Permian Albaillellaria (Radiolaria) from a limestone lens at the Arrow Rocks in the Waipapa Terrane (Northland, New Zealand)

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KEY WORDS
Radiolaria,
Albaillellaria,
Permian,
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Follicucullus,
Arrow Rocks,
new species.

ABSTRACT
Well-preserved Permian radiolarians are present in a limestone lens at Arrow Rocks in the Whangaroa Area within Waipapa Terrane, New Zealand. This fauna contains eight species of albaillellarians, six species of genus *Follicucullus* and two of *Pseudoalbaillella*, and is Late Middle to Early Late Permian in age. In the Whangaroa Area, basalts are probably as old as Middle Permian, while cherts are mostly Late Permian. Although the radiolarian fauna from Arrow Rocks contains two new species of *Follicucullus*, this fauna can nevertheless be assigned a low-latitude origin. Two new species, *Follicucullus sphaericus* and *Follicucullus whangaroaensis*, are described.

MOTS CLÉS
Radiolaire,
lbaillellarides,
Permien,
Nouvelle Zélande,
Waipapa Terrane,
Follicucullus,
Arrow Rocks,
nouvelles espèces.

RÉSUMÉ
Albaillellaridés (radiolaires) permiens d'un banc calcaire à Arrow Rocks dans la Waipapa Terrane (Nouvelle Zélande septentrionale).
Des radiolaires permiens bien conservés ont été trouvés dans un banc calcaire à Arrow Rocks dans la région de Whangaroa de la Waipapa Terrane, Nouvelle Zélande. Cette faune contient huit espèces d'albaillellaridés, six espèces du genre *Follicucullus* et deux de *Pseudoalbaillella*, et est d'âge Permien moyen à début Permien supérieur. Dans la région de Whangaroa, les basaltes sont probablement aussi anciens que le Permien moyen, alors que les cherts sont principalement Permien supérieur. Bien que la faune à radiolaires à Arrow Rocks contiennent deux nouvelles espèces de *Follicucullus*, cette faune peut néanmoins être considérée comme de basse latitude. Deux nouvelles espèces, *Follicucullus sphaericus* et *Follicucullus whangaroaensis*, sont décrites.

INTRODUCTION

Our knowledge of Permian radiolarians has significantly increased since Ormiston & Babcock (1979) described genus *Follicucullus* from Guadalupian sequences in West Texas. After this pioneering research, taxonomy and biostratigraphy of Permian fauna developed rapidly in the United States, Russia and Japan (e.g., Holdsworth & Jones 1980; Ishiga & Imoto 1980; Takemura & Nakaseko 1981; Ishiga *et al.* 1982a, b; Nazarov & Ormiston 1986; Ishiga 1986). Most of this work was, however, done in the northern hemisphere, and most Permian radiolarians recorded from the southern hemisphere are from New Zealand.

Permian radiolarians are known from only a few fossil localities in New Zealand, one of which is Red Rocks near Wellington in Torlesse Terrane (Fig. 1), where Grapes *et al.* (1990) reported Middle Permian radiolarians from bedded chert. The other localities are concentrated within the Whangaroa Area in the northern Waipapa Terrane. Several radiolarian localities of bedded chert and limestone have been reported from this area, geologic age of which ranges from Middle to Late Permian (Caridroit & Ferrière 1988; Adachi 1988; Takemura *et al.* 1998).

We have made geological and biostratigraphic surveys in the Whangaroa Area (1995-1996), and have already reported the occurrence of Permian and Triassic radiolarians from this area. At Arrow Rocks, an almost continuous section from basalt with limestone, bedded chert to siliceous mudstone is exposed. Well-preserved radiolarians are present in a limestone lens within spilitic basalt, the age of which is Middle to Late Permian (Takemura *et al.* 1998). This fauna includes several albaillellarian species of the genera *Follicucullus* Ormiston & Babcock, 1979 and a

