654. AN ARMORED WORM FROM THE MIOCENE YOKO-O FORMATION, NAGANO PREFECTURE, JAPAN*

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Introduction

During the summer field work in 1974 in the Sakaki area in Nagano Prefecture, abundant tubular structures were discovered in the black siltstone distributed widely in the area. The majority of the tubular structures occurred in a position parallel with the stratification of the tuff layers interbedded in the black massive siltstone, and only a few specimens were noted to be preserved more or less oblique to the bedding of the formation.

The stratigraphic position of the black colored siltstone of the Yoko-o Formation in the surveyed area is shown in Fig. 1. The Yoko-o Formation is about 1250m in total thickness; the altered andesite and its tuff breccia are intercalated in the lower, and the black massive siltstone develops mainly at the upper part of the formation. The present tubular fossils were collected from the middle part of the formation.

* Received July 3, 1975; read June 14, 1975 at Morioka.

The tubular specimens occurred both horizontally and vertically as a crowded assemblage of complete to fragmental (broken) individuals. Vertically the tubular specimens were found to superpose others obliquely, horizontally or as a mixed assemblage of broken tubes as shown in the annexed illustrations (Pl. 19, Figs. 1–2; Pl. 22, Fig. 1). All of the specimens were found at a locality geographically not remote (about 1.2 km north from the present locality) from the one where HATAI and SAITO (1962) recorded the occurrence of Terebellina kattoi HATAI and SAITO. At the time of description of Terebellina kattoi, HATAI and SAITO (1962) considered that their new form occurred from the Bessho Formation. However, the stratigraphical work by SHIMIZU (1975MS) and YAMAGISHI (1958, 1964) shows that the black massive siltstone distributed around the area mentioned above should be placed in the middle part of the Yoko-o Formation, a stratatal unit proposed by YAMAGISHI (1958) based upon the traceable tuff layers. The discussions on the strati-
Fig. 1. Stratigraphy and geological map around the fossil locality (SHIMIZU, 1975MS).

graphy will be published at another opportunity.

The tubular specimens are thought to be worthy of description and illustration for several reasons. The reasons are; (1) specimens comparable with but distinct from the present ones are known to, or have been recorded (Hyalinoecia tubicola) from the continental slope and shelf of the western north Atlantic Ocean (HEEZEN and HOLLISTER, 1971; WIGLEY and EMERY, 1962) from depths of 274-1170 meters in the former area and at 1935 meters depth at the latter area. The Recent specimens called Hyalinoecia tubicola show similarity with the fossil ones dealt with in this article, and is stated by WIGLEY and EMERY (1961) to have a depth range of 13-4380 meters for all oceans. The average density of that species is 461/m³ on the Atlantic continental slope, 272/m³ for the western North Atlantic Ocean, 15/m³ for off California. The length of the mentioned Recent species is 6-15 cm, but most tubes are 8-12 cm in length, (2) the fossil specimens are similar to the Recent species cited above in some morphological features, but quite different in others; they represent an undescribed form, (3) the black colored siltstone in which the fossil tubes were found suggests the kind of
marine bottom sediments on and in which the living *Hyalinocera tubicola* has been recorded. The resemblance of bottom conditions seem to be noteworthy, (4) since little work has been published on the fossil tubular structures of the kind presented in this article, their descriptions and illustrations are thought to contribute to our knowledge on the group, and (5) the rather rare and few occurrences of fossils from the thick black siltstone is a characteristic of the formation.

Before entering into the description and discussion of the fossil tubular structures, sincere gratitude should be expressed to Professor Tamio KOTAKA of the Tohoku University and Associate Professor Yutaka SAITO of the Shinshu University for their kind discussions on the stratigraphy. Deep acknowledgements are due to Dr. Munemoto Nedachi, and Mr. Kenshi Ogasawara of the Tohoku University for their EPMA and X-ray operations and analyses. The writers also thank Mr. Toshihide Shimizu of the Teikoku Petroleum Company for his information on the stratigraphy and fossil locality, and Mr. Kimiji Kumagai and Mr. Shohei Ohtomo of the Tohoku University for photographic work.

