relation to the Lower Triassic Kamura Formation. However, no further paleontologic evidence has been reported to better constrain the age determination.

Moreover, uncertainty regarding the presence or absence of strata directly correlated to the Changhsingian of South China have been similarly left unresolved in other Panthalassan-originated limestones outside the Mitai Formation. Kobayashi (2004) did not specify either Wuchiapingian or



Changhsingian ages for Lopingian foraminiferal faunas of the Shirokawa-Nomura and Tsukumi areas on account of the absence of *Codonofusiella*, *Palaeofusulina*, and *Colaniella*. Wuchiapingian age was given for the Lopingian fauna of the southern Kanto Mountains based on the co-occurrence of *Nanlingella* and *Codonofusiella* and the absence of *Palaeofusulina* (Kobayashi, 2001a). The uppermost part of the Akasaka Limestone is entirely Wuchiapingian based on the *Nanlingella suzukii* Zone conformably overlying the Capitanian *Yabeina globosa* Zone and the absence of Changhsingian faunal elements in the *N. suzukii* Zone (Kobayashi, 2011).

Limestones directly correlated to the Changhsingian in the Japanese upper Permian are restricted to those with detrital quartz grains and siliciclastic seams in the Kurosegawa (Kobayashi, 1997), Southern Kitakami (Kobayashi, 2002), and Maizuru (Kobayashi, 2003) belts where *Palaeofusulina sinensis* and *Colaniella parva* (Colani, 1924) are common and very characteristic. *Colaniella parva* is also reported from the Wuchiapingian limestone of the Maizuru Belt (Kobayashi, 2006c) in association with *Nanlingella? simplex* (Sheng and Chang, 1958) and *Codonofusiella* cf. *kwangsiensis*. These geotectonic belts are thought to have been proximal to the ancient Chinese continent. By contrast, ancient seamounts contained in the Southern Chichibu and Mino-Tamba belts were concentrated within the Panthalassan domain in the late Permian (Kobayashi, 1999).

There are no significant differences in foraminifer taxonomic diversity between the seamount limestone and continental shelf limestone during the Lopingian or the Capitanian (Kobayashi, 2012). Nevertheless, the species composition is significantly different. *Palaeofusulina* and *Colaniella* have not been reported from the Lopingian seamount limestones, including those of the Mitai Formation. Presence or absence of the uppermost Permian that is correlative to the Chinese Changhsingian remains unresolved in seamount limestones within the Jurassic accretionary complex of Japan. The age of the upper part of the Mitai Formation studied by Kammer and Nakazawa (1973) might be better dated as simply Lopingian without any subdivisions until the presentation of more reliable biostratigraphic evidence.

#### FAUNAL CHANGE IN THE GUADALUPIAN/LOPINGIAN BOUNDARY

An abrupt decrease of species abundance and richness occurs at the boundary between the *Yabeina higoensis* and *Neoendothyra permica* zones in Section B. *Yabeina* with a large test and numerous chambers completely disappears at the top of the *Yabeina higoensis* Zone and the *Neoendothyra permica* Zone consists exclusively of non-fusuline foraminifers. A gradual increase in the abundance and richness of foraminiferal taxa occurs at the boundary between the *Neoendothyra permica* and *Nanlingella suzukii* zones with many new taxa appearing in the *Nanlingella suzukii* Zone.

Biotic turnovers are thus recorded twice in a 11.4 m thick interval (*Neoendothyra permica* Zone) of the Iwato-Mitai formations, which is poor in biota and characterized by black fine-grained micritic limestone in Section B. The biotic turnover recorded within the Capitanian is more conspicuous than that in the Capitanian/Wuchiapingian boundary with respect to the total disappearance of large fusulines and neoschwagerinids and more a remarkable change of both richness and test size of foraminifers between the *Yabeina higoensis* and *Neoendothyra permica* zones. The number of species abruptly decreases from nine in Mi-D to two in Mi-50. On the other hand, a lithologic change in the limestone is not apparent between the *Yabeina higoensis* and *Neoendothyra*

*permica* zones and it is a gradual boundary between *Neoendothyra permica* and *Nanlingella suzukii* zones.

Isozaki and Ota (2001) thought that the biotic event recorded in the boundary between the Iwato and Mitai formations was linked with an environmental change caused by explosive acidic volcanism. This was based on a 2 mm thick “tuff” in the boundary that was may have been derived from South China. Deep participation of the Emeishan flood basalt of South China in the end-Guadalupian mass extinction is suggested by Wignall (2001), Zhou et al. (2002), and Lai et al. (2008) in addition to Isozaki and Ota (2001).

In the same interval as Section B, Isozaki et al. (2007) recognized three intervals of negative carbon isotope ratio shifts in carbonate ( $\delta^{13}\text{C}_{\text{carb}}$ ) alternating with four positive shifts with the most marked one occurring as a negative shift starting 2 m below the top of the Iwato Formation (“Segment 4”). Based on this profile in connection with fusuline faunal change between Iwato and Mitai formations, they proposed the Kamura event resulted from global cooling at the end of Guadalupian that resulted in extinction of large fusulines and a faunal turnover. This interpretation is generally consistent with that of Lai et al. (2008) who showed a similar profile to the Isozaki et al. (2007)’s with respect to the negative shift of  $\delta^{13}\text{C}_{\text{carb}}$  toward the top of the Capitanian Maokou Formation in the eastern part of Sichuan Province of South China. More precisely, the 1) major negative shift of  $\delta^{13}\text{C}_{\text{carb}}$  was finished before the deposition of Capitanian “Unit 2” between the “Maokou Formation (Unit 1)” and the Wuchiaping Formation; 2) neoschwagerinids and schwagerinids disappeared by the top of the “Maokou Formation (Unit 1)”; and 3) the 12 m thick “Unit 2,” which is poor in biota, consists of chert, limestone, and overlying 2 m thick light brown claystone referable to as an “acidic tuff” derived from the Emeishan flood basalt (Lai et al., 2008).

The disappearance level of large fusulines (top of the *Yabeina higoensis* Zone), the most remarkable faunal shift in Section B of the Takachiho area, occurs within a high positive  $\delta^{13}\text{C}_{\text{carb}}$  plateau interval (“Segment 1”) of Isozaki et al. (2007). This level might be correlated to the uppermost part of the “Maokou Formation (Unit 1)” shown in Lai et al. (2008). In the Takachiho area, this level corresponds to the early stage of this warm age (“Segment 1”) with  $\delta^{13}\text{C}_{\text{carb}}$  values over + 5‰ before the first initiation of a cooling event (“Segment 2”). Two cooling events are recognized within the upper part of the “barren interval” (= *Neoendothyra permica* Zone) according to Isozaki et al. (2007). How are these geochemical results interpreted in relation to the conspicuous faunal change between the *Yabeina higoensis* and *Neoendothyra permica* zones and monotonous lithology and faunal composition poor in diversity and richness almost throughout the *Neoendothyra permica* Zone?

