Fusuline foraminifera from the basal part of the Sakamotozawa Formation, South Kitakami Belt, Northeast Japan

Katsumi UENO*, Jun-ichi TAZAWA** and Tomohiko SHINTANI**

Abstract

A small fusuline fauna, composed of *Schubertella* sp., *Quasifusulina*? sp., *Rugosofusulina* sp., *Eoparafusulina* aff. *perplexa* (Grozdilova and Lebedeva), and *Nipponitella explicata* Hanzawa, is described for the first time from the basal part (Sa member) of the Sakamotozawa Formation in the type (Nagaiwa) area, South Kitakami Belt, Northeast Japan. The fauna is somewhat similar to that from the lower part of the overlying Sb member with a Sakmarian age, but lacks *Robustoschwagerina nunosei* (Hanzawa), which is biostratigraphically the most significant fusuline species of the latter. This faunal similarity, together with conformable stratigraphic relationship between the Sa and Sb members, suggests that the present Sa fauna is also highly probably referable to the Sakmarian. It is further concluded that the base of the Sakamotozawan Stage widely used in the regional Permian chronostratigraphic subdivisions of Japan broadly coincides with that of the Sakmarian in the standard international chronostratigraphic scale of the Permian System.

Key words: Early Permian, fusuline foraminifera, Northeast Japan, Sakamotozawa Formation, Sakmarian, South Kitakami Belt.

Introduction

The Sakamotozawa Formation is a well-defined Lower Permian lithostratigraphic unit in the South Kitakami Belt, Northeast Japan and, due to the relatively complete stratigraphic and fusuline faunal successions, its chronostratigraphic derivative, the Sakamotozawa Series, is

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widely accepted as one of regional standard Permian chronostratigraphic subdivisions of Japan (Toriyama, 1967a, b; Minato et al., 1978; Jin et al., 1997). The detailed lithostratigraphy and fusuline biostratigraphy of the Sakamotozawa Formation in the Sakamotozawa-Nagaiwa area were studied by Mikami (1965) and Kanmera and Mikami (1965a, b). Until now, however, age-diagnostic fusuline species has not been reported substantially from the basal part (Sa member of Mikami, 1965) of the Sakamotozawa Formation. This resultantly makes not only the age of the basal part of the formation but also the basal limit of the Sakamotozawa Series unclear.

In April 2006, one of the junior authors (TS), in the course of mapping under the supervision of the second author (JT), collected fusuline-bearing samples from the locality KF128 (Fig. 1), which stratigraphically belongs to the basal part of the Sakamotozawa Formation (Fig. 2), in the upper reaches of Imahorasawa, a tributary of the Sakarigawa River, in the Nagaiwa area of the northeastern part of the South Kitakami Belt. Then the samples were sent to the first author (KU) for taxonomy. In this paper, we for the first time describe and illustrate a small but important fusuline fauna from the basal member of the Sakamotozawa Formation, and discuss its age. The fusuline specimens treated in this study are housed in the Department of Geology, Faculty of Science, Niigata University, with prefix NU-F.

Stratigraphy and samples

The Sakamotozawa Formation, originally proposed by Onuki (1937) as the Sakamotozawa Stage of the Yukisawa Series for a younger Paleozoic chronostratigraphic unit of the Kitakami Mountains, represents an essentially carbonate-dominant succession with frequent development of siliciclastic beds, particularly in its basal and uppermost parts. The formation, about 270 m thick, is well-exposed in the Sakamotozawa-Nagaiwa area of Ofunato City, Iwate Prefecture, and unconformably rests upon the Pennsylvanian (Late Carboniferous) Nagaiwa Formation. According to Mikami (1965) and Kanmera and Mikami (1965a), the Sakamotozawa Formation of this area is subdivided into four members in two, unconformity-bounded subformations: the Sa and Sb members in the Lower Subformation and the Sc and Sd members in the Upper Subformation, respectively in ascending order (Fig. 2). The Sb member is further subdivided into the Sb1, Sb2, and Sb3 units based on sedimentary cycles although we cannot recognize the boundary of each unit in the field. Of the four members, the Sa member of about 30 m thick in the Nagaiwa area consists of the basal conglomerate followed by fine- to medium-grained sandstone and shale in the middle and upper parts.

In terms of fusuline biostratigraphy, the Sakamotozawa Formation was divided into five biozones (Mikami, 1965; Kanmera and Mikami, 1965b): in ascending order the *Zellia nunosei* and *Monodiexodina langsonensis* zones in the Sb member, the *Pseudofusulina vulgaris* Zone in the Sc member, and the *Pseudofusulina fusiformis* and *Pseudofusulina ambigua* zones in

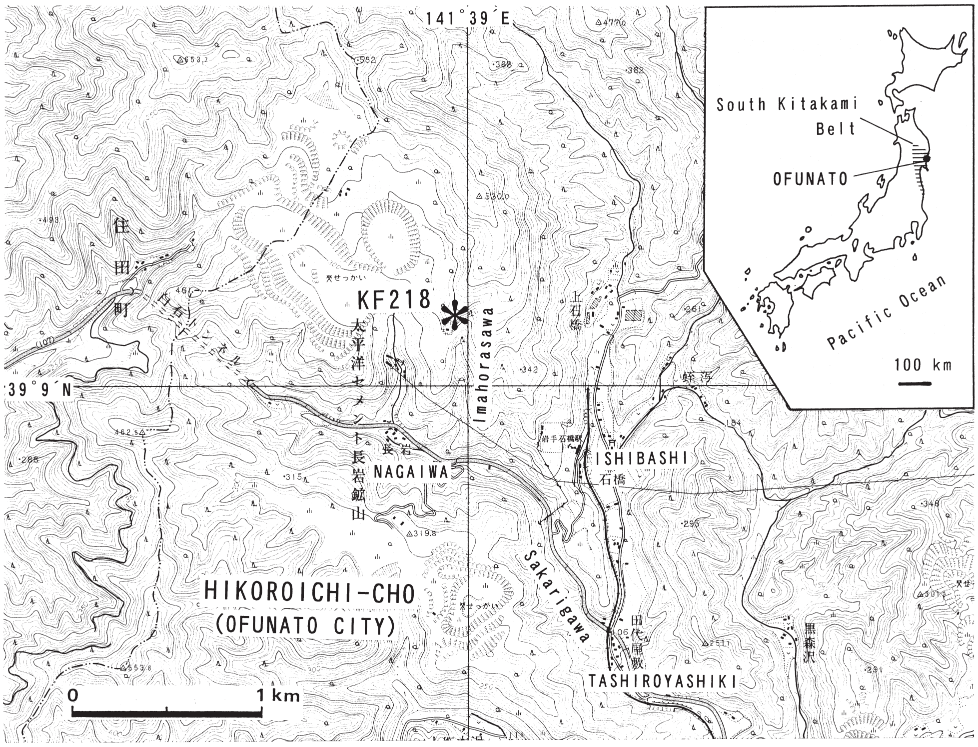

Fig. 1. Index map showing locality KF128 in the Nagaiwa area, South Kitakami Belt, Northeast Japan. A part of 1:25,000 scale topographic map "Sakari" published by Geographical Survey Institute, Japan, is used for base map.

the Sd member with a clearly defined barren interval in the upper part of the Sb member between the *Monodiexodina langsonensis* and *Pseudofusulina vulgaris* zones. The former two biozones in the Lower Subformation are correlated broadly to the Sakmarian, while the latter three in the Upper Subformation to the Artinskian (Watanabe, 1991). In contrast to the limestone-dominated Sb to Sd members, the essentially siliciclastic Sa member of the basal part of the formation is very poor in fusuline fossils. So far as the published data are concerned, Mikami (1965, fig. 6) listed questionable occurrences of *Quasifusulina tenuissima* (Schellwien) and *Zellia nunosei* Hanzawa from the Sa member of respectively the Sakamotozawa and Nagaiwa areas, and Kanmera and Mikami (1965b, p. 266) noted the occurrence of abundant fusuline casts that are similar to those of primitive species of *Monodiexodina* (*Ferganites*) from a sandstone bed of the Sa member. Unfortunately, they are mere documentation without illustration of specimens.