**Description and remarks**

Family Serpulidae Burmeister, 1837

Genus *Yokoia*, new genus

*Type species:* *Terebellina katoi* Hatai and Saito, Yoko-o Formation, Miocene. 

*Diagnosis:* Straight, sigmoidal to slightly convex, calcareous and siliceous, solid tubular structures. Shell surface with irregular concentric growth lines and irregularly spaced periodic swellings.

Generally creased longitudinally along middle.

*Remarks:* The genus *Yokoia* shows morphological resemblance with the genus *Longitubus* Howell, 1943 (Howell, 1962, p. 158, fig. 98-3) from the Upper Cretaceous of North America (Howell, 1962, p. 162) but differs from it by "the concentric ridges not being closely spaced" by the more irregular growth lines and by the characteristic development of irregularly spaced periodic bulges or swellings.

In order to know the characteristics of the newly discovered tubular structure, EPMA and X-ray analyses were made, and photomicrographs are annexed to show the details. EPMA and X-ray analyses of the tubular structure show that they consists of siliceous material embedded in a matrix that is composed of both calcareous and siliceous materials. The abundant spiculate structures noted within the shell are all composed of SiO₂ and the abundant grains distributed within the matrix also consist of SiO₂. X-ray analysis of the Nagano tubules show the first peak at 26.6 and the second one at 20.8 degrees in 2θ, both of silica. *Terebellina shikokuensis* Katto (1960) shows the first peak at 26.7 and the second one at 20.9 in 2θ also for silica. In comparison the X-ray analyses of the sponge hitherto known as *Makiyama* (previously as Sagarites; Makiyama, 1931) from the Taga Formation in the Joban coal-field, Fukushima Prefecture and from the type area of the genus in the Sagara oil-field, Shizuoka Prefecture show the first peak of Silica at 26.7 and the second one at 20.8 for the specimens from both of the areas. Thus from X-ray analyses the Sagara and Taga so-called Makiyama are identical in their silica peaks, and also similar to the Shikoku *Terebellina* and the Nagano *Yokoia*
Fig. 2. X-ray diffraction patterns of (A) *Terebellina shikokuensis* Katto from the Naharigawa Formation, (B) *Yokoia kattoi* (Hatai and Saito) from the Yoko-o Formation, (C) "Makiyama" chitanii (Makiyama) from the Sagara Formation, and (D) "Makiyama" chitanii (Makiyama) from the Taga Formation. Target/Filter: Cu/Kα, Intensity: 30 kV, 15 mA.

**Explanation of Plate 19**

Figs. 1–3. *Yokoia kattoi* (Hatai and Saito).

Showing the straight and slightly convexed shells with weak concentric growth lines, some swellings and medial creasing in part. The longest specimen (fig. 3 ×2, IGPS coll. cat. no. 92616–b) measures 54.5 mm and a mixed assemblage of broken tubes (fig. 2 ×3, IGPS coll. cat. no. 92618–a) are illustrated. Some orientations of the worm tubes are observable (fig. 1 ×3, IGPS coll. cat. no. 92616–c).

Locality and geological formation is mentioned in the text.
K. KUMAGAI photo.
(n. gen.) (Fig. 2).

The spicate structure found within the tubular structure of *Yokoia* are all monaxons in shape, silica in substance, crowded in arrangement and generally 150–200 microns in length, being nearly straight to weakly curved along their length. From the arrangement of the spicate structures it is difficult to decide whether they represent their original orientation, subsequently arranged orientation, or secondary developed ones. Whatever be the case it seems that the original animal that occupied the tubular structures may have been able to secrete siliceous substance to make the spicate structures, to have devoured foreign spicate organisms and retained the spicles in their shells as waste matter, or to have secreted siliceous spicles to make the tubular structures, or less probably to have the spicles agglutinated on their shells for self protection.