Contrary to workers’ views of abrupt changes, Clapham et al. (2009) considered that the end-Guadalupian “extinction” was actually a prolonged but gradual decrease in diversity from the Wordian to the end of the Permian based on no peak in extinction rates and reduced genus richness exhibited by all studied invertebrate groups. They showed that a gradual reduction in diversity precludes the need to invoke drastic extinction mechanisms under their approval of a consistent relation between the global cooling of the Kamura event and the Capitanian/Wuchiapingian biotic changes.

It is an undisputed fact that smaller non-fusuline foraminifers occur throughout the Iwato and Mitai formations and they survived after the disappearance of large, multi-chambered fusulines. These turnovers recorded in the Takachiho area

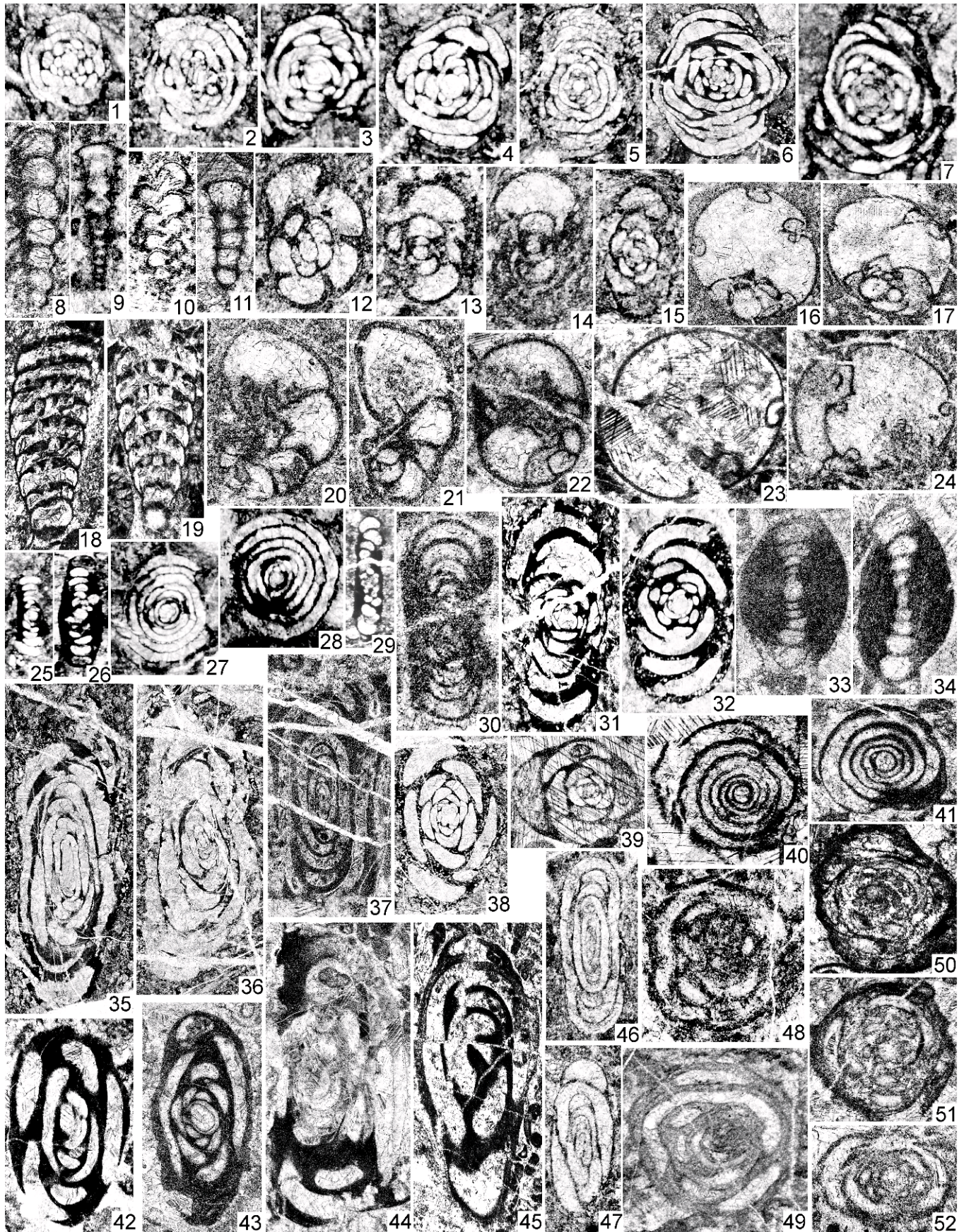


FIGURE 8—Foraminifera of the Ivato and Mitai formations. 1–7, *Glomospira?* sp., Mi-C: 1, D2-039837,  $\times 100$ ; 2, D2-039836,  $\times 100$ ; 3, D2-039861,  $\times 100$ ; 4, D2-039846,  $\times 100$ ; 5, D2-039849,  $\times 72$ ; 6, D2-039854,  $\times 60$ ; 7, D2-039860,  $\times 90$ ; 8–11, *Dagmarita* spp.,  $\times 40$ ; 8, D2-039981, Mi-33; 9, 10, D2-030371, Mi-J; 11, D2-039957, Mi-30; 12–14, *Postendothyra guangxiensis* (Lin, 1978), D2-013590, Shioino,  $\times 60$ ; 15, *Endothyra?* sp., D2-013544, SLR-14,

probably were the result of late Capitanian–Wuchiapingian environmental changes. These changes were sufficient to cause the disappearance of large fusulines such as *Yabeina* and allow the appearance of an ‘ultimate’ Paleozoic foraminiferal assemblage, though how the changes influenced the end-Guadalupian biotic crisis is uncertain.

## SYSTEMATIC PALEONTOLOGY

Order FORAMINIFERIDA Eichwald, 1830  
Suborder TEXTULARINA Delage and Hérouard, 1896  
Superfamily AMMODISCOIDEA Reuss, 1862  
Family AMMODISCIDAE Reuss, 1862  
Subfamily AMMOVERTELLINAE Saidova, 1981  
Genus GLOMOSPIRA Rzehak, 1885  
GLOMOSPIRA? SP.  
Figure 8.1–8.7

*Material examined.*—Illustrated seven and other specimens.

*Description.*—Test subglobular and about 0.3 to 0.5 mm in diameter. Proloculus about 0.01 to 0.05 mm, followed by enrolled undivided second chamber, coiled streptospirally in early stage of one to three whorls, becoming sigmoidally in late stage of three to four whorls. Wall thin and microgranular without agglutinated materials, and further thin in recrystallized specimens.