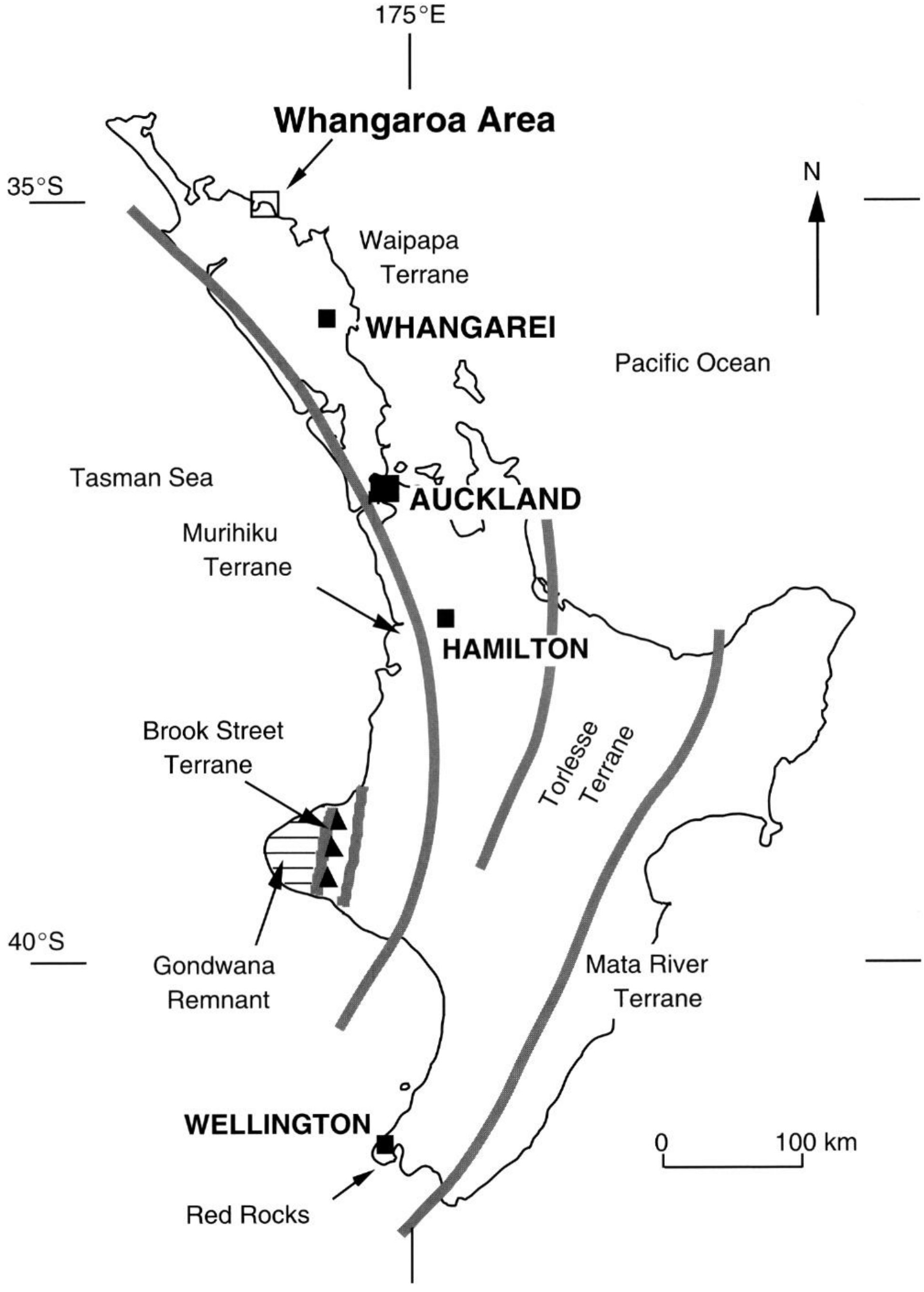

FIG. 1. — Index map of the North Island, New Zealand, showing the distribution of terranes (Aita & Spörli 1992) and the location of the Whangaroa Area, as well as Red Rock near Wellington.

few of *Pseudoalbaillella* Holdsworth & Jones, 1980. We describe albaillellarians of this fauna, including two new species of genus *Follicucullus*.

GEOLOGICAL SETTING, STRATIGRAPHY AND METHOD

Basement of New Zealand North Island consists mostly of five lithostratigraphic units, Murihiku, Dun Mountain, Waipapa, Torlesse and Mata River Terranes (Aita & Spörli 1992; Fig. 1). These terranes becomes younger in geological age from west to east, and the latter three, Waipapa, Torlesse and Mata River, are Mesozoic accretionary complexes.

The Whangaroa Area (Figs 1, 2) is situated at about 90 km northwest of Whangarei in Northland. This area belongs to the northern part of Waipapa Terrane, which is composed mostly of terrigenous clastic rocks associated with spilitic basalt, chert and argillites. Geological age of the northern part of this terrane is Permian to Triassic, based on radiolarians and fusulinids (Aita & Spörli 1992; Takemura *et al.* 1998).

The Waipapa Terrane rocks in the Whangaroa Area consists of massive to thick bedded sandstone (greywacke), spilitic basalt, bedded chert, green siliceous mudstone (argillite) and limestone lenses within basalt (Fig. 2). Prior to this study, more than six localities of Permian fossils were known from chert and limestone in this area. Radiolarian fossils show Middle to Late Permian age from five localities (Caridroit & Ferrière 1988; Adachi 1988; Takemura *et al.* 1998). Leven & Grant-Mackie (1997) described fusulinids from limestone lenses at Wherowhero Point (Fig. 2), the same locality from which Hornibrook (1951) reported fusulinids. They concluded that the fusulinid fauna belonged to *Yabeina-Lepidolina* zone and therefore is part of the Midian Stage of Tethyan Realm. They also mentioned the paleogeographic relationship of this fauna with eastern Asia. At Mahinepua Peninsula about 5 km east of the Wherowhero Point, very well-preserved Triassic radiolarians occur in the phosphatic nodules within green siliceous mudstone (Aita & Bragin 1999).

The material studied in this paper was obtained at Arrow Rocks (Oruatemanu Island), a small island located within Whangaroa Bay, north of Whangaroa Harbour (Fig. 2). The Grid Reference for Arrow Rocks, based on the New Zealand 1:50,000 topographic map, is PO4 & QO4/837895 corresponding to latitude 34°59.7'S and longitude 173°46.8'E. On this small island, we have observed a 135 m thick seemingly continuous section composed of spilitic basalt with limestone layers, bedded chert, and red, maroon and green siliceous mudstones. Takemura *et al.* (1998) made a preliminary report on the lithostratigraphy of this sequence, and divided it into eight lithological units (Fig. 3). Field observation of lithologies and thickness in these units in ascending order is as the follows:

- Unit 1: spilitic basalt with limestone lenses, 31.5 m;
- Unit 2: bedded chert, 11 m;
- Unit 3: alternation of chert and black shale, 1 m;
- Unit 4: red siliceous mudstone and red chert with manganese-rich layers, 6.6 m;
- Unit 5: red siliceous mudstone with thin red chert, 17.2 m;
- Unit 6: maroon chert and siliceous mudstone, 29.5 m;
- Unit 7: alternation of maroon and green siliceous mudstone, 11.2 m;
- Unit 8: green siliceous mudstone with vitric tuffs, 27 m.

Within this sequence, we observed no significant faulting except between Units 2 and 3. Boundaries between the units described above are conformable and appear to represent continuous deposition.

Takemura *et al.* (1998) report the occurrence of Late Permian Radiolaria including *Albaillella triangularis* Ishiga, Kito & Imoto, 1982 and *Hegleria* sp. in a bedded chert sample (ARR-7) within Unit 2. The horizon of ARR-7 lies about 10 m above that of ARR-1 (Fig. 3). Triassic radiolarians such as *Parentactinia* (Dumitrica, 1978), *Archaeosemantis* (Dumitrica, 1978) and forms belonging to genus *Glomeropyle* (Aita & Bragin 1999) are present in siliceous mudstones within Units 6 and 8.