We examined three samples (Samples 1-3) in the present study. They were collected from the locality KF128 on a ridge (approximately 390 m above sea level) at the west side of the upper reaches of Imahorasawa, about 750 m NNE of Nagaiwa, Hikoroichi-cho, Ofunato City,

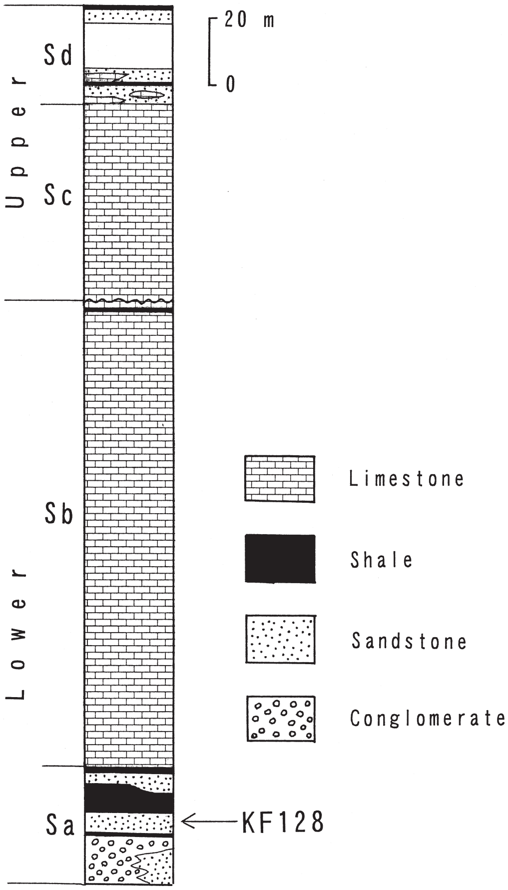

Fig. 2. Generalized columnar section of the Sakamotozawa Formation in the Nagaiwa area, showing fossil horizon of KF128. Stratigraphic column adapted from Mikami (1965).

Iwate Prefecture (Fig. 1). According to Kanmera and Mikami (1965a), the basal (Sa) member of the Sakamotozawa Formation is widely distributed around the locality, resting unconformably upon the Upper Carboniferous Nagaiwa Formation distributed to the south and southeast. The samples studied herein are all obtained as loose blocks, but are definitely derived from nearby outcrops belonging to the basal (Sa) member of the formation. Our field investigation revealed that the stratigraphic position from which the samples come is approximately 20 m above the base of the Sa member (Fig. 2).

Among the three samples, Sample 1 is slightly weathered, brownish-gray granular conglomerate mainly composed of coarse calcareous debris, such as fusuline shells, crinoid stems, brachiopod shells, and gastropod shells, embedded within a matrix of medium-grained calcareous and terrigenous (lithic and quartz) particles. Fusuline shells are the main component of this rock sample, but most of them are more or less abraded and, in some cases, slightly deformed.

Sample 2 is dark-gray, fine-grained sandstone to siltstone. A small number of calcareous debris, such as fusuline shells and crinoid stems, are scattered in it. Owing to weathering of the sample, fusuline remains are very poorly preserved and some parts of the shells are too fragile to make thin section.

Sample 3 is strongly weathered, brownish-gray fine-grained sandstone, in which fusuline and brachiopod shells are condensed in some layers that are almost parallel to lamination. Moreover, casts of centimeter-sized oncoids are scattered on the surface of the sample. It is considered to be more or less calcareous originally judging from the presence of these shells and oncoids although calcareous components are already completely dissolved now. On a weathered surface of this sample, a number of external molds of large subcylindrical fusuline shells are observed.

Fusuline fauna and its age

In the three samples examined in this study, we discriminated *Schubertella* sp., *Rugosofusulina* sp., *Eoparafusulina* aff. *perplexa* (Grozdilova and Lebedeva), and *Nipponitella explicata* Hanzawa from Sample 1 and *Quasifusulina*? sp. from Sample 3. In Sample 2, we found several fusuline specimens that are potentially comparable to *E.* aff. *perplexa* from Sample 1, but their preservation is too poor to give any reliable identification. Thus, a total of five species consist of the fusuline fauna from the basal (Sa) member of the Sakamotozawa Formation.

Among them, *Eoparafusulina* aff. *perplexa* is somewhat similar to *E. langsonensis* (Saurin) described by Kanmera and Mikami (1965b) from the Sb member of the Sakamotozawa Formation, but has a smaller shell with slightly smaller number of volutions and slightly more expanded outer volutions. Based on their morphological features and stratigraphic occurrences, the former is considered as the possible direct ancestor of the latter. The types of *E. perplexa* were reported by Grozdilova and Lebedeva (1961) from the lower Sakmarian (Tastubian) of North Timan, in the northern part of the Russian Platform. The present Sakamotozawa specimens are somewhat close to the types in their gross shell morphology, but have slightly more expanded outer volutions and slightly more developed axial fillings than the latter.

Eoparafusulina is essentially an Early Permian cosmopolitan fusuline genus (Loeblich and Tappan, 1988; Rauser-Chernousova et al., 1996; Ueno, 2006). Particularly, elongate subcylindrical species of the genus, such as *E. gracilis* (Meek), *E. allisonensis* Ross, *E linearis* (Dunbar and Skinner), *E. paralinearis* (Thorsteinsson), *E. prolongada* (Berry), *E. langsonensis*, and *E. perplexa*, are reported from a younger part of the Asselian to the Sakmarian in Eurasia (e.g., Saurin, 1950; Kanmera and Mikami, 1965b; Grozdilova and Lebedeva, 1961; Han, 1980) and a younger part of the Wolfcampian in the Americas (e.g., Wood et al., 2002; Ross and Ross, 2003; see Ueno, 2006 for their detailed age assessment) although some of these species such as *E. paralinearis* occur in rather geologically poorly documented areas so that it is difficult to fix their (chrono-) stratigraphic positions exactly.

Nipponitella explicata is a typical indigenous species, which is only known from the Sakamotozawa Formation of the South Kitakami Belt. In its type area, this species is restricted to the Sb member of the formation (Kanmera and Mikami, 1965a). Besides the type species from the South Kitakami Belt, the genus *Nipponitella* is only known from the Amushan Formation of Inner Mongolia, Northeast China (Han and Guo, 1979), where it is associated with *Pseudoschwagerina*, *Zellia*, *Eoparafusulina*, *Chalaroschwagerina*, and others. The Amushan Formation is broadly referred to the Asselian-Sakmarian by Editorial Committee of Stratigraphic Lexicon of China (2000), but the occurrence of *Chalaroschwagerina* is indicative that the formation partly ranges up to the early Artinskian. With respect to *Nipponitella*-bearing levels of the Amushan Formation, they are referable to the Sakmarian-early Artinskian based on the coexistence with *Zellia* and *Chalaroschwagerina* species.

Among the three unidentified species in this study, *Rugosofusulina* sp. is probably identical with *R*. sp. reported by Kanmera and Mikami (1965b) from the lower part of the Sb member of the Sakamotozawa Formation. Another species, *Quasifusulina*? sp., is based on a number of external mold specimens. Thus, its generic assignment is even problematic due to the lack of internal shell information. Nevertheless, the large, cigar-like subcylindrical shells with the presence of strong polar torsion and strongly and regularly fluted septa somewhat remind of *Q. tenuissima*, which also occurs in the Sb member.