*Occurrence.*—Common to rare in Mi-B, Mi-C and Mi-D in the *Yabeina higoensis* Zone.

*Remarks.*—Although apparent foreign material is absent in the wall, specimens examined seem allied to *Glomospira* than to small globular hemigordiopsids having streptospirally and sigmoidally coiled second chamber with many whorls. Their assignment to *Gandinella* Ciarapica and Zaninetti, 1985 might be possible on account of their sigmoidal coiling in late stage and very thin microgranular wall. The present specimens are doubtfully assigned to *Glomospira*.

Suborder FUSULININA Wedekind, 1937  
Superfamily Endothyroidea Brady, 1884  
Family Endothyridae Brady, 1884  
Genus *Neoendothyra* Reitlinger, 1965  
NEOENDOTHYRA PERMICA (Lin, 1978)  
Figure 7.20–7.22?

1978 *Endothyra permica* LIN, p. 31, pl. 6, figs. 4, 5.  
1984 *Neoendothyra permica* (Lin). LIN, p. 128, pl. 4, figs. 1, 2.  
1997 *Neoendothyra permica* (Lin). KOBAYASHI, pl. 4, figs. 25–29.  
2009 *Neoendothyra permica* (Lin). KOBAYASHI, SHIINO, AND SUZUKI, p. 85, fig. 4.1–4.4.

*Material examined.*—Illustrated three specimens.

*Occurrence.*—Rare in Mi-47 and -49 in the *Neoendothyra permica* Zone.

*Remarks.*—Two specimens illustrated (Fig. 7.20, 7.21) are identical with this species originally assigned to *Endothyra* by Lin (1978) and transferred to *Neoendothyra* by Lin (1984). They are also closely similar to those from the Changhsingian of the Iwai-Kanyo area (Kobayashi, 1997) and from the

Capitanian Kamiyasse Formation (Kobayashi et al., 2009). Compared with these two specimens, pointed periphery and secondary deposits are less remarkable in one specimen (Fig. 7.22) questionably assigned to this species.

Superfamily Fusulinoidea von Möller, 1878  
Family SCHUBERTELLIDAE Skinner, 1931  
Subfamily BOULTONIINAE Skinner, 1931  
Genus CODONOFUSIELLA Dunbar and Skinner, 1937  
CODONOFUSIELLA KWANGSIANA Sheng, 1963  
Figure 10.23–10.29

1963 *Codonofusiella kwangsiiana* SHENG, p. 44, pl. 6, figs. 1–9. non 2000 *Codonofusiella kwangsiiana* SHENG; Ota, Kanamera, and Isozaki, fig. 6.11, 6.12.

2000 *Codonofusiella* cf. *paradoxica* DUNBAR AND SKINNER, 1937; Ota, Kanamera, and Isozaki, fig. 6.10.

*Material examined.*—Illustrated seven and other specimens.

*Occurrence.*—Common to rare in nine levels in the *Nanlingella suzukii* Zone, mostly in association with *Nanlingella suzukii*.

*Remarks.*—All specimens examined are safely referable to *Codonofusiella kwangsiiana* erected from the Wuchiapingian of Guanxi by Sheng (1963) based on similarities of the size of the test, number of whorls, and the degree of uncoiling of the outermost test, though mode and strength of septal folding cannot be exactly compared due to recrystallization of the present material. The identification of two specimens by Ota et al. (2000) with this species is doubtful on account of larger height of the corresponding whorls and thicker wall than those of the types. They are probably reassigned to *Nanlingella suzukii* based on the morphologic variation of the topotypes of *N. suzukii* from the Kuzu area. One specimen named by Ota et al. (2000) as *Codonofusiella* cf. *paradoxica* seems to be more similar to this species than the types of *paradoxica* from Texas by Dunbar and Skinner (1937).

Genus NANLINGELLA Rui and Sheng, 1981  
NANLINGELLA SUZUKII (Igo and Igo, 1977)  
Figure 10.30–10.54

1977 *Dunbarula suzukii* IGO AND IGO, p. 94, pl. 13, figs. 7–20.

1981 *Nanlingella* cf. *meridionalis* RUI AND SHENG; Ota, Kanamera, and Isozaki, 2000, fig. 6.2–6.4.

2000 *Palaeofusulina* sp. OTA, KANAMERA, AND ISOZAKI, fig. 6.5.

2000 *Codonofusiella kwangsiiana* SHENG, 1963; OTA, KANAMERA, AND ISOZAKI, fig. 6.11, 6.12.

2001a *Nanlingella* cf. *meridionalis* RUI AND SHENG, 1981; KOBAYASHI, fig. 3.14–3.18.

2011 *Nanlingella suzukii* (IGO AND IGO); KOBAYASHI, p. 463, pl. 4, figs. 14–38.

*Material examined.*—Illustrated 25 and other specimens.

*Description.*—Test inflated fusiform to fusiform with broadly ached periphery and bluntly pointed to rounded

×50: 16, 17, 23, 24, *Paraglobivalvulina* sp., ×30: 16, D2-040067, Mi-41; 17, D2-040062, Mi-41; 23, D2-030374, Mi-J; 24, D2-040026, Mi-37; 18, 19, *Climacammina* sp., D2-030400, Mi-K, ×40: 20–22, *Globivalvulina* sp. B, Mi-43, ×40: 20, D2-040145; 21, D2-040142; 22, D2-040141; 25–27, *Hemigordius* sp. B, ×75: 25, D2-039852, Mi-C; 26, D2-030292, Mi-D; 27, D2-039860, Mi-C; 28, 29, *Hemigordius discoides* Lin et al., 1990; 28, D2-030296, Mi-D, ×75; 29, D2-30291, Mi-D, ×70; 30, *Hemigordius* sp. A, D2-039944, Mi-30, ×60; 31, 32, *Neodiscus* sp. A, Mi-D: 31, D2-030292, ×40; 32, D2-030290, ×50; 33, 34, 40, 41, *Multidiscus* sp.: 33, D2-039923, Mi-29, ×40; 34, D2-039939, Mi-30, ×40; 40, D2-030361, Mi-I, ×30; 41, D2-039952, Mi-30, ×40; 35–39, *Agathammina psebaensis* Pronina-Nestell: 35, D2-039857, Mi-C, ×30; 36, D2-039860, Mi-C, ×20; 37, D2-039990, Mi-34, ×20; 38, D2-039852, Mi-C, ×30; 39, D2-040102, Mi-42, ×30; 42–45, *Agathammina asymmetricus* (Han), ×20: 42, D2-030354, Mi-I; 43, D2-039947, Mi-30; 44, D2-039919, Mi-28; 45, D2-030405, Mi-K; 46, 47, *Agathammina ovata* Wang, Shioinuso, ×40: 46, D2-013596; 47, D2-013590; 48–52, *Neodiscus* sp. B, 48, D2-030371, Mi-J, ×40; 49, D2-013567, SLR-20, ×40; 50, D2-030381, Mi-K, ×30; 51, D2-039926, Mi-29, ×30; 52, D2-040137, Mi-43, ×40.