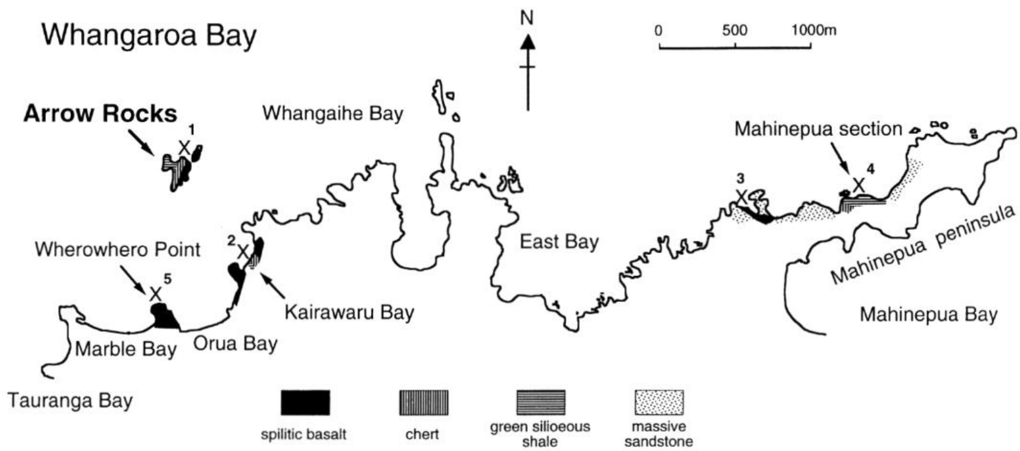

FIG. 2. — Permian and Triassic fossil localities in the Whangaroa Area. **X**, fossil localities, **1**, Permian radiolarians from limestone and bedded chert at Arrow Rocks (Takemura *et al.* 1998 and this study); **2**, Permian radiolarians from bedded chert at Kairawaru Bay (Caridroit & Ferrière 1988; Adachi 1988); **3**, Permian radiolarians from limestone and chert at west of Mahinepua Peninsula (Takemura *et al.* 1998); **4**, Triassic radiolarians from phosphate nodules in green argillite at the Mahinepua Section (Aita & Bragin 1999); **5**, Permian fusulinids from limestones at Wherowhero Point (Hornibrook 1951; Leven & Grant-Mackie 1997).

The material treated in this study is a limestone lens (ARR-1) within Unit 1. The unit includes four red, pale red or white limestone layers, 0.7 to 2 m thick, intercalated within basalts, which are usually green grey to green coloured, massive or showing pillow structure, or sometimes are fragmental. ARR-1 is a purple grey coloured, laminated limestone lens, situated at about 24 m above the base horizon. This lens is intercalated just below the uppermost red limestone layer within Unit 1 (24-26 m, Fig. 3).

ARR-1 contains numerous radiolarian shells, but they have been altered by $CaCO_3$ so that we obtained no or very few residues by extraction using diluted hydrochloric, nitric or acetic acids. As a result of this, it was decided to process the sample using diluted hydrofluoric acid (HF, 1 to 3%) for about 20 hours. We successfully recovered residues including radiolarians by this process, but the preservation was not good enough for determination of species. The same sample was then again processed by diluted nitric acid (HNO_3, 1 to 2%) for up to 24 hours. After this step, we were able to obtain well-preserved radiolarian shells. Although other acids such as hydrofluoric, hydrochloric or acetic acids were tried for the second step after HF, the best preservation was achieved by using nitric acid.

RADIOLARIAN FAUNA FROM ARROW ROCKS AND GEOLOGIC AGE OF BASALT-CHERT SEQUENCE IN THE WHANGAROA AREA

The limestone lens sample (ARR-1) contains well-preserved albaillellarian fauna. The fauna includes six species of genus *Follicucullus* and two of genus *Pseudoalbaillella* (Figs 4, 5). Ishiga (1986, 1991) established Permian radiolarian zonation based on the ranges of albaillellarians from mostly bedded chert sequences in Southwest Japan. His zonation is applicable for the ARR-1 fauna, because many albaillellarians from our sample were already included within Ishiga's zonation.

Among these albaillellarians with conical shells investigated by Ishiga (1986, 1991), *Pseudoalbaillella fusiformis* (Holdsworth & Jones, 1980), *P.* aff. *longicornis* of Ishiga *et al.* (1982a), *Follicucullus scholasticus* Ormiston & Babcock, 1979 and *F. porrectus* Rudenko, 1984 (= *F. japonicus* of Ishiga 1991) are present in our sample ARR-1. Because both *Follicucullus monacanthus* Ishiga & Imoto, 1982 (Ishiga *et al.* 1982b) and species of genus *Neoalbaillella* Takemura & Nakaseko, 1981 are absent in this sample, we correlate this fauna with *Follicucullus scholasticus* zone of Ishiga (1986).