All these lines of evidence, together with conformable stratigraphic relationship between the Sa and Sb members, are suggestive that the fusuline fauna from the basal (Sa) member of the Sakamotozawa Formation is not essentially different in age from that of the lower part of the overlying Sb member and broadly referable to around an Asselian-Sakmarian boundary age. The basal part of the Sb member (Sb1) is biostratigraphically characterized by *Robustoschwagerina nunosei*, which has been subsumed in the genus *Zellia* by most authors (e.g., Morikawa and Isomi, 1961; Kanmera and Mikami, 1965b; Watanabe, 1991) since the introduction of this species by Hanzawa (1938b), but is recently suggested to be closer to *Robustoschwagerina* by Forke (2002). As the Sb1 fusuline fauna is definitely younger than the Asselian by the occurrence of a primitive robustoschwagerinid (e.g., Leven, 1980, 1993, 2001; Forke, 2002) and is referable to the Sakmarian (Watanabe, 1991), it is reasonable to consider that the conformably underlying Sa member with somewhat similar fusuline faunal composition to the Sb member would be also assignable to the Sakmarian rather than the Asselian. The essential absence of large and inflated *R. nunosei* in the Sa member is interpreted due probably to its siliciclastic facies although Mikami (1965) once questionably mentioned the occurrence of this species from the Sa member without illustration.

The present assessment on the age of the basal part of the Sakamotozawa Formation reaffirms that the Sakamotozawan Stage often used as a regional, Lower Permian chronostratigraphic unit in Japanese Younger Paleozoic researches (e.g., Toriyama, 1967a; Minato et al., 1978) starts from the base of the Sakmarian, the second stage of the Lower Permian in the standard international chronostratigraphic scale for the Permian System (Jin et al., 1997; Gradstein et al., 2004). The Sakamotozawa Formation is generally accepted as representing the lowermost stratigraphic unit of the Permian in the South Kitakami Belt. Thus, our conclusion further implies that the Asselian of the basal Permian is highly probably absent in this belt.

Description of species

(by KU)

Superfamily Fusulinoidea von Möller, 1878
Family Schubertellidae Skinner, 1931
Subfamily Schubertellinae Skinner, 1931
Genus *Schubertella* Staff and Wedekind, 1910

Type species.—*Schubertella transitoria* Staff and Wedekind, 1910.

Schubertella sp.
Fig. 3.8

Figured specimen.—Sagittal section (NU-F134).

Remarks.—Only one sagittal section is available for study. Its small shell size and the nature of coiling and septa are suggestive of *Schubertella* for its generic belonging.

Occurrence.—Rare in Sample 1.

Family Fusulinidae von Möller, 1878
Subfamily Fusulininae von Möller, 1878
Genus *Quasifusulina* Chen, 1934

Type species.—*Fusulina longissima* von Möller, 1878.

Quasifusulina? sp.
Figs. 3.1-3.2

Figured material.—A number of mold specimens on a weathered rock surface of Sample 3 (NU-F129).

Descriptive remarks.—Several specimens of external molds of fusuline shells, crowded on a surface of a weathered rock sample, were obtained for this study, so that their internal shell features, which are essential for fusuline taxonomy, are completely lost. These specimens exhibit fairly large, cigar-like subcylindrical shells with their length of about 8.0-13.0 mm and width of about 2.0-3.5 mm. Some of them remain external furrows of septa (Fig. 3.2). Moreover,

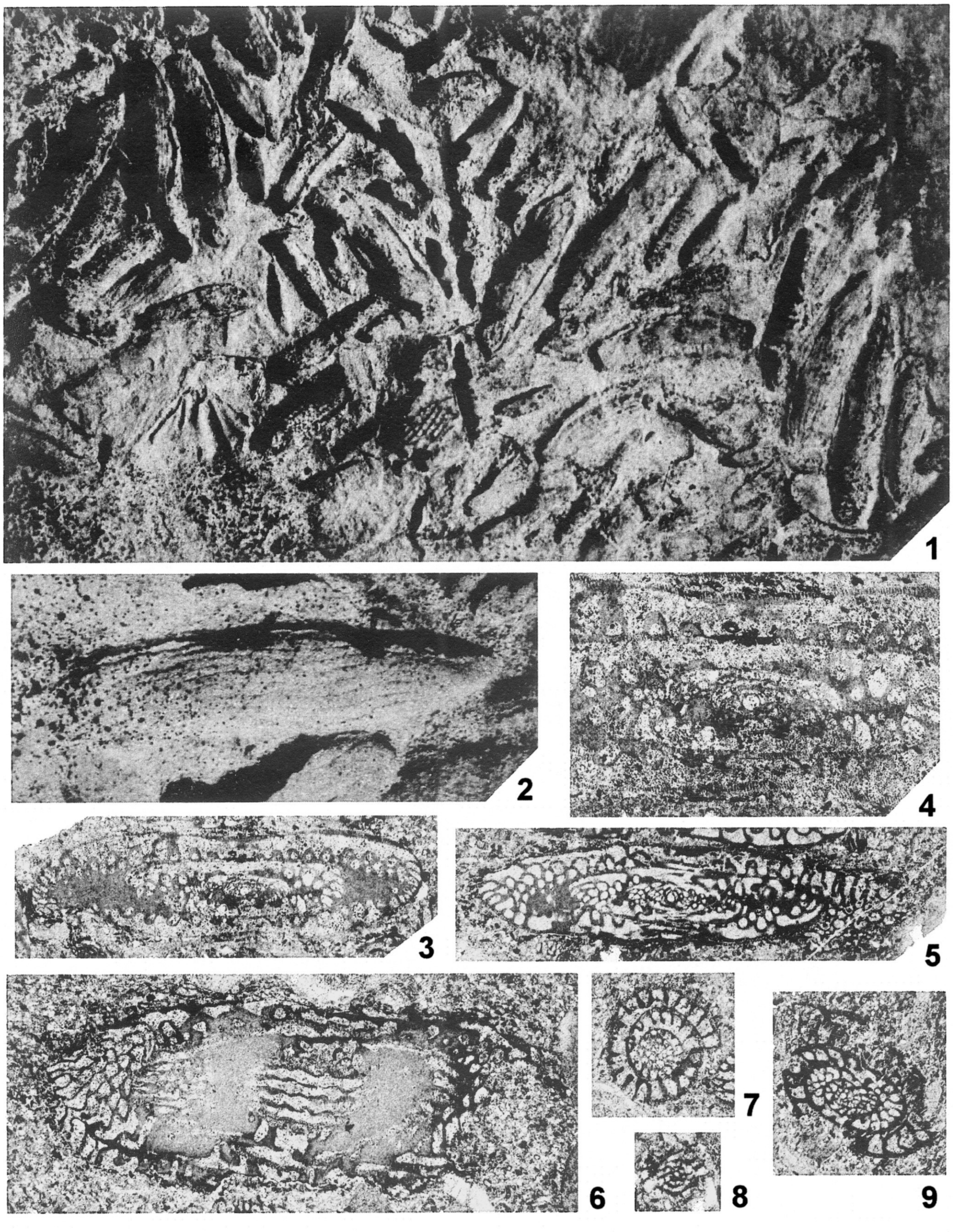

Fig. 3. 1, 2. *Quasifusulina*? sp., 1: A number of external molds of shells on a weathered rock surface of Sample 3, NU-F129, 2: One of slightly well-preserved external molds on a weathered surface of Sample 3, showing external furrows of septa. **3-5, 7, 9.** *Eoparafusulina* aff. *perplexa* (Grozdilova and Lebedeva, 1961), 3,5: axial sections NU-F130 and NU-F131, 4: enlarged part of 3, showing spherical proloculus followed by rather tightly coiled early volutions and slightly expanded, compared with inner ones, outer volutions, 7: parallel section, NU-F133, 9: slightly oblique sagittal section, NU-F135, all from Sample 1. **6:** *Rugosofusulina* sp., tangential section from Sample 1, NU-F132. **8:** *Schubertella* sp., sagittal section from Sample 1, NU-F134. 1: × 2, 2: × 5, 3, 5-7, 9: × 10, 4: × 20, 8: × 40.

some specimens leave imprints of strong polar torsion together with strongly and regularly fluted septa, though very poorly preserved. These morphological characters are suggestive of *Quasifusulina* to some extent, particularly of *Q. tenuissima* in their large subcylindrical shells, which also occurs in the Sb member (Sb1 and Sb2 units) of the Sakamotozawa Formation (Kanmera and Mikami, 1965a, b). Because of the lack of information on their internal shell structure, however, the identification of the present specimens is left open nomenclaturally and they are only questionably identified as *Quasifusulina*.