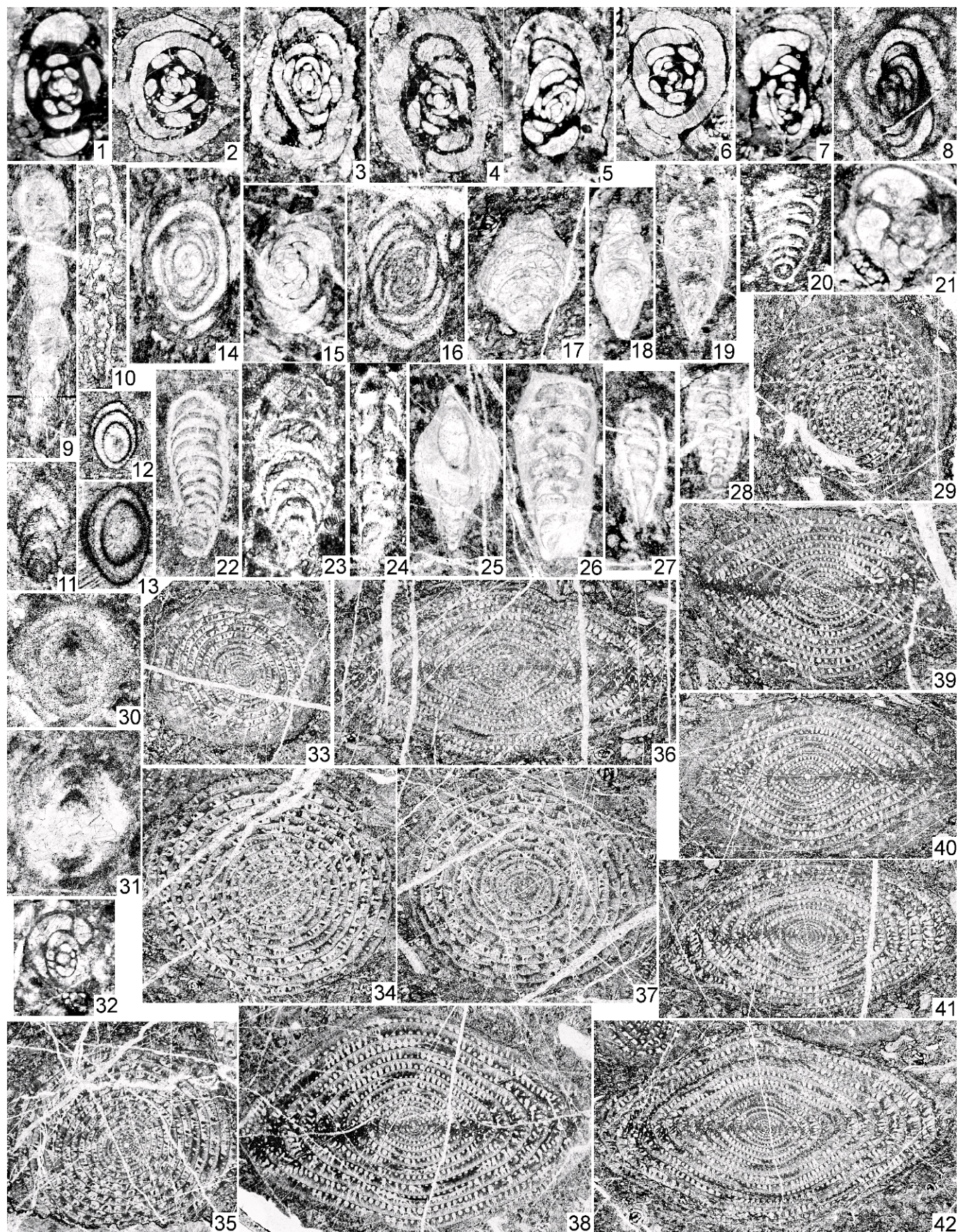


FIGURE 9—Foraminifers of the Iwato and Mitai formations. 1–8, *Glomomidiella* sp. A: 1, D2-039854, Mi-C,  $\times 50$ ; 2, D2-039852, Mi-C,  $\times 50$ ; 3, D2-039851, Mi-C,  $\times 50$ ; 4, D2-039842, Mi-C,  $\times 50$ ; 5, D2-039859, Mi-C,  $\times 50$ ; 6, D2-039835, Mi-C,  $\times 50$ ; 7, D2-039846, Mi-C,  $\times 60$ ; 8, D2-040000, Mi-35,  $\times 50$ ; 9, *Vervilleina* sp., D2-013540, SLR-13,  $\times 30$ ; 10, 23, 24, *Nodosinellidae* indet.: 10, D2-039983, Mi-33,  $\times 40$ ; 23, D2-013567, SLR-20,  $\times 40$ ; 24,

poles. Mature test consists of about five whorls, 1.30 to 1.95 mm in length, 0.80 to 1.12 mm in width, and 1.4:1 to 2.1:1 in approximate form ratio. Proloculus is minute and 0.03 to 0.10 mm in outside diameter. Inner one to one and a half whorls short lenticular and tightly coiled in specimens with small proloculus, and short fusiform to subspherical and loosely coiled in those with large proloculus. Succeeding whorls inflated fusiform to fusiform and rapidly to gradually expanding, with a sharp to slight change of axis of coiling toward the initial whorls.

Wall thin, less than 0.01 mm in inner whorls and less than 0.04 mm in its thickest part of the outer whorls, structureless in inner whorls, and consists of a tectum and underlying thicker translucent layer in outer whorls. Septa weakly and rather irregularly fluted in the median part of the test and strongly fluted in polar regions of outer whorls, closely spaced and count 30 to 35 in the last whorl. Tunnel low, narrow, and having irregular path bordered by distinct but asymmetrical chomata.

*Occurrence.*—Common to rare in 11 levels in the *Nanlingella suzukii* Zone.

*Remarks.*—Numerous specimens of *Nanlingella* were obtained from the Mitai Formation. Shape, size, and expansion of the test, and proloculus size are variable from specimen to specimen. These differences are thought to represent the broad morphologic variation of this species. Specimens with small test and a few whorls are due to the abrasion of outer test or incomplete specimens of early stage of the growth. All specimens of *Nanlingella* examined are identified with the types originally assigned to *Dunbarula* by Igo and Igo (1977) from the upper Permian limestone block in the Kuzu area, that were reassigned to *Nanlingella* based on the material of the Akasaka Limestone (Kobayashi, 2011). The Mitai, Kuzu, and Akasaka specimens are also common in frequent association with *Nankinella kuzuensis*.