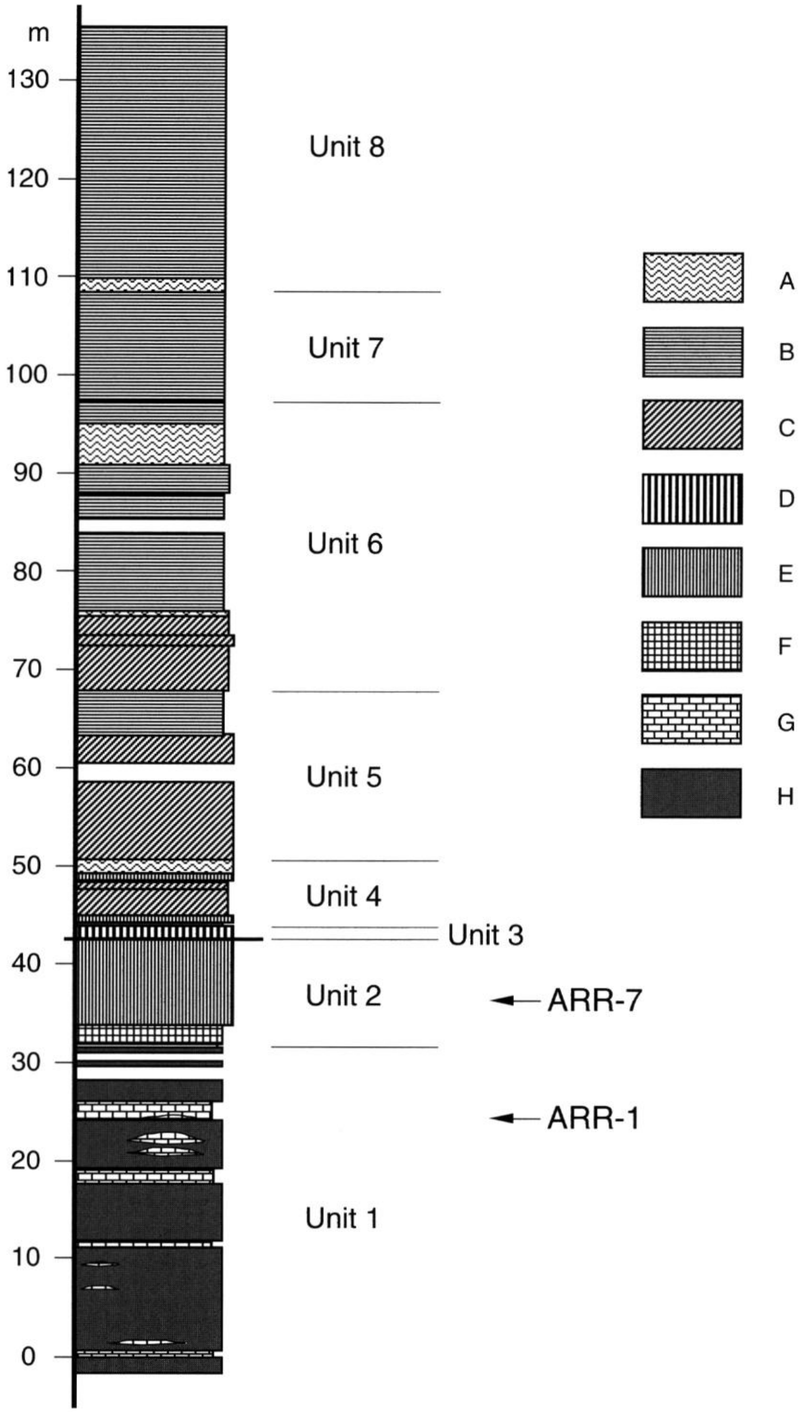

FIG. 3. — Summarized geologic column of the Arrow Rocks. **A**, fold zone; **B**, siliceous mudstone; **C**, bedded siliceous mudstone and chert; **D**, alternation of black shale and chert; **E**, bedded chert; **F**, tuff; **G**, limestone; **H**, spilitic basalt. ARR-1 and ARR-7 are the horizons where Permian radiolarians occurred (Takemura *et al.* 1998).

Following Ishiga's zonation, the upper limits of the ranges of *Pseudoalbaillella fusiformis* and *P.* aff. *longicornis* are within *Follicucullus monacanthus* zone or lower. However, occurrences of these two species in ARR-1 are few and they are usually less well preserved than *Follicucullus*. It is possible that these two species might be reworked, or that the ranges might be longer than that suggested by Ishiga's (1986) zonation.

The fauna in ARR-1 can be also correlated to the *Follicucullus japonicus* zone of Ishiga (1991) because of the co-occurrence of *F. porrectus* (= *F. japonicus*) and *F. scholasticus*, and because of the absence of *F. monacanthus*, *F. charveti* Caridroit & De Wever, 1984, *F. bipartitus* Caridroit & De Wever, 1984 and *Neoalbaillella*. According to the correlation of radiolarian zonation with fusulinid and conodont zonations by Ishiga (1986, 1990, 1991), the geologic age of *Follicucullus scholasticus* zone and *F. japonicus* zone is in the vicinity of the boundary between Middle and Late Permian.

Besides these species, Kozur (1993) described *Cariver dorsoconvexus* (herein treated as a species of the genus *Follicucullus*) from Upper Permian sequence in Sicily, Italy. *F. sphaericus* n. sp. was figured by Kuwahara (1997) as *Follicucullus* sp. A, which is present in bedded chert of GA section in Gujo-Hachiman Area, central Japan. These samples are within *Neoalbaillella optima* and *N. ornithoformis* zones, indicating a Late Permian age. The ranges of these two species, *Follicucullus dorsoconvexus* and *F. sphaericus* n. sp., however, are not clarified yet. Therefore, we regard the geologic age of our sample ARR-1 as Late Middle or Early Late Permian.

Takemura *et al.* (1998) reported Permian radiolarians from a limestone lens (MAH-5) at the west end of Mahinepua Peninsula (Fig. 2). MAH-5 contains *Follicucullus porrectus* Rudenko and *Pseudoalbaillella* (?) sp. They correlated this sample with the *F. monacanthus* zone of Ishiga (1986), and with the *F. japonicus* zone of Ishiga (1991), because of the absence of other species of *Follicucullus*. The geologic age of this sample is also near the Middle/Late Permian boundary.

Recently Leven & Grant-Mackie (1997) described fusulinids from some limestone lenses within spilitic basalt at Wherowhero Point (Fig. 2). These fusulinids include *Lepidolina shiraiwensis* Ozawa, 1925, *Neoschwagerina margaritae* Deprat, 1913 and *Yabeina globosa* (Yabe, 1906), and the fauna was correlated with the *Yabeina-Lepidolina* zone. Leven & Grant-Mackie (1997) regard the geologic age of these fusulinids as Midian, and most samples probably as Early Midian. The Midian stage corresponds to the Capitanian and late Wordian in North America (Leven & Grant-Mackie, 1997) and Ishiga (1990) correlated the fusulinid *Yabeina-Lepidolina* zone with the radiolarian *Follicucullus monacanthus* and *F. scholasticus* zones.

Thus, the three limestone samples within spilitic basalts from northern New Zealand show similar geologic ages. Bedded cherts are sometimes associated with these basalts and are characteristic of ocean floor sedimentary sequences. Indeed, at Arrow Rocks, bedded cherts comformably overlie spilitic basalt (Fig. 3). The ages of these cherts are reported from three localities in the Whangaroa Area (Caridroit & Ferrière 1988; Adachi 1988; Takemura *et al.* 1998) to be about Late Permian. Therefore, the age of ocean floor sequence represented by basalt and chert in the Whangaroa Area is Middle to Late Permian.

The radiolarian fauna from Arrow Rocks contains two new species of *Follicucullus*, *F. sphaericus* n. sp. and *F. whangaroaensis* n. sp. The former was already figured by Kuwahara (1997) from Japan, but the latter has not been reported yet. These two species are common elements within this fauna, and they may reflect a significant faunal difference in albaillellarian distribution between New Zealand and northern hemisphere regions.

Leven & Grant-Mackie (1997), however, also maintained that the fusulinid fauna from Wherowhero Point showed a clear affinity with those in the eastern Paleotethys and Panthalassa region, and that these limestone blocks had been moved from the original site of deposition. Because the radiolarian-bearing limestones which we describe herein show similar geologic age as these fusulinid limestones, and because they all occur within a restricted area, the radiolarian fauna from these samples must originate from near the region where the fusulinids were deposited. Therefore, the radiolarian fauna from Arrow

Rocks originated in a low-latitude area of Middle to Late Permian time.

SYSTEMATIC DESCRIPTION

The following description was made by the first author, Takemura A. The type specimens are deposited at Hyogo University of Teacher Education.