Occurrence.—Common in Sample 3.

Family Schwagerinidae Dunbar and Henbest, 1930
?Subfamily Schwagerininae Dunbar and Henbest, 1930
Genus *Rugosofusulina* Rauser-Chernousova, 1937

Type species.—*Alveolina prisca* Ehrenberg, 1842 emend. von Möller, 1878.

Rugosofusulina sp.
Fig. 3.6

Figured material.—Tangential section (NU-F132).

Descriptive remarks.—One tangential section, having an approximate shell length of 7.6 mm and width of 2.3 mm with definite axial fillings and somewhat ambiguous rugosity in spirotheca, is available for this study. Judging from these morphological characters, together with its shell dimension, this unidentified species is probably conspecific with *Rugosofusulina* sp. of Kanmera and Mikami (1965b) reported from the lower part of the Sb member of the Sakamotozawa Formation.

Occurrence.—Rare in Sample 1.

?Subfamily Pseudofusulininae Dutkevich, 1934
Genus *Eoparafusulina* Coogan, 1960

Type species.—*Fusulina gracilis* Meek, 1864. See Wilson (1967) for the details of complicated history on the fixation of the type species of the genus and on the taxonomic and nomenclatural change of the species *gracilis*.

Eoparafusulina Coogan, 1960, p. 262.
Alaskanella Skinner and Wilde, 1966, p. 57.

Remarks.—Skinner and Wilde (1966) established *Alaskanella* with *A. laudoni* Skinner and Wilde from the Tahkandit Limestone (Lower Permian) of Alaska as the type species. They noted that the absence of cuniculi in *Alaskanella* is the main diagnosis to distinguish it from *Eoparafusulina*. However, the intensity of septal fluting between *Alaskanella* species (e.g., *A. laudoni*) and typical elongate *Eoparafusulina* species [e.g., *E. gracilis* and *E. thompsoni* reported by Skinner and Wilde (1965) from the Lower Permian McCloud Limestone of northern California, U.S.A.] is not essentially different when compared based on their illustration. As already discussed in Ross (1967a, b), *Alaskanella* is judged a junior synonym of *Eoparafusulina*. This view has been also retained by Loeblich and Tappan (1988), Rauser-Chernousova et al. (1996), and Ueno (2006).

The genus *Mccloudia*, originally proposed by Ross (1967b) as a subgenus of *Eoparafusulina*, is here regarded as an independent genus. The former can be distinguished from the latter by having a shorter axis of coiling, thus giving a smaller form ratio, and generally smaller proloculus with the deviation of coiling in early volutions.

Eoparafusulina aff. *perplexa* (Grozdilova and Lebedeva, 1961)
Figs. 3.3-3.5, 3.7, 3.9, 4.1-4.16, 5.1-5.5

Compare.—

Pseudofusulina? *perplexa* Grozdilova and Lebedeva, 1961, p. 197-198, pl. 7, figs. 1, 2.

Pseudofusulina? *perplexa* forma *pertenia* Grozdilova and Lebedeva, 1961, p. 198-199, pl. 7, figs. 3, 4.

Figured materials.—Axial sections (NU-F130, NU-F131, NU-F136, NU-F137, NU-F138, NU-F139, NU-F140, NU-F141, NU-F142, NU-F143, NU-F144, NU-F145, NU-F146, NU-F147, NU-F148, NU-F149, NU-F150, NU-F151, NU-F152, NU-F153, NU-F154), slightly oblique sagittal section (NU-F135), tangential sections (NU-F155, NU-F-156), parallel section, (NU-F133). Several additional specimens that are not illustrated here are also used for the following description.

Description.—Shell is rather small for genus and elongate subcylindrical with rounded to bluntly pointed poles and almost parallel central part of shell. Some specimens exhibit slightly depressed central part of shell. Mature specimens having four and a half to five and a half volutions are 5.2-6.9 mm in length, 1.1-1.6 mm in width, and 3.3-5.2 in form ratio. Coiling planispiral throughout growth. Inner volutions are tightly coiled; outer one or one and a half volutions are slightly expanded compared with inner ones. Radius vectors of the first to fifth volutions are 0.08-0.19, 0.14-0.30, 0.22-0.59, 0.38-0.87, and 0.57-0.90 mm, and their form ratios are 1.1-2.4, 1.7-2.9, 2.3-3.9, 3.1-4.6, and 3.4-4.6, respectively. Proloculus is spherical and 0.09-0.22 mm in outside diameter. Spirotheca consists of a tectum and lower structureless layer in inner one or two volutions, which often looks composed of a single structureless layer. From the second or third volution, it exhibits coarsely alveolar. Thicknesses of spirotheca in outer keriotheca-bearing volutions are usually 0.05-0.08 mm. Septa are strongly and regularly fluted, forming narrow and high septal loops in axial regions. Cuniculi are present in outer volutions (Fig. 5.4). Septal pores are well observed in some specimens (e.g., Fig. 5.5). Small asymmetrical chomata are developed in generally inner two volutions, probably replaced by pseudochomata in outer ones. Tunnel is straight and rather narrow in early volutions, gradually becoming wider toward outer ones. Axial fillings are present in various degrees.

Remarks.—The present species is closest to *Eoparafusulina perplexa* originally described by Grozdilova and Lebedeva (1961) from the Tastubian (early Sakmarian) of North Timan, Russia, among elongate *Eoparafusulina* species typically represented by *E. gracilis* and *E. linearis*. The former is, however, regarded as distinct from the latter in having slightly more expanded outer volutions and more developed axial fillings.

Kanmera and Mikami (1965b) described *Monodiexodina* (*Ferganites*) *langsonensis* from the Sb member of the Sakamotozawa Formation, which was originally established by Saurin (1950) based on specimens from the Ky-Lua Limestone of Langson, Viet Nam. Recently, Ueno (2006) stated that the Sakamotozawan *langsonensis* is neither referable to *Monodiexodina* nor *Ferganites* based on the taxonomic and phylogenetic reassessment of *Monodiexodina* and its morphologically similar but taxonomically distinct genera. He concluded that the relevant species should be subsumed in the genus *Eoparafusulina*. *Eoparafusulina* aff. *perplexa* is somewhat similar to *E. langsonensis* from the Sb member, but can be distinguished from the latter by a smaller shell, slightly smaller number of volutions, and slightly more expanded outer volutions. As noted already in the precedent section, the former is judged the direct ancestor of the latter based on their morphology and stratigraphic occurrences.

The present *Eoparafusulina* aff. *perplexa* is morphologically close to *E. gracilis*, the type species of the genus, described originally by Meek (1864) from the Early Permian McCloud Limestone of California, U.S.A. The latter has more tightly coiled volutions than the former, judging from topotypes by Skinner and Wilde (1965).

Occurrence.—Abundant in Sample 1.

Genus *Nipponitella* Hanzawa, 1938a

Type species.—*Nipponitella explicata* Hanzawa, 1938a.

Nipponitella explicata Hanzawa, 1938a
Figs. 5.6-5.13, 6.1-6.13

Nipponitella explicata Hanzawa, 1938a, p. 256-257, figs. 8-16; Kanmera and Mikami, 1965b, p. 290-291, pl. 49, figs. 1-19.

?*Nipponitella* cf. *explicata* Hanzawa: Kanomata and Miyawaki, 1967, p. 161, pl. 1, figs. 6, 7.