Some specimens of *Nanlingella* that have been compared with *N. meridionalis*, the type species of the genus, were illustrated without description by Ota et al. (2000) from the Mitai Formation and by Kobayashi (2001a) from the Gozenyama Formation in the southern Kanto Mountains. They have weaker septal folds than the Chinese types and are thought to be more closely resemble *Nanlingella suzukii*.

One specimen with about 0.1 mm in proloculus size and two whorls was named as *Palaeofusulina* sp. by Ota et al. (2000). Though it is incomplete, the specimen is comparable to incomplete specimens of *Nanlingella suzukii* in this paper (e.g., Fig. 10.33, 10.38, 10.40), and should be excluded from *Palaeofusulina*. Two specimens illustrated as *Codonofusiella kwangsiensis* by Ota et al. (2000) are probably reassigned to this species, as mentioned above.

Family NEOSCHWAGERINIDAE Dunbar and Condra, 1927  
Subfamily NEOSCHWAGERININAE Dunbar and Condra, 1927

Genus YABEINA Deprat, 1914  
YABEINA COLUMBIANA (Dawson, 1879)

Figure 11.1–11.5, 11.7, 11.8

1879 *Loftusia columbiana* DAWSON, p. 69, pl. 6, figs. 1–7.

1942 *Yabeina columbiana* (Dawson); THOMPSON AND WHEELER, p. 708, pl. 106, fig. 5; pl. 107, fig. 5; pl. 108, fig. 1; pl. 109, figs. 1–4.

2000 *Lepidolina* cf. *shiraiwensis* (Ozawa, 1925); OTA, KANMERA, AND ISOZAKI, fig. 6.1.

2007 *Yabeina columbiana* (Dawson). KOBAYASHI, ROSS, AND ROSS, figs. 2.1–2.4, 4.1–4.18, 5.1–5.11, 6.1–6.9, 7.1–7.14, 8.1–8.23, 9.1–9.12.

*Material examined.*—Illustrated six and other specimens, and one specimen reproduced from Ota et al. (2000, fig. 6.1)

*Description.*—Test inflated fusiform, with straight axis of coiling, broadly rounded periphery, slightly convex lateral slopes, and rounded to bluntly pointed poles. Mature specimens with 16 to 18 whorls, and about 8 to 10 mm in length and about 4.5 to 6.5 mm in width, giving approximate form ratio 1.5:1 to 1.7:1, but exactly unknown on account of abrasion of outer whorls and many calcite veinlets.

Proloculus nearly spherical, and 0.06 to 0.27 mm. Inner one to two whorls subspherical, the succeeding three to four whorls inflated fusiform with rounded poles, and further outer ones inflated fusiform with bluntly pointed to rounded poles, gradually increasing their length and width.

Wall rather thin for the genus, less than 0.03 mm in thickness in outer whorls, though not precise because of secondary calcareous deposits and recrystallization, and composed of a tectum and fine alveolar keriotheca. Septa slender, widely spaced, and as many as 30 in outer whorls.

Primary transverse septula, rather slender, elongate triangular, increasing their numbers ontogenetically. Some of them are in contact with parachomata. Secondary transverse septula short and first appeared in the fifth to seventh whorl. Commonly one, rarely two secondary transverse septula present between adjacent primary ones. Axial septula well developed, three to six between adjacent septa in outer whorls. Parachomata low and present throughout the test.

*Occurrence.*—Abundant in sample Shioinuso (a limestone erratic) and common in Mi-A in the *Yabeina higoensis* Zone.

*Remarks.*—Kobayashi et al. (2007) studied the morphology of *Yabeina columbiana* from southern British Columbia in comparison with other species of *Yabeina* and related genera described from the circum-Pacific regions. They recognized wide morphologic variations of this species.

The present specimens are thought to correspond to a form of *Yabeina columbiana* having relatively thick wall and septula and a large proloculus among the British Columbia ones. Seven specimens described as *Yabeina columbiana* by Kanmura (1954) from the Kuma Formation and by Nogami (1958) from the Maizuru Group are different from the types by their smaller test, fewer whorls, and lesser developed primary transverse septula. Kobayashi (2010) assigned them to *Lepidolina takagamiensis* (Chisaka, 1960) emend. Tazawa and Hasegawa, 2007, as *Yabeina kaizensis* Huzimoto, 1936 emend. Kobayashi, 2006b is somewhat similar to *Yabeina columbiana*. However, secondary transverse septula are more abundant in the latter than in the former.

D2-013584, Shioinuso, ×30; 11–13, *Fronidina* sp., ×50; 11, D2-040028, Mi-37; 12, D2-040017, Mi-36; 13, D2-040018, Mi-36; 14, 16, *Neodiscus?* sp., ×40; 14, D2-013567, SLR-20; 16, D2013549, SLR-15; 15, *Hemigordius* sp. B, D2-013568, SLR-20, ×40; 17–19, *Cryptoseptida?* sp.: 17, D2-039853, Mi-C, ×40; 18, D2-039850, Mi-C, ×50; 19, D2-013591, Shioinuso, ×30; 20, *Geinitzina* sp., D2-030384, Mi-K, ×50; 21, *Globivalvulina* sp. A, D2-039858, Mi-C, ×70; 22, *Pachyphloia?* sp., D2-040148, Mi-43, ×40; 25–28, *Pachyphloia* spp.; 25, D2-013585, Shioinuso, ×30; 26, D2-030374, Mi-J, ×50; 27, D2-030370, Mi-J, ×40; 28, D2-039856, Mi-C, ×40; 29, 33–42, *Yabeina higoensis* Kobayashi, Mi-C, ×10; 29, D2-039859; 33, D2-039843; 34, D2-039853; 35, D2-039846; 36, D2-039855; 37, D2-039837; 38, D2-039856; 39, D2-039851; 40, D2-039841; 41, D2-039839; 42, D2-039852; 30, 31, *Sphaerulina* sp., Mi-37, ×30; 30, D2-040030; 31, D2-040029; 32, *Kahlerina* sp., D2-030295, Mi-D, ×40.