Subclass RADIOLARIA Müller, 1838
Order POLYCYSTINA Ehrenberg, 1838
emend. Riedel, 1967
Suborder ALBAILLELLARIA Deflandre, 1953
emend. Holdsworth, 1969

Family ALBAILLELLIDAE Deflandre, 1952
emend. Holdsworth, 1977

REMARKS

Cheng (1986) classified Albaillellaria into two groups, Albaillellacea and Follicucullacea, based on the presence of a cross-bar. This criterion is, however, applicable only for very well-preserved specimens, and we cannot observe such fragile parts in most Permian samples.

Kozur (1981, 1993) and Kozur & Mostler (1989) described many genera for Permian albaillellarians with conical shells. His classification seems to be so minute that sometimes we cannot make generic assignment. In this paper, the first author therefore adopts four genera for Permian albaillellarians, *Albaillella* Deflandre, 1952, *Pseudoalbaillella* Holdsworth & Jones, 1980, *Follicucullus* Ormiston & Babcock, 1979, and *Neoalbaillella* Takemura & Nakaseko, 1981, same as Ishiga & Imoto (1980), Ishiga (1982) and Ishiga *et al.* (1982a, b).

Genus *Follicucullus*
Ormiston & Babcock, 1979

Follicucullus Ormiston & Babcock, 1979: 332.
Ishigaconus Kozur & Mostler, 1989: 181-182.
Cariver Kozur, 1993: 108-109.
Lacisus Kozur, 1993: 109.

TYPE SPECIES. — *Follicucullus ventricosus* Ormiston & Babcock, 1979.

REMARKS

Most Permian taxonomic works followed the original definition of Genus *Follicucullus* made by Ormiston & Babcock (1979). Only Kozur & Mostler (1989) and Kozur (1993) divided this group, with descriptions of three new genera. However, their division are so minute that we cannot use them to assign a genus to poorly preserved specimens. Therefore, for this paper, the author regards these three genera as junior synonyms of the genus *Follicucullus*.

The author generally follows the specific division of *Follicucullus* established by Ishiga (1991), who lumped forms of this genus into six species from Permian sediments in Japan. They are *F. monacanthus* Ishiga & Imoto, 1982 (Ishiga *et al.* 1982b), *F. ventricosus* Ormiston & Babcock, 1979, *F. charveti* Caridroit & De Wever, 1984, *F. scholasticus* Ormiston & Babcock, 1979, *F. porrectus* Rudenko, 1984 (= *F. japonicus* Ishiga, 1991) and *F. bipartitus* Caridroit & De Wever, 1984. Other than these forms, three species *F. dorsoconvexus* (Kozur, 1993), *F. sphaericus* n. sp. and *F. whangaroaensis* n. sp. were distinguished in the sample ARR-1.

Follicucullus scholasticus
Ormiston & Babcock, 1979
(Fig. 4A, B)

Follicucullus scholasticus Ormiston & Babcock, 1979: 333-334, pl. 1, figs 1-5.
Follicucullus scholasticus Ormiston & Babcock morphotype I – Ishiga 1985: 180, 181, pl. 1, figs 15-21.

REMARKS

Ishiga (1984) proposed two morphotypes within this species. *F. scholasticus* morphotype I has simple conical shell without undulation and it resembles forms described by Ormiston & Babcock (1979) under the name of this species (Ishiga 1985). In this paper, the author follows Ishiga's taxonomy and *F. scholasticus* is used for forms with simple conical shell without undulation.

Kozur & Mostler (1989) proposed a new genus *Ishigaconus* for *Follicucullus* forms without shell undulation. However, the distinction of this species and *F. porrectus* is sometimes difficult because