?*Nipponitella explicata* Hanzawa: Choi, 1973, p. 29-30, pl. 2, figs. 16, 17, pl. 3, fig. 2; Minato

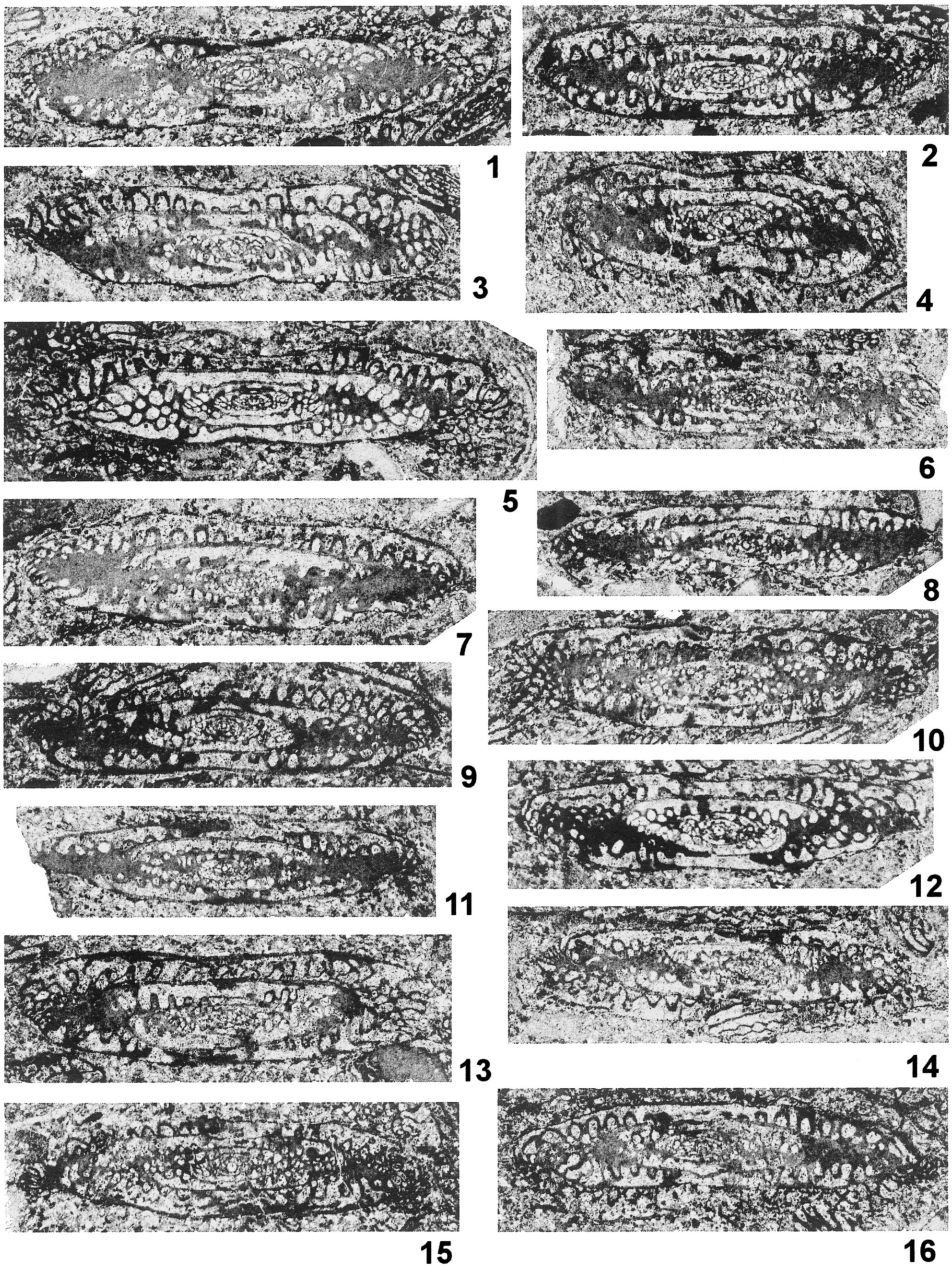

Fig. 4. 1-16: *Eoparafusulina* aff. *perplexa* (Grozdilova and Lebedeva, 1961), axial sections from Sample 1, NU-F136, NU-F137, NU-F138, NU-F139, NU-F140, NU-F141, NU-F142, NU-F143, NU-F144, NU-F145, NU-F146, NU-F147, NU-F148, NU-F149, NU-F150, NU-F151. All × 10.

et al., 1979, pl. 40, figs. 3, 4.
not *Nipponitella explicata* Hanzawa: Han and Guo, 1979, p. 85, pl. 1, figs. 6, 9, pl. 2, figs. 1, 4, 8, 10, 11.

Figured materials.—Axial sections (NU-F158, NU-F159, NU-F163, NU-F165, NU-F168, NU-F169, NU-F173, NU-F174, NU-F177), slightly oblique axial sections (NU-F162, NU-F170, NU-F171), sagittal section (NU-F166); tangential sections (NU-F157, NU-F161, NU-F167, NU-F175, NU-F176), parallel sections (NU-F160, NU-F164, NU-F172).

Description.—Mature shell consists of two parts: an early normally coiled part and ultimate uncoiled flaring one. The early part, consisting of planispiral, four to five and a half volutions, is subcylindrical to elongate subcylindrical with rounded to bluntly pointed polar ends, measuring 3.6-6.3 mm in length, 0.9-1.6 mm in width, and 3.6-4.7 in form ratio. Total shell length attains up to 7.2 mm, and width to 4.0 mm. Radius vectors of the first to fifth volutions of early coiled part are 0.08-0.17, 0.12-0.26, 0.20-0.48, 0.32-0.67, and 0.58-0.83 mm, and their form ratios are 1.4-2.4, 1.7-3.7, 1.9-4.6, 3.0-4.9, and 3.4-3.9, respectively. Proloculus is spherical and 0.10-0.16 mm in outside diameter. Spirotheca is seemingly composed of a tectum and lower less dense layer in inner one to two, rarely two and a half volutions, but of a tectum and keriotheca in outer ones. Thicknesses of spirotheca in outer volutions with coarse alveoli are 0.04-0.07 mm. Septa are strongly and regularly fluted in early coiled volutions, but septal folding becomes irregular in the ultimate uncoiled part. Septal pores are discernible in some specimens. In early coiled part, cuniculi are present in polar regions of outer volutions (Fig. 6.12). Small asymmetrical chomata are developed in the first two volutions. Axial fillings are generally developed in early coiled part although they are absent in some specimens (e.g., Figs. 5.7, 5.12).

Remarks.—*Nipponitella explicata* is a quite unique, "aberrant" schwagerinid species that has an uncoiled part in the final stage of its ontogeny. The type species was reported by Hanzawa (1938a) from the Permian "Maiya Group" distributed at Sakamotozawa in Hikoroichi, which is now known as the Sakamotozawa Formation. Later, Kanmera and Mikami (1965b) described and illustrated a number of topotypes including well-oriented axial and sagittal sections from the Sb member of the formation, which resulted in figuring the entire morphological features of this species. The present specimens from the Sa member are essentially similar to the types by Hanzawa (1938a) and topotypes by Kanmera and Mikami (1965b) although the former has a slightly more elongate inner coiled part than the latter two.