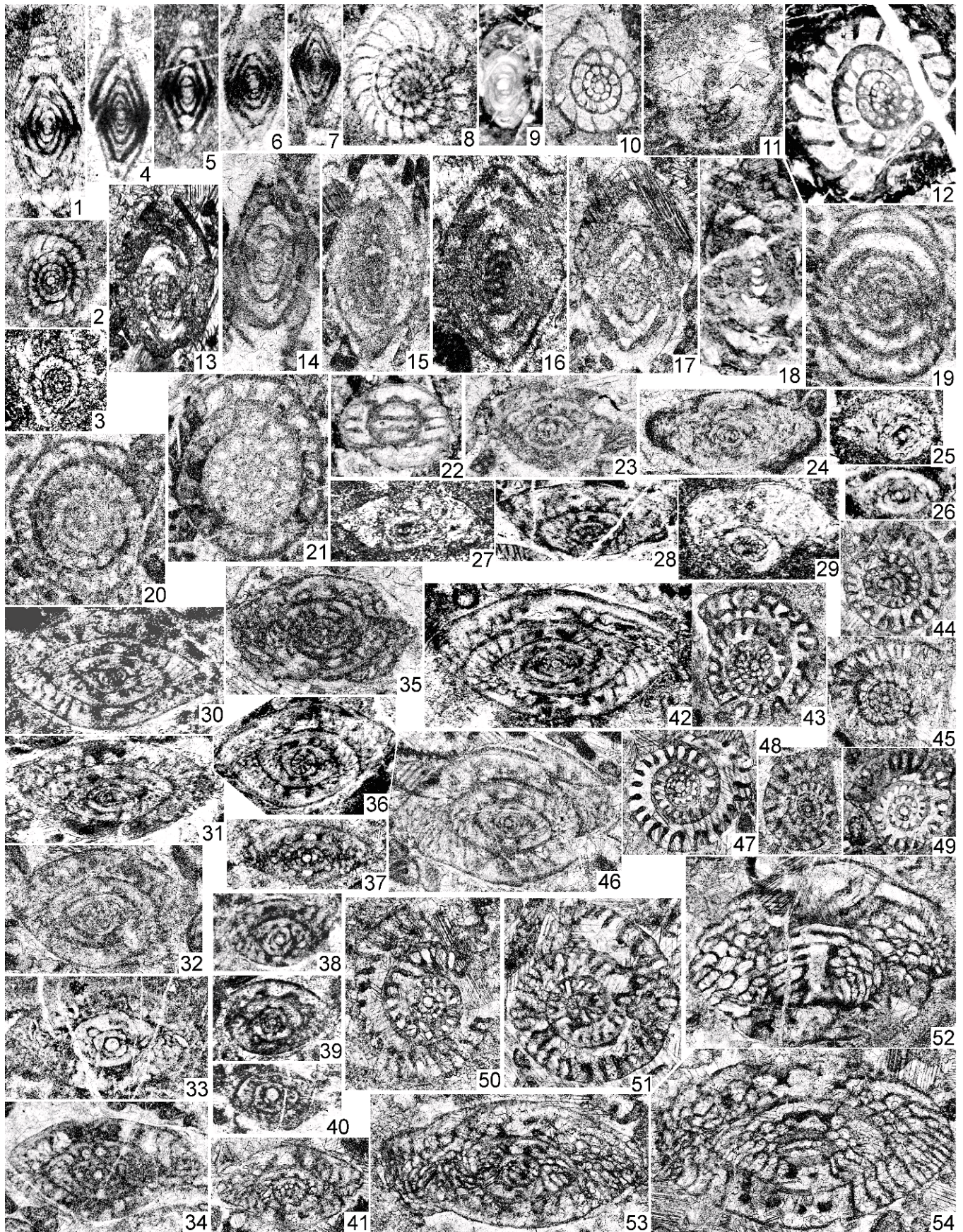


FIGURE 10—Foraminifera of the Iwato and Mitai formations. 1–8, *Reichelina media* Miklukho-Maklay: 1, D2-030359, Mi-I,  $\times 50$ ; 2, D2-039995, Mi-35,  $\times 40$ ; 3, D2-030367, Mi-I,  $\times 50$ ; 4, D2-030389, Mi-K,  $\times 50$ ; 5, D2-030341, Mi-I,  $\times 50$ ; 6, D2-030398, Mi-13,  $\times 50$ ; 7, D2-039880, Mi-24,  $\times 50$ ; 8, D2-030365, Mi-I,  $\times 50$ ; 9, 10, *Sichotenella* sp.,  $\times 50$ ; 9, D2-030286, Mi-B; 10, D2-039840, Mi-C; 11, *Staffella?* sp., D2-040030, Mi-37,  $\times 30$ ; 12, 18, *Nankinella*

The specimen from the Iwato Formation named by Ota et al. (2000) as *Lepidolina* cf. *shiraiwensis* is reproduced in Figure 11.5. Although it is incomplete and its test characters in the mature stage are uncertain, the specimen is different from and not compared with the types of Akiyoshi (Ozawa, 1925; Toriyama, 1958; Kobayashi, 2012) in having smaller proloculus and should be reassigned to this species.

YABEINA HIGOENSIS Kobayashi, 2001b  
Figure 9.29, 9.33–9.42

2001b *Yabeina higoensis* KOBAYASHI, p. 72, fig. 6.4, 6.8; pl. 5, figs. 1–9.

2006b *Yabeina higoensis* Kobayashi; KOBAYASHI, p. 189, fig. 6.1–6.17.

*Material examined*.—Illustrated 11 and other specimens.

*Description*.—Test inflated fusiform, with straight axis of coiling, broadly rounded periphery, slightly convex to straight lateral slopes, and rounded to bluntly pointed poles. Mature specimens with about 15 whorls, and up to 7 mm in length and up to 4.5 mm in width, giving approximate form ratio 1.3:1 to 1.7:1, but exactly unknown on account of abrasion of outer whorls and calcite veinlets in most specimens.

Proloculus spherical, and 0.04 to 0.14 mm. Inner one to two whorls subspherical or inflated eostaffella-like. Succeeding whorls becoming inflated fusiform with bluntly pointed poles, gradually increasing their length and width.

Wall relatively thin, less than 0.03 mm in thickness, and composed of a tectum and fine alveolar keriotheca in outer whorls. Septa possibly more than 25, but an accurate count is not possible due to poor preservation.

Primary transverse septula elongate triangular, and well developed except for embryonic whorls, partly in contact with parachomata, increasing their numbers outward. Distinct secondary transverse septula first appeared in the sixth or seventh whorl. One secondary transverse septulum inserted between adjacent primary transverse septula up to the tenth whorl, and one to rarely two in further outer whorls. Axial septula well developed except for inner three whorls, commonly four to six between adjacent septa in outer whorls. Parachomata low and massive, well developed throughout whorls except for embryonic ones.

*Occurrence*.—Abundant in Mi-B and Mi-C, and rare in Mi-A and Mi-D in the *Yabeina higoensis* Zone.