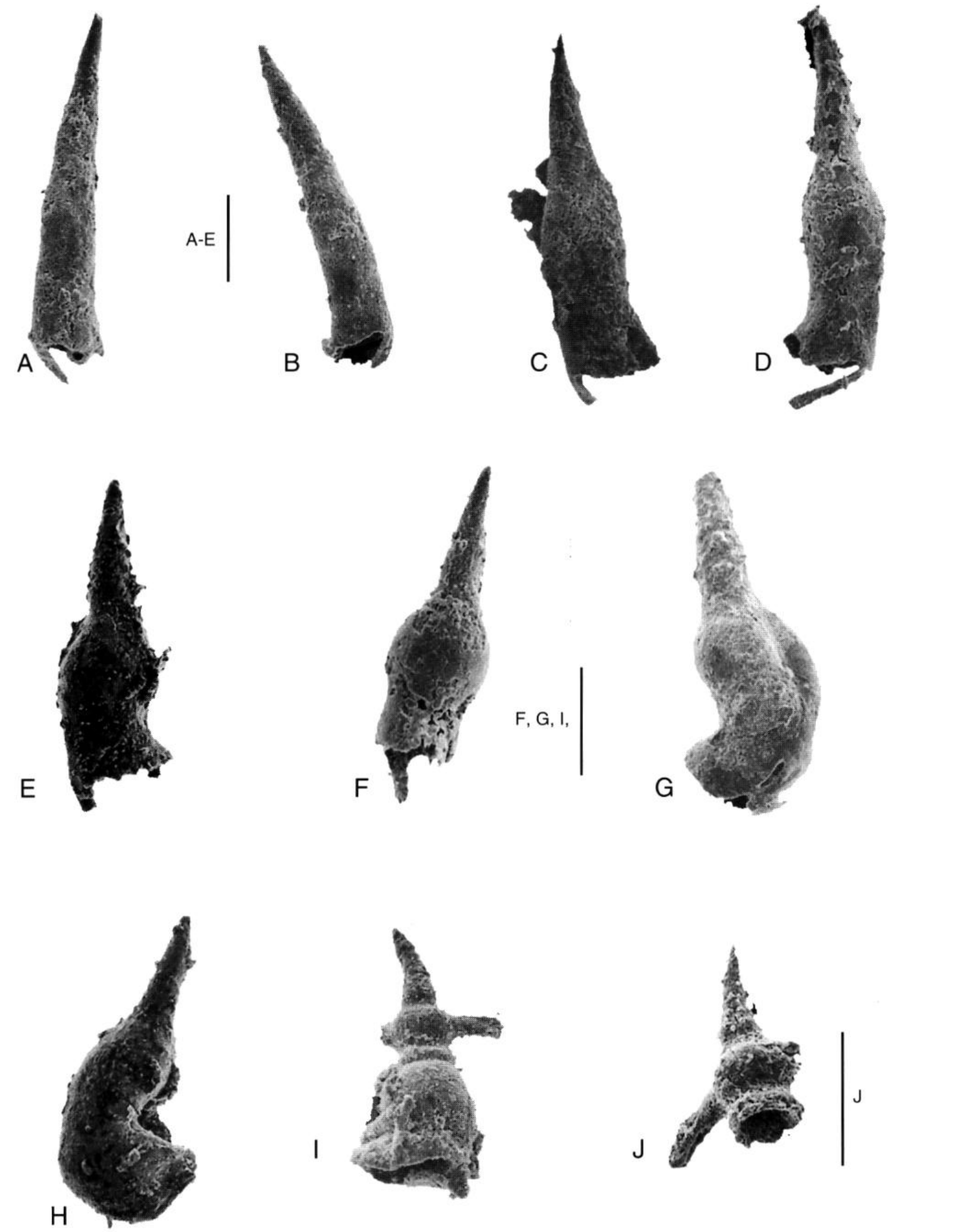

FIG. 4. — **A**, *Follicucullus scholasticus* Ormiston & Babcock, 1979; **B**, *Follicucullus scholasticus* Ormiston & Babcock, 1979; **C**, *Follicucullus porrectus* Rudenko, 1984; **D**, *Follicucullus porrectus* Rudenko, 1984; **E**, *Follicucullus ventricosus* Ormiston & Babcock, 1979; **F**, *Follicucullus ventricosus* Ormiston & Babcock, 1979; **G**, *Follicucullus dorsoconvexus* (Kozur, 1993); **H**, *Follicucullus dorsoconvexus* (Kozur, 1993); **I**, *Pseudoalbaillella fusiformis* (Holdsworth & Jones, 1980); **J**, *Pseudoalbaillella* aff. *longicornis* Ishiga & Imoto, 1980. Scale bars: 100 µm.

the undulation or tripartite division of shells is often unclear.

Follicucullus porrectus
Rudenko, 1984
(Fig. 4C, D)

Follicucullus porrectus Rudenko, 1984 – Beljanskij, Nikitina & Rudenko 1984, pl. 8, figs 3, 10.
Follicucullus scholasticus Ormiston & Babcock morphotype II – Ishiga 1984: 430, 431, pl. 1, figs 1-8.
Follicucullus japonicus Ishiga, 1991: 108-111, pl. 1, figs 1-22, pl. 2, fig. 1.

REMARKS
In this paper, the author uses this species name for intermediate forms between *F. scholasticus* and *F. ventricosus*. There are much variations of shell shapes within this species from sample ARR-1, same as described by Ishiga (1991). Such variations seem to be continuous from simple conical shape of *F. scholasticus* to clearly tripartite *F. ventricosus* with inflated spherical pseudothorax. Therefore, it is sometimes difficult to distinguish this species from the other two species.

Follicucullus ventricosus
Ormiston & Babcock, 1979
(Fig. 4E, F)

Follicucullus ventricosus Ormiston & Babcock, 1979: 332-333, pl. 1, figs 6-14.

REMARKS
Ishiga (1991) made a comparison between *F. porrectus* (= *F. japonicus*) and *F. ventricosus* under the description of the former species. He used the width/length ratio (W/L) of shells, strongly inflated pseudothorax and existence of groove (sinus) on pseudothorax as criteria to distinguish these two species.
F. ventricosus of the present study has strongly inflated and subspherical pseudothorax and a distinctly tripartite conical shell. However, there is usually no groove on the dorsal side of pseudothorax as seen in *F. dorsoconvexus*. The author tentatively include tripartite forms without grooves on subspherical pseudothorax within *F. ventricosus* in this paper. The difference between this species and *F. porrectus* is only the degree of inflation of the pseudothorax, and the variation between them seems to be continuous.

Follicucullus dorsoconvexus
(Kozur, 1993)
(Fig. 4G, H)

Cariver dorsoconvexus Kozur, 1993: 109, pl. 1, figs 15-17, 19.

REMARKS
Kozur (1993) proposed a new genus *Cariver* for *Follicucullus* species with curved shell and aperture perpendicular to the shell axis. If we adopt such minute generic division, we can assign genera only for well-preserved specimens.
F. dorsoconvexus resembles to *F. ventricosus*. Both two species have tripartite shell with inflated pseudoabdomen and sinus on the dorsal side of the shell. The aperture is sometimes not exactly perpendicular to the shell axis, because the dorsal side of the shell wall becomes shorter (Fig. 4G).

Follicucullus sphaericus
Takemura, n. sp.
(Figs 5A-F, 6)

Follicucullus sp. A. – Kuwahara 1997, pl. 2, fig. 8.
Follicucullus (?) sp. – Takemura *et al.* 1998, pl. 1, fig. 13.

TYPES. — Holotype HUTE-R-4024 (Fig. 5A), paratypes HUTE-R-4025 (Fig. 5B) and HUTE-R-4026 (Fig. 5D).

ETYMOLOGY. — The species name was derived from the characteristic shape of this species.

MEASUREMENTS. — Length of shell, 260-350 µm; length of upper conical part, 120-180 µm; width of shell, 160-230 µm; width of the base of upper conical part, 50-110 µm; measured in 28 specimens.

DESCRIPTION
Imperforate and smooth shell composed of two parts, upper conical part and lower part with flattened hemispherical shape. The upper conical part slender, and straight or sometimes slightly curved dorsally. The lower portion of this cone often slightly inflated. The inflated and curved lower part large with smooth surface and