When Hanzawa (1938a) proposed *Nipponitella*, he described three new species (*N. explicata*, *N. auricula*, and *N. expansa*) of the genus from three different localities in the South Kitakami Belt. In that paper, the second species was erroneously spelled as "*auriculla*" in the original description, but the specific name should correctly be *auricula*. Among the three species, *N. auricula* and *N. expansa* are only represented by several sagittal and diagonal sections. Although their taxonomic validity is not very clear, they seem to be distinguished from

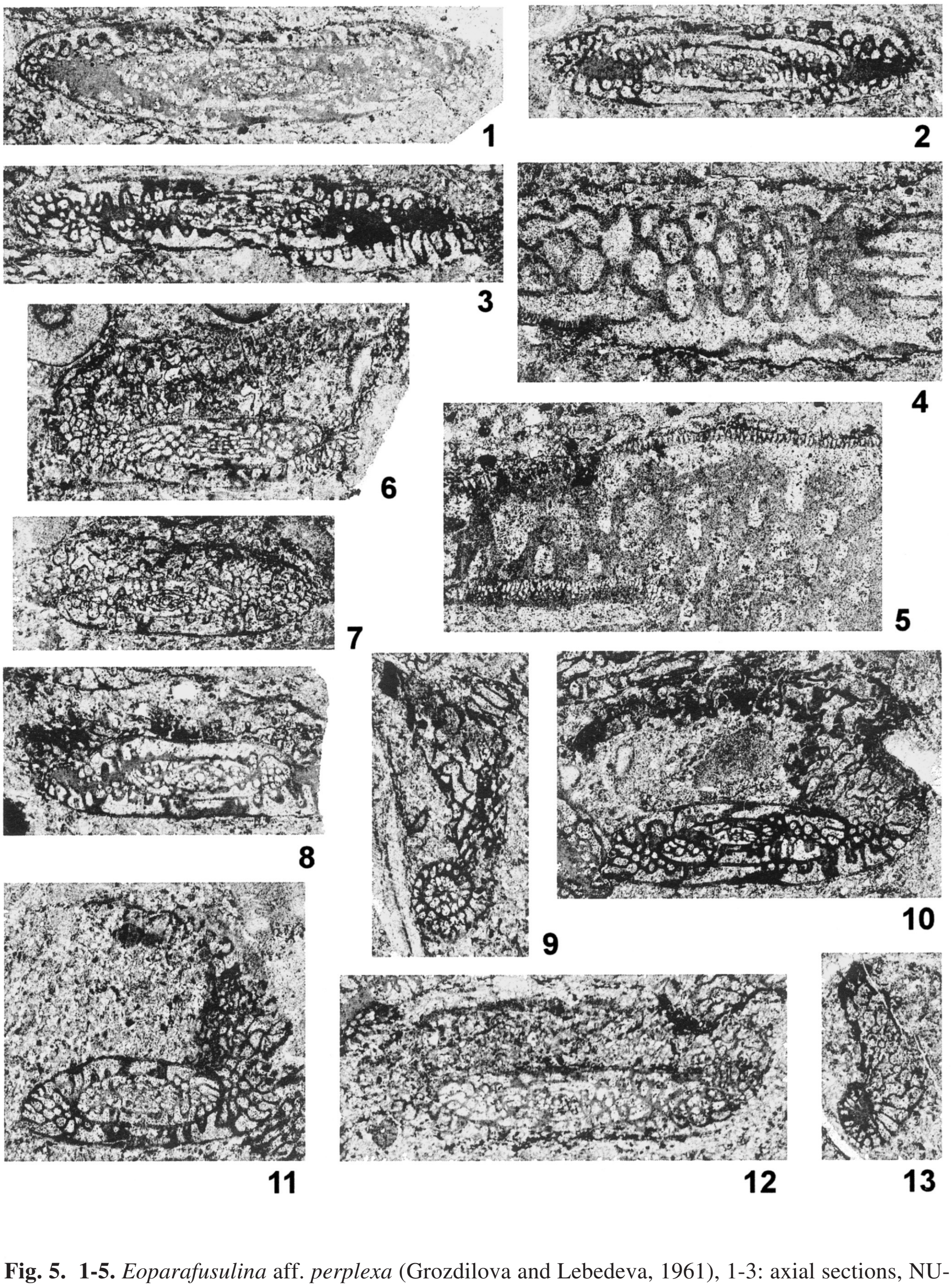

Fig. 5. 1-5. *Eoparafusulina* aff. *perplexa* (Grozdilova and Lebedeva, 1961), 1-3: axial sections, NU-F152, NU-F153, NU-F154, 4: enlarged part of one tangential section, showing rudimentary development of cuniculi in axial region of outer volution, NU-F155, 5: enlarged part of one tangential section, showing well-developed septal pores and coarsely alveolar spirotheca in outer volutions, NU-F156, all from Sample 1. **6-13.** *Nipponitella explicata* Hanzawa, 1938a, 6,10: tangential sections, NU-F157 and NU-F161, 7, 8,12: axial sections, NU-F158, NU-F159, NU-F163, 9, 13: parallel sections, NU-F160 and NU-F164, 11: slightly oblique axial section, NU-F162, all from Sample 1. 1-3, 6-13: × 10, 4, 5: × 25.

N. explicata by having a more developed uncoiled part.

Kanomata and Miyawaki (1967) reported *Nipponitella* cf. *explicata* from the Kamiyasse area, and Choi (1973) described *N. explicata* from the Setamai-Yahagi area, both of which belong to the South Kitakami Belt. Later, two of the Choi's (1973) specimens were re-illustrated by Minato et al. (1979). These forms are only represented by rather poorly preserved and poorly oriented specimens, which do not include any axial section. They are, thus, only questionably referable to *N. explicata* in this study.

Han and Guo (1979) described and illustrated totally four species of *Nipponitella* from the Amushan Formation [broadly of Asselian and Sakmarian according to Editorial Committee of Stratigraphic Lexicon of China (2000), but is probably partly of early Artinskian; see discussion in the precedent chapter] of Soniteyouqi (Sonid Right Banner) of Inner Mongolia, Northeast China. They are *Nipponitella explicata* (s.s.), *N. explicata neimongolensis*, *N.* sp. 1, and *N.* sp. 2, of which the second one was proposed as a new subspecies at that time. Han and Guo (1979) noted that this new subspecies can be distinguished from *N. explicata* (s.s.) by having fewer number of volutions, more loosely coiled volutions, and comparatively larger proloculus. Judging from their illustration, however, these morphological differences that Han and Guo (1979) considered having value of subspecific distinction can be considered as merely intraspecific variability. Moreover, the Inner Mongolian specimens of both *N. explicata* (s.s.) and *N. explicata neimongolensis* definitely have larger shells with more strongly fluted septa than those of *N. explicata* from the Sakamotozawa Formation. They can be treated as a distinct species and, thus, should be identified as *N. neimongolensis*.

With respect to the phylogenetic origin of *Nipponitella*, Choi (1973) considered that the genus may be a small off-shoot from some primitive *Nagatoella* in the lowest Permian, after synonymizing *Darvasites* and *Mccloudia* [*Eoparafusulina* (*Mccloudia*) in the sense by Ross (1967b)] into *Nagatoella*. In regard to this, it is noteworthy that the inner coiled part of the present *Nipponitella explicata* specimens is quite similar to *Eoparafusulina* aff. *perplexa* of this study. Kanmera and Mikami (1965b) also noted in the description of *N. explicata* that the inner volutions of the species and their *E. langsonensis* share similar morphological features in many respects although their mature shells are apparently very distinct from each other. These similarities warrant their close phylogenetic relation, and *N. explicata* would be highly probably a specialized off-shoot, derived from an elongate *Eoparafusulina* species without uncoiled flaring part; that is *E.* aff. *perplexa* in this study.

This morphological, and highly probably phylogenetic, close relation between *Nipponitella explicata* and *Eoparafusulina* aff. *perplexa* in this study gives rise to very practical difficulties for the distinction in thin section between some specimens of the former species that are particularly represented only by the inner coiled part due to their orientation in thin section and those of the later one without development of uncoiled part innately. As *N. explicata* has a flattened, “washbasin-shaped” shell, composed of an early coiled and ultimate uncoiled flaring parts, it is highly depending on the orientation of specimen in thin section