*Remarks*.—This species was proposed from the Kuma Formation (Kobayashi, 2001b) and later described from the Capitanian limestone blocks of Kaize (Kobayashi, 2006b). Most diagnostic features of this species are smaller heights of the whorl in middle and late stages than of those of other species of *Yabeina* and well developed secondary transverse septula and axial septula in comparison with relatively small test. By these features the present specimens are certainly identified with the original Kuma's and the succeeding Kaize's ones. Smaller test appearances of the present specimens than Kuma's and Kaize's are due to more remarkable abrasion and

recrystallization of outer test. *Yabeina higoensis* also resembles *Yabeina osakamensis* Kobayashi, 2007 erected from the southern end of the Chichibu Belt in Osakama, western Kyushu in many respects. The former differs, however, from the latter by its smaller proloculus and stouter septula and parachomata as indicated by Kobayashi (2007).

Family STAFFELLIDAE Miklukho-Maklay, 1949  
Genus NANKINELLA Lee, 1934

NANKINELLA KUZUENSIS Igo and Igo, 1977  
Figure 10.13–10.17, 10.20, 10.21

1977 *Nankinella kuzuensis* IGO AND IGO, p. 93, pl. 13, figs. 1–6.

*Material examined*.—Illustrated seven and other specimens.

*Occurrence*.—Common to rare in 12 levels in the *Nanlingella susukii* Zone.

*Remarks*.—The present material is identical with the types described by Igo and Igo (1977) from the upper Permian limestone block of the Kuzu area in their size and shape of the test, and number of whorls. In addition to this species, late Permian *Nankinella* illustrated by Kobayashi (1997) from the Iwai-Kanyo area, west Tokyo and by Kobayashi (2002) from the Toyoma Formation of South Kitakami are significantly different from those from South China (e.g., Sheng, 1963) in having much smaller test and much fewer whorls.

Suborder MILIOLINA Delage and Hérouard, 1896

Superfamily CORNUSPIROIDEA Schultze, 1854

Family HEMIGORDIOPSIDAE Nikitina, 1969

Genus AGATHAMMINA Neumayr, 1887

AGATHAMMINA PSEBAENSIS Pronina-Nestell in

Pronina-Nestell and Nestell, 2001

Figure 8.35–8.39

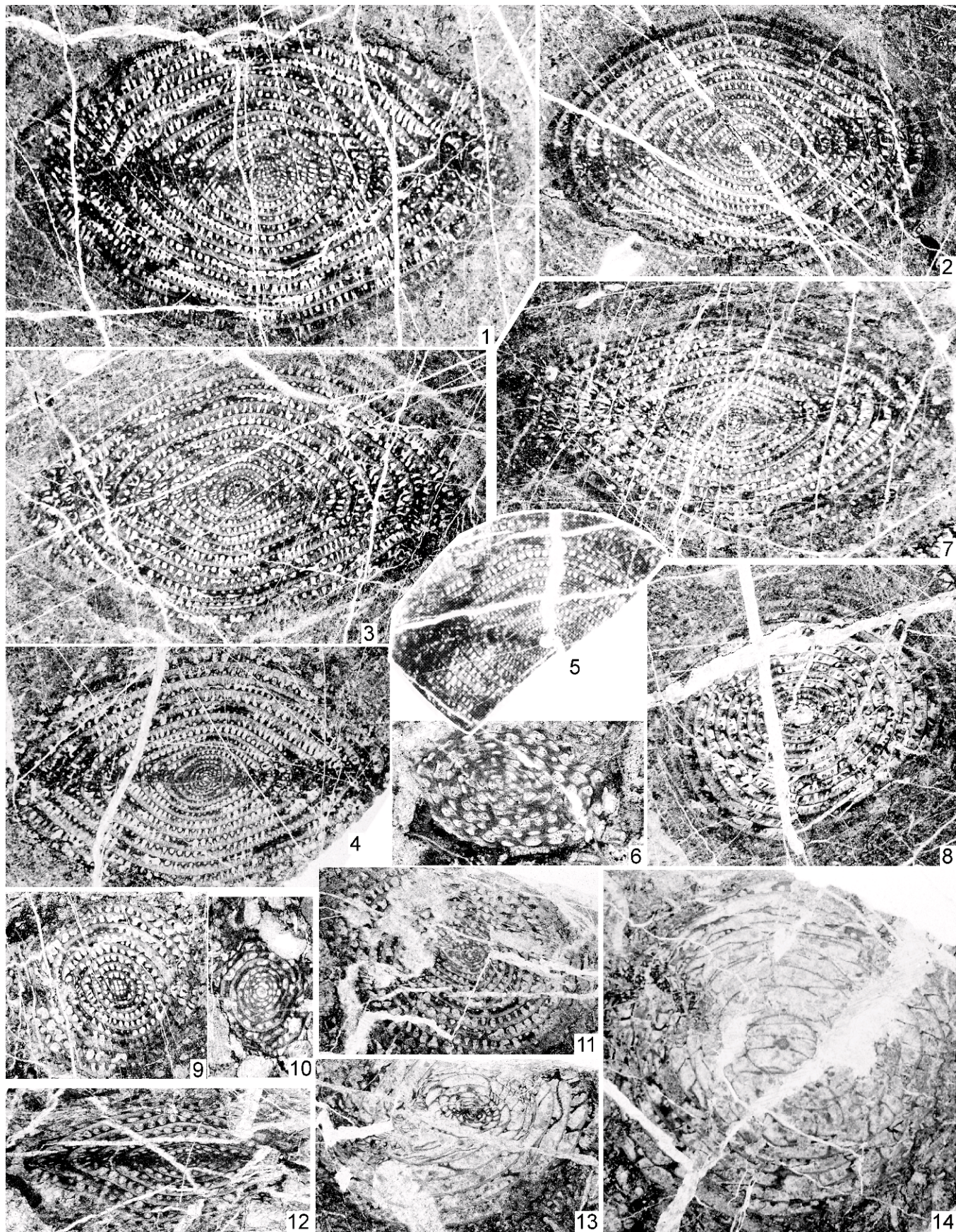
2001 *Agathammina psebaensis* Pronina-Nestell in PRONINA-NESTELL AND NESTELL, p. 214, pl. 1, figs. 25, 26.

*Material examined*.—Illustrated five specimens.

*Occurrence*.—Common in Mi-C in the Iwato Formation and rare in six levels of the Mitai Formation.