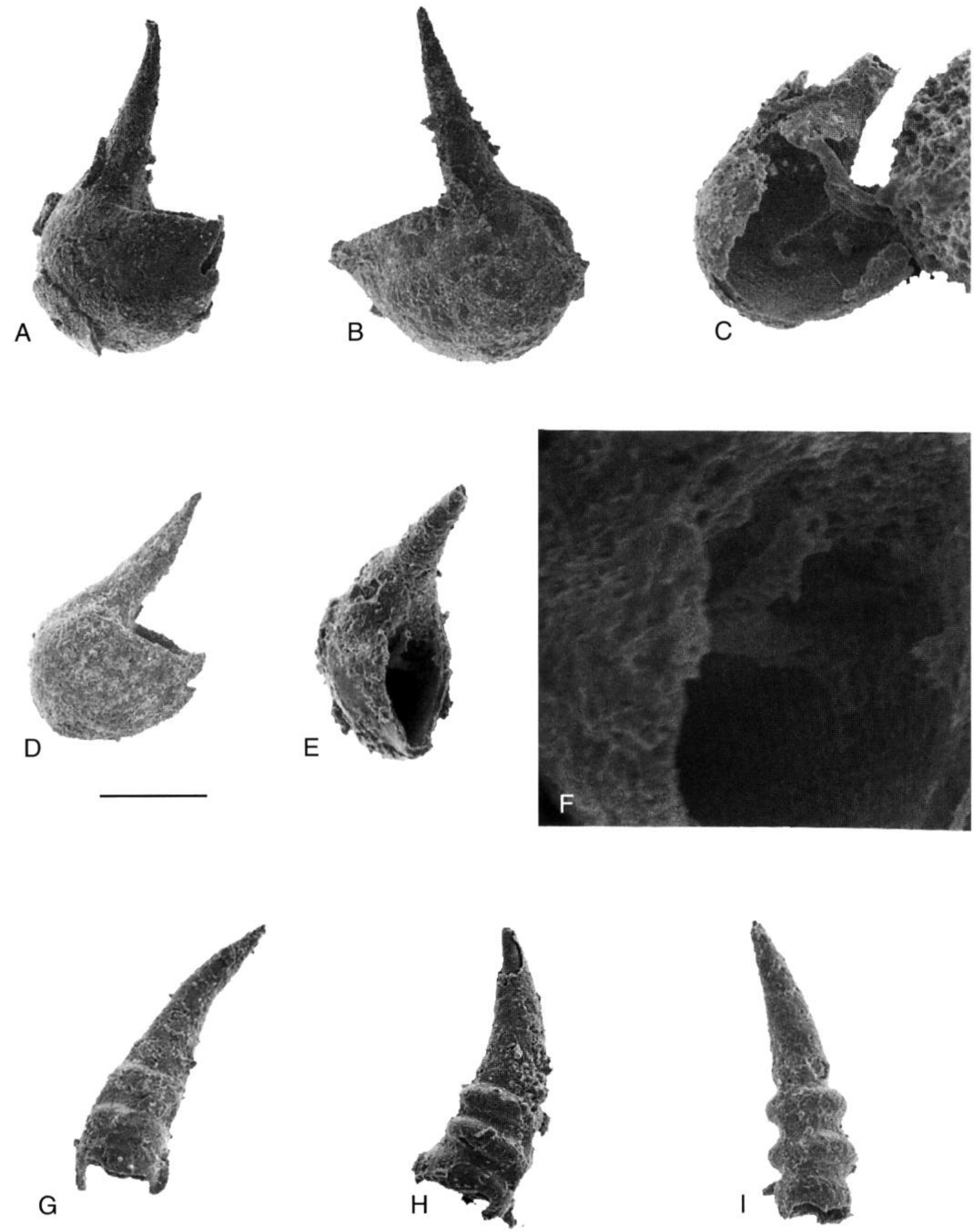

FIG. 5. — **A**, *Follicucullus sphaericus* n. sp., right lateral view, holotype (HUTE-R-4024); **B**, *Follicucullus sphaericus* n. sp., left lateral view, paratype (HUTE-R-4025); **C**, *Follicucullus sphaericus* n. sp., a broken specimen showing the inner surface of the inflated lower part, a hook-shaped trace of the inner wall can be observed; **D**, *Follicucullus sphaericus* n. sp., right lateral view, paratype (HUTE-R-4026); **E**, **F**, *Follicucullus sphaericus* n. sp., apertural view of partly broken specimen, a tube-like ventral spine arises upward from the edge of bended wall; **G**, *Follicucullus whangaroaensis* n. sp., right lateral view, holotype (HUTE-R-4027); **H**, *Follicucullus whangaroaensis* n. sp., left lateral view, paratype (HUTE-R-4028); **I**, *Follicucullus whangaroaensis* n. sp., ventral view, paratype (HUTE-R-4029). Scale bar: A, B, D, E, G-I, 100 μm; C, 83 μm; F, 20 μm.

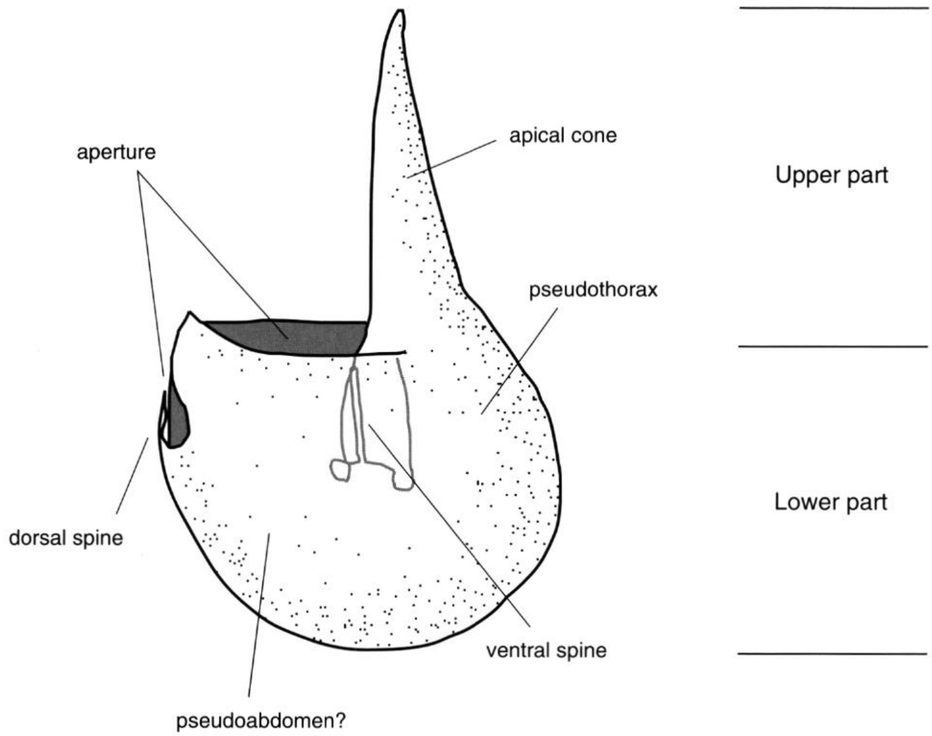

FIG. 6. — Schematic diagram of *Follicucullus sphaericus* n. sp. The inflated lower part of the shell is so strongly curved that the aperture opens upward. Within the inflated lower part, the shell wall of ventral side is curved and turned upward. Then, both dorsal and ventral spines also extend upward.

showing a semicircular shape in lateral view. Two apertures present on the lower part. A large aperture situated at the ventral side of the upper conical part and opening upward. This large aperture subelliptical in shape and tapering distally from the upper part. One more small aperture opening at the distal end of the shell in well-preserved specimens. This small aperture teardrop-shaped and opening toward the ventral side of the shell, with small dorsal spine or flap originating the lower end of this aperture. Inside the shell wall of the inflated and curved lower part, the ventral side of the shell wall of conical part strongly curved and turned upward. Tube-like ventral spine extending upward from the center of the turned end of the wall.