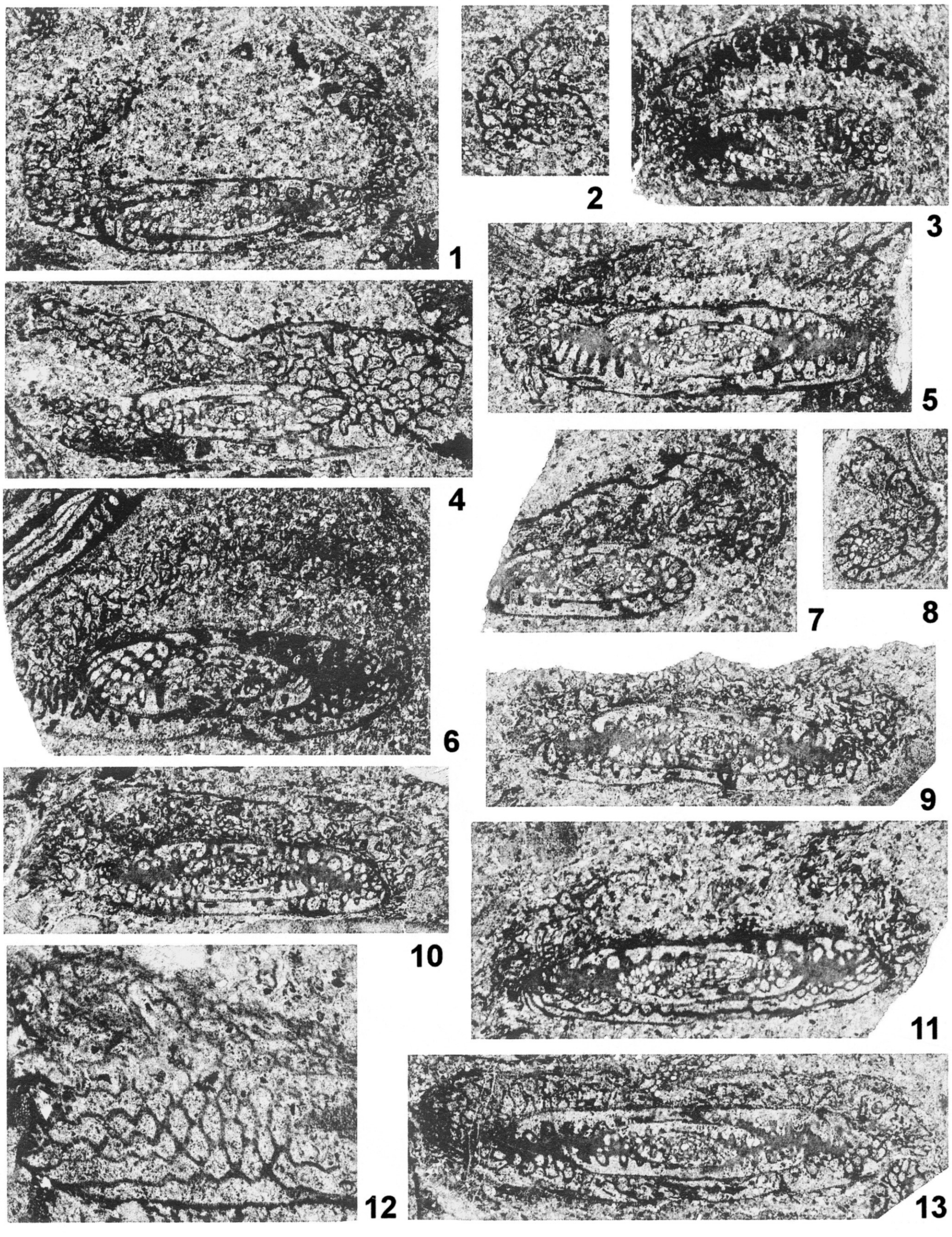

Fig. 6. 1-13. *Nipponitella explicata* Hanzawa, 1938a, 1, 4, 5, 9, 10, 13: axial sections, NU-F165, NU-F168, NU-F169, NU-F173, NU-F174, NU-F177, 2: sagittal section, NU-F166, 3,11: tangential sections, NU-F167 and NU-F175, 6, 7: slightly oblique axial sections, NU-F170 and NU-F171, 8: parallel section, NU-F172, 12: enlarged part of one tangential section, showing presence of rudimentary cuniculi in axial region of outer volution in early normally coiled part, with rather irregular septal fluting in ultimate uncoiled part illustrated in upper left of specimen, NU-F176, all from Sample 1. 1-11, 13:×10, 12:×20.

whether or not the uncoiled flaring part is visible in a two-dimensional section. For example, one axial section here referred to *N. explicata* illustrated on Fig. 6.13 looks similar to that of *E.* aff. *perplexa* due to the apparent lack of the uncoiled part that is diagnostic for the former. This is, however, interpreted as merely due to the orientation of the specimen in thin section, which is not cut through the main part of the ultimate uncoiled portion of shell. Careful observation reveals that the relevant specimen has the slightly more expanded last half volution than those of *E.* aff. *perplexa*. Moreover, the septal fluting of this last half volution is more irregular and complicated than the precedent ones, and is essentially similar to that in the uncoiled part of *N. explicata*.

Occurrence.—Common in Sample 1.

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References

Chen, S., 1934, Fusulinidae of South China, Part 1. *Palaeont. Sinica, Ser. B*, **4** (2), 1-185.

Choi, D.R., 1973, Permian fusulinids from the Setamai-Yahagi District, southern Kitakami Mountains, N. E. Japan. *Jour. Fac. Sci., Hokkaido Univ., Ser. IV, Geol. Mineral.*, **16**, 1-132.

Coogan, A.H., 1960, Stratigraphy and paleontology of the Permian Nosoni and Dekkas formations (Bollibokka Group). *Univ. California Publ. Geol. Sci.*, **36**, 243-316.

Dunbar, C.O. and Henbest, L.G., 1930, The fusulinid genera *Fusulina, Fusulinella* and *Wedekindella*. *Am. Jour. Sci., Ser. 5*, **20**, 357-364.

Dutkevich, G.A., 1934, O nekotorykh novykh vidakh Fuzulinid iz verkhnego i srednego Karbona verkhne-Chusovskikh Gorodkov na R. Chusovoy (Zapadnyy sklon srednego Urala). *Tr. Neft. Geol.-Razved. Inst., Ser. A*, **36**, 1-98. (in Russian)

Editorial Committee of Stratigraphic Lexicon of China (Jin, Y.G., Shang, Q.H., Hou, J.P., Li, L., Wang, Y.J., Zhu, Z.L. and Fei, S.Y.), 2000, *Stratigraphic Lexicon of China, Permian System*. Geol. Publ. House, Beijing, 149 p. (in Chinese)

Ehrenberg, C.G., 1842, Der Bergkalk am Onega-See aus Polythalamien bestehend. *Bericht über die zu Bekanntmach. Verhandl. König. Preuss. Akad. Wissenschaf. Berlin,* 1842, 273-275.

Forke, H.C., 2002, Biostratigraphic subdivision and correlation of uppermost Carboniferous/ Lower Permian sediments in the Southern Alps: Fusulinoidean and conodont faunas from the Carnic Alps (Austria/Italy), Karavanke Mountains (Slovenia), and Southern Urals (Russia). *Facies*, **47**, 201-276.

Gradstein, F.M., Ogg, J.G. and Smith, A.G. (eds.), 2004, *A Geologic Time Scale*. Cambridge Univ. Press, Cambridge, 589 p.

Grozdilova, L.P. and Lebedeva, N.S., 1961, Nizhnepermskie foraminifery severnogo Timana. *Tr. VNIGRI*, **179** (*Mikrofauna SSSR Sbornik 13*), 161-329. (in Russian)

Han, J.X., 1980, The morphology, evolution and distribution of the genus *Monodiexodina* and its allied genera. *Bull. Shenyang Inst. Geol. Min. Res.*, **1**, 90-102.

Han, J.X. and Guo, S.Z., 1979, Discovery of the *Nipponitella* fauna in Sonid Right Banner of Inner Mongolia. *Acta Palaeont. Sinica*, **18**, 83-87. (in Chinese)

Hanzawa, S., 1938a, An aberrant type of the Fusulinidae from the Kitakami Mountainland, Northeastern Japan. *Proc. Imp. Acad. Tokyo*, **14**, 255-259.

Hanzawa, S., 1938b, Stratigraphical distribution of the genera *Pseudoschwagerina* and *Paraschwagerina* in Japan, with descriptions of two new species of *Pseudoschwagerina* from the Kitakami Mountainland, northeastern Japan. *Jap. Jour. Geol. Geogr.*, **16**, 65-73.

Jin, Y.G., Wardlaw, B.R., Glenister, B.F. and Kotlyar, G.V., 1997, Permian chronostratigraphic subdivisions. *Episodes*, **20**, 10-15.