*Remarks*.—Among the described species, the present specimens are most similar to *Agathammina psebaensis* described from the Changhsingian of northwestern Caucasus by Pronina-Nestell in Pronina-Nestell and Nestell (2001). In spite of older occurrence of the present material than the types, both are common in large size and similar quinqueloculine coiling pattern of the test and thickness of wall in initial and late stages. Based on these features, the present material is distinguished from other two species of *Agathammina*, *A. ovata* Wang, 1976 from the Iwato Formation (Fig. 8.46, 8.47) and *A. asymmetrica* from the Mitai Formation (Fig. 8.42–8.45). *Agathammina ovata* originally described from the Changhsingian of western Guizhou (Wang, 1976) has smaller test, fewer whorls, and thinner wall than this species. *A. asymmetrica* from the middle Permian (*Neoschwagerina* Zone) of Jilin and originally assigned to *Glomospira* by Han (1982) has much thicker wall than this species.

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spp., ×40: 12, D2-030276, Mi-B; 18, D2-013560, SLR-17; 13–17, 20, 21, *Nankinella kuzuensis* Igo and Igo, ×30: 13, D2-030311, Mi-F; 14, D2-040004, Mi-35; 15, D2-039943, Mi-30; 16, D2-030405, Mi-K; 17, D2-040087, Mi-42; 20, D2-040028, Mi-37; 21, D2-040056, Mi-40; 19, *Staffella* sp., D2-040030, Mi-37, ×30; 22, *Neofusulinella?* sp., D2-013545, SLR-15, ×40; 23–29, *Codonofusiella kwangsiensis* Sheng: 23, D2-039918, Mi-28, ×40; 24, D2-039931, Mi-29, ×30; 25, 26, D2-030364, Mi-I, ×50; 27, D2-030367, Mi-I, ×50; 28, D2-030401, Mi-K, ×30; 29, D2-030352, Mi-I, ×50; 30–54, *Nanlingella susukii* (Igo and Igo), ×30: 30, D2-030398, Mi-K; 31, D2-030411, Mi-K; 32, D2-039924, Mi-29; 33, D2-040001, Mi-35; 34, D2-039939, Mi-30; 35, D2-039923, Mi-29; 36, D2-030412, Mi-K; 37, D2-040080, Mi-42; 38, D2-030320, Mi-F; 39, D2-030312, Mi-F; 40, D2-030401, Mi-K; 41, D2-040111, Mi-42; 42, D2-030413, Mi-K; 43, D2-040118, Mi-42; 44, D2-040093, Mi-42; 45, D2-039934, Mi-29; 46, D2-039950, Mi-30; 47, D2-040102, Mi-42; 48, D2-039928, Mi-29; 49, D2-030313, Mi-F; 50, D2-040119, Mi-42; 51, D2-040107, Mi-42; 52, D2-040078, Mi-42; 53, D2-040086, Mi-42; 54, D2-040107, Mi-42.





Genus GLOMOMIDIELLA Vachard et al., 2008

GLOMOMIDIELLA SP. A

Figures 7.10–7.13, 7.16, 7.17, 9.1–9.8

*Material examined.*—Illustrated 14 and other specimens.

*Description.*—Test small, ovate to subglobular, involute, with rounded periphery, 0.35 to 0.60 mm in diameter. Proloculus about 0.03 to 0.05 mm, followed by enrolled undivided second chamber, gradually increasing height of whorls. Early whorls coiled streptospirally, and gradually changing to sigmoidal outwards. Lateral thickenings in umbilical regions indistinct. Wall calcareous and variable in thickness. Aperture simple and opens at the end of the tubular chamber.

*Occurrence.*—Common to rare in four levels in the *Yabeina higoensis* Zone, six levels of the *Neoendothyra permica* Zone, and four levels of the *Nanlingella suzukii* Zone.

*Remarks.*—Wall of the present specimens is thought to be originally porcelaneous. Variable thickness and microgranular appearance of the wall of them, even in the same specimen, might be due to weak recrystallization. According to Vachard et al. (2008), *Glomomidiella* is distinguished from *Pseudomidiella* Pronina-Nestell in Pronina -Nestell and Nestell, 2001 by the entirely streptospiral coiling of the second chamber. Illustrated 14 specimens are thought to be assigned to *Glomomidiella* rather than to *Pseudomidiella* on account of more globular test and streptospirally to sigmoidally coiled second chamber, and indistinct lateral thickenings. *Glomomidiella* sp. B from two levels of the *Neoendothyra permica* Zone is provisionally distinguished from this unnamed species in its more globular test and thicker wall.

There are many reports of small miliolines that were assigned to *Agathammina*, *Neodiscus*, *Hemigordius*, or indeterminate Miliolina. Most of them (e.g., Kobayashi, 1986, 2002, 2004, 2005; Kobayashi et al., 2009) are better transferred to *Glomomidiella*, including specimens erroneously belonged to *Glomospira* (Kobayashi, 2006a). They are common in subglobular to ovate tests, streptospirally or sigmoidally coiled second chamber. An appearance of a microgranular wall in some specimens might be due to recrystallization of the test.

Genus MULTIDISCUS Miklukho-Maklay, 1953

Gaillot and Vachard, 2007 emend.

MULTIDISCUS SP.

Figure 8.33, 8.34, 8.40, 8.41

*Material examined.*—Illustrated four and other specimens.

*Occurrence.*—Rare in eight levels in the *Nanlingella suzukii* Zone.

*Remarks.*—*Multidiscus* was treated as one of genera of uncertain status in the foraminiferal classification of Loeblich and Tappan (1988). Gaillot and Vachard (2007) redefined the genus and thought that *Neohemigordius* Wang and Sun, 1973 is a junior synonym of *Multidiscus*. This unnamed species is assigned to *Multidiscus* from noticeable lamellar thickenings, planispiral coiling of the second chamber, and large proloculus in comparison with test size. In having smaller test and thinner wall, this unnamed species is distinguished from *Multidiscus maopingensis* (Wang and Sun, 1973) from the lower Permian

of Shaanxi of North China that was designated the type species of *Neohemigordius*.

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FIGURE 11—Foraminifers of the Iwato and Mitai formations. 1–5, 7, 8, *Yabeina columbiana* (Dawson), all but 5 Shioinuso,  $\times 10$ ; 1, D2-013591; 2, D2-013590; 3, D2-013584; 4, D2-013592; 5, the specimen named as *Lepidolina* cf. *shiraiwensis* (Ozawa) by Ota, Kanmera, and Isozaki (Ota et al., 2000, fig. 6.1); 7, D2-013582; 8, D2-013595; 6, *Pseudodoliolina* sp., D2-013561, SLR-17,  $\times 20$ ; 9–11, *Neoschwagerina* sp. A: 9, D2013549, SLR-15,  $\times 10$ ; 10, D2-013559, SLR-17,  $\times 20$ ; 11, D2-013562, SLR-17,  $\times 15$ ; 12, *Neoschwagerina* sp. B, D2-013572, SLR-23,  $\times 15$ ; 13, 14, *Verbeekina verbeeki* (Geinitz), SLR-15,  $\times 10$ ; 13, D2-013551; 14, D2-013552.

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