REMARKS

In the broken specimen (Fig. 5C), the trace of the shell wall could be observed on the inner surface of the lower inflated part of the shell. The trace is smoothly continuous from the upper conical part and somewhat inflated within the lower part, which resembles the inflated pseudothorax of *F. porrectus* or *F. ventricosus*. Then, the trace is curved strongly and turned upward.

From the turned end of this wall, cylindrical tube-like spine is arises upward inside the shell wall (Figs 5E, F, 6). This skeleton is homologous with a ventral spine or flap of other *Follicucullus* species. A small dorsal flap also exists below the small aperture on the distal part of the lower shell.

The upper conical part often shows slight inflation on its lower portion similar to the pseudothorax of *F. porrectus* or *F. ventricosus*. Therefore, the upper conical part of *F. sphaericus* n. sp. is homologous either with the apical corn alone or with both apical cone and upper pseudothorax of the other *Follicucullus* species. The lower shell shape of this new species was formed by the strong bending and inflating of the pseudothorax and pseudoabdomen of the other species like *F. porrectus* or *F. dorsoconvexus*.

F. sphaericus n. sp. differs from all the other species of *Follicucullus* in its flattened hemispherical and curved shell shape, its aperture opening upward, and both ventral and dorsal flaps arising upward. The characteristic shape of this species resembles that of *Pseudoalbaillella bulbosa* Ishiga (Ishiga 1982: 335, pl. 1, figs 8-13, 16, 17). The strongly inflated and curved pseudoabdomen of *P. bulbosa* is quite similar to the lower part of *F. sphaericus* n. sp., except for a small flap of the former species. *F. sphaericus* n. sp. does not have pseudothorax and wings observed in *Pseudoalbaillella*. *P. bulbosa* ranges from Late Carboniferous to Early Permian in age, and there should be no direct phylogenetic relationship between these two species. *F. sphaericus* n. sp. should be evolved from the other *Follicucullus* species like *F. porrectus* or *F. dorsoconvexus*.

Follicucullus whangaroaensis Takemura, n. sp. (Fig. 5G-I)

Follicucullus sp. – Takemura *et al.* 1998, pl. 1, fig. 14.

TYPES. — Holotype HUTE-R-4027 (Fig. 5G), paratype HUTE-R-4028 (Fig. 5H) and HUTE-R-4029 (Fig. 5I).

ETYMOLOGY. — The species name is after Whangaroa Area in Northland, New Zealand, where Arrow Rocks is located.

MEASUREMENTS. — Length of shell, 240-330 µm; length of apical cone, 130-180 µm; width of shell, 70-110 µm; width of the base of apical cone, 60-70 µm; measured in 12 specimens.

DESCRIPTION

Imperforate conical shell slightly curved ventrally, and undulated at the lower part with two distinct inflated rings. Apical cone with smooth surface and with a length more than half of the total shell. Apical cone slightly flattened laterally and curved ventrally. In some specimens, vague ring-like inflation observed at the lowest part of apical cone. The lower part of the shell distinctly undulated in dorsal or ventral view. Two rings inflated laterally between apical cone and apertural region, with circular shape in transverse section. Distinct furrows existing between the two rings, and between the lower ring and inflated apertural region. In dorsal or ventral view, shell distinctly undulated because of these rings and furrows. A vague furrow may divide apical cone and the upper ring. These furrows not present or becoming weak at the dorsal and ventral sides of this ring region. The outline of the shell not undulated distinctly in lateral view. The apertural region, the lowermost part of conical shell, inflated like rings. Two small spines or flaps, dorsal and ventral ones, arising obliquely downward.

REMARKS

F. whangaroaensis n. sp. differs from the other species of *Follicucullus* by its banded lower shell. This kind of rings has never been observed in the other *Follicucullus* species. The author included this new species within genus *Follicucullus* because of the similarity of its shell shape to other *Follicucullus*, such as *F. scholasticus* or *F. porrectus*. The ring region of this species may correspond with inflated pseudothorax of the other species.

Similar structure to this undulated shell with rings was observed in the pseudoabdomen of *Pseudoalbaillella globosa* Ishiga & Imoto (Ishiga *et al.* 1982b). *P. globosa* has one ring and inflated apertural region below the spherical pseudothorax with two wings. The author considers that there is no direct phylogenetic relationship between these two species.

Genus *Pseudoalbaillella* Holdsworth & Jones, 1980

Pseudoalbaillella Holdsworth & Jones, 1980: 284. – Ishiga, Kito & Imoto 1982b: 274, 275.

TYPE SPECIES. — *Pseudoalbaillella scalprata* Holdsworth & Jones, 1980.

REMARKS

Ishiga & Imoto (1980), Ishiga (1982) and Ishiga *et al.* (1982a, b) assigned this genus for Late

Paleozoic albaillellarians with conical, usually imperforate and tripartite shells and with two wings on the inflated pseudoabdomen. The author follows their taxonomy of this genus.

Pseudoalbaillella fusiformis
(Holdsworth & Jones, 1980)
(Fig. 4I)

Parafollicucullus fusiformis Holdsworth & Jones, 1980: 285, figs D, E.
Pseudoalbaillella fusiformis (Holdsworth & Jones) – Ishiga, Kito & Imoto 1982b: 275, 276, pl. 4, figs 10-12.

REMARKS

Most specimens of this species extracted from ARR-1 are more or less broken. The preservation of this species seems to be worse than that of *Follicucullus*.

Holdsworth & Jones (1980) described this species as *Parafollicucullus fusiformis* and they regarded the existence of a ring-like prepseudoabdominal segment as a criterion of this genus. However, some specimens from ARR-1 have no ring on their pseudoabdomen.

Pseudoalbaillella aff. *longicornis*
Ishiga & Imoto, 1980
(Fig. 4J)

Pseudoalbaillella sp. aff. *P. longicornis* Ishiga & Imoto – Ishiga, Kito & Imoto 1982a: 18, pl. 3, fig. 11; 1982b: 275, pl. 2, figs 1-7.

REMARKS

Most specimens of this form are broken and their preservation is usually poor. The total shape and size of this form is almost same as the upper half of *P. fusiformis*.

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