Kanmera, K. and Mikami, T., 1965a, Succession and sedimentary features of the Lower Permian Sakamotozawa Formation. *Mem. Fac. Sci., Kyushu Univ., Ser. D, Geol.*, **16**, 265-274.

Kanmera, K. and Mikami, T., 1965b, Fusuline zonation of the Lower Permian Sakamotozawa Series. *Mem. Fac. Sci., Kyushu Univ., Ser. D, Geol.*, **16**, 275-320.

Kanomata, N. and Miyawaki, A., 1967, On the fusulinids at Kamiyatsuse district in Kesennuma City, Miyagi Prefecture, North-east Japan. *Jour. Coll. Arts Sci., Chiba Univ.*, **5**, 159-165.

Leven, E.Ya., 1980. *Ob'yasnitel'naya Zapiska k Stratigraficheskoy Shkale Permskikh Otlozheniy Oblasti Tetis*. Minist. Geol. SSSR, VSEGEI, Leningrad, 51 p. (in Russian)

Leven, E.Ya., 1993, Main events in Permian history of the Tethys and fusulinids. *Strat. Geol. Correlat.*, **1**, 51-65.

Leven, E.Ja., 2001, On possibility of using the global Permian stage scale in the Tethyan region. *Strat. Geol. Correlat.*, **9**, 118-131.

Loeblich, A.R., Jr. and Tappan, H., 1988, *Foraminiferal Genera and Their Classification*. Van Nostrand Reinhold, New York, 970 p.

Meek, F.B., 1864, Description of the Carboniferous fossils. *Geol. Surv. California, Palaeont.*, **1**, 1-16.

Mikami, T., 1965, The type Sakamotozawa Formation. *Jour. Geol. Soc. Japan*, **71**, 475-493. (in Japanese)

Minato, M., Kato, M., Nakamura, K., Hasegawa, Y., Choi, D.R. and Tazawa, J., 1978, Biostratigraphy and correlation of the Permian of Japan. *Jour. Fac. Sci., Hokkaido Univ., Ser. IV, Geol. Mineral.*, **18**, 11-47.

Minato, M., Kato, M., Nakamura, K., Hasegawa, Y., Choi, D.R., Tazawa, J., Suyama, K., Takeda, H., Yamada, K., Suetomi, H., Kakimi, T., Kozuchi, Y., Maekawa, T., Hashimoto, T., Oikawa, M., Harada, J., Yato, N., Egawa, Y., Yasuda, M., Takaiwa, M., Nakajima, M., Kumano, N., Okabe, Y., Takahashi, T., Nakajima, K., Sugiyama, S., Ohtake, T., Ohmori, M., Kawamura, M., Kudo, S., Nakamura, T., Chitoku, T., Matsui, M., Suga, M., Tazika, J., Seta, O., Nozawa, K. and Watanabe, Y., 1979, Chapter 2k, Lower Permian. *In* Minato, M., Hashimoto, M., Watanabe, J. and Kato, M., *eds*., *Variscan Geohistory of Northern Japan: The Abean Orogeny*, Tokai Univ. Press, Tokyo, 171-177, 205-214 (pls. 39-48), 257-260 (explanation of plates).

Möller, V. von, 1878, Die spiral-gewunden Foraminiferen des russischen Kohlenkalkes. *Mém. l'Acad. Imp. Sci. St. Pétersbourg, Sér. 7*, **25**, 1-147.

Morikawa, R. and Isomi, H., 1961, Studies of Permian fusulinids in the east of Lake Biwa, central Japan. *Geol. Surv. Japan, Rept.*, no. 191, 1-29.

Onuki, Y., 1937, On the Paleozoic formation near Sakamotozawa, Kitakami Mountainland. *Jour. Geol. Soc. Japan*, **44**, 168-186. (in Japanese)

Rauser-Chernousova, D.M., 1937, *Rugosofusulina*-novyy rod fuzulinid. *Etyudy po Mikropaleontologiy, Paleont. Laborat. Mosk. Gosud. Univ.*, **1**, 9-26. (in Russian)

Rauser-Chernousova, D.M., Bensh, F.R., Vdovenko, M.V., Gibshman, N.B., Leven, E.Ya., Lipina, O.A., Reytlinger, E.A., Solov'eva, M.N. and Chediya, I.O., 1996, *Spravochnik po Sistematike Foraminifer Paleozoya (Endotiroidy, Fuzulinoidy*). Rossiysk. Akad. Nauk, Geol. Inst., Nauka, Moskva, 207 p. (in Russian)

Ross, C.A., 1967a, Late Paleozoic Fusulinacea from northern Yukon Territory. *Jour. Paleont*., **41**, 709-725.

Ross, C.A., 1967b, *Eoparafusulina* from the Neal Ranch Formation (Lower Permian), West Texas. *Jour. Paleont.*, **41**, 943-946.

Ross, C.A. and Ross, J.R.P., 2003, Sequence evolution and sequence extinction: Fusulinid biostratigraphy and species-level recognition of depositional sequences, Lower Permian, Glass Mountains, West Texas, U.S.A. *In* Olson, H.C. and Leckie, R.M., *eds*., *Micropaleontologic Proxies for Sea-Level Change and Stratigraphic Discontinuities*. Soc. Econ. Paleont. Mineral., Spec. Publ., no. 75, 317-359.

Saurin, E., 1950, Les fusulinides des calcaires de Ky-Lua, Langson (Tonkin). *Bull. Serv. Géol. l'Indochine*, **29** (5), 1-32.

Skinner, J.W., 1931, Primitive fusulinids of the Mid-Continent region. *Jour. Paleont.*, **5**, 253-259.

Skinner, J.W. and Wilde, G.L., 1965, Permian biostratigraphy and fusulinid faunas of the Shasta Lake area, northern California. *Univ. Kansas Paleont. Contrib*., *Art*., 39 (Protozoa 6), 1-98.

Skinner, J.W. and Wilde, G.L., 1966, Permian fusulinids from Pacific Northeast and Alaska, Part 8. *Alaskanella*, new Permian fusulinid genus. *Univ. Kansas Paleont. Contrib.*, *Pap*., 4, 55-58.

Staff, H. von and Wedekind, R., 1910, Der Oberkarbon Foraminiferensapropelit Spitzbergens. *Bull. Geol. Inst., Univ. Upsala*, **10**, 81-123.

Toriyama, R., 1967a, The fusulinacean zones of Japan. *Mem. Fac. Sci., Kyushu Univ., Ser. D, Geol.*, **18**, 35-260.

Toriyama, R., 1967b, Permian Period. *In Historical Geology, Volume 1*, Asakura Shoten, Tokyo, 254-305. (in Japanese)

Ueno, K., 2006, The Permian antitropical fusulinoidean genus *Monodiexodina*: Distribution, taxonomy, paleobiogeography and paleoecology. *Jour. Asian Earth Sci*., **26**, 380-404.

Watanabe, K., 1991, Fusuline biostratigraphy of the Upper Carboniferous and Lower Permian of Japan, with special reference to the Carboniferous-Permian boundary. *Palaeont. Soc. Japan, Spec. Pap*., no. 32, 1-150.

Wilson, E.C., 1967, *Fusulina gracilis* Meek, 1864 (Foraminiferida): Proposed invalidation of neotype-material, designation as type-species of *Eoparafusulina* Coogan, 1960, and related actions. Z.N.(S.) 1794. *Bull. Zool. Nomencl*., **24**, 234-237.

Wood, G.D., Groves, J.R., Wahlman, G.P., Brenckle, P.L. and Alemán, A.M., 2002, The paleogeographic and biostratigraphic significance of fusulinacean and smaller foraminifers, and palynomorphs from the Copacabana Formation (Pennsylvanian-Permian), Madre de Díos Basin, Peru. *In* Hills, L.V., Henderson, C.M. and Bamber, E.W., *eds*., *Carboniferous and Permian of the World. Can. Soc. Petrol. Geol. Mem.*, no. 19, 630-664.