Whatever be the real cause of the spicate structures, it is evident that the chemical and X-ray analyses made for the tubular structures of *Yokoia*, the so-called *Makiyama* and the *Terebellina shikokuensis* are almost identical and closely similar with one another but their structures differ. This may point to the intimate relationship of the three kinds of tubular structures just mentioned.

Showing a remote similarity with *Yokoia* is the genus *Bathysiphon* M. Sars, 1872 which is described and illustrated by LOEBLICH and TAPPAN (in Treatise on Invertebrate Paleontology, Part C, Protista, vol. 1, p. C186, fig. 105, 4–10). It is said to have an agglutinated shell that is long (up to 50 mm), narrow and may have annular constrictions. The wall is described to be agglutinated "commonly of siliceous sponge spicles and fine sand or other mineral matter in calcareous cement", features which seem to be similar to the shell of *Yokoia kattoi* (HATAI and SAITO). However, the agglutinated shell of *Bathysiphon* differs from both *Yokoia* and *Makiyama* (discussion reserved for another opportunity) in the following features, namely, (1) the material filling the interior of the tubular structure of *Yokoia* is composed of sediments the same as the matrix, (2) the periodically and irregularly spaced concentric bulges or constrictions of *Yokoia* are more defined on the calcareous to siliceous shell, (3) the length of *Bathysiphon* is said to be up to 50 mm, whereas that of the tubular structures of *Yokoia* exceed that length, and the true length remains unknown because both ends are broken in all of the preserved specimens, and (4) the shell wall is not agglutinated as in *Bathysiphon*. From these reasons, the shell of *Yokoia* can not be identified with that of *Bathysiphon* (Foraminifera). However, whether *Bathysiphon* is a true Foraminifera may be in need of a re-examination. Dr. Yasumoti MATOBA, foraminiferologist at the Akita University of Mining, informed the junior writer that he has a similar thinking about *Bathysiphon* with the writers.

Detail examination of *Bathysiphon* and *Makiyama* will be reserved for another opportunity. Other organisms, such as the foraminiferal genera showing a more or less remote resemblance with the shell of *Yokoia* may be *Nodellum RHUMBLER, 1913* (Op. cit., p. C179, fig. 97, 3–4); *Protobotellina HERON-ALLEN and EARLAND* (Op. cit., p. C190, fig. 106, 7–9); and *Schixammina HERON-ALLEN and EARLAND, 1929* (Op. cit., p. C194, fig. 107, 6–10). But these three genera can be distinguished from *Yokoia* in the same way as *Bathysiphon*.

The generic name is taken from the name of the formation.
Yokoia kattoi (HATAI and SAITO, 1962)

Pl. 19, figs. 1-3; Pl. 20, figs. 1-7a; Pl. 21, figs. 1-7; Pl. 22, fig. 1


Description: Tube long, narrow, string-like, orifices rounded, surface with strong to weak concentric growth lines and periodic, irregularly spaced concentric bulges or swellings; tube rounded originally, generally creased medially and longitudinally; tube straight to broadly sigmoidal to more or less broadly bow-shaped. Length exceeds 50 mm because both ends lost, width about 2 mm when not creased medially, but measuring 3 mm or a little more when creased. Concentric buldge or swellings or annulations separated by distances of about 0.2 mm to 1.5 mm in width.

Locality: Road side cliff at the entrance to the forest road at Goshozawa (Hirasa-wa-rindo), Sakaki-cho, Hanishina-gun, Nagano Prefecture.

Geological formation and age: Middle part of the Yoko-o Formation, Middle Miocene.

Depository: Illustrated specimens (IGPS coll. cat. nos. 92615, 92616, 92617, 92618) are preserved in the collection of the Institute of Geology and Paleontology, Faculty of Science, Tohoku University and some specimens collected from the same locality are in the collection of the Saito Ho-on Kai Museum of Natural History.

Associated fossils: Eutrephoceras izumoensis (YOKOYAMA), some thin shelled pelecypods, detached fish scales and drifted plant leaves.

Remarks: Most of the specimens referred to Yokoia kattoi are creased medially and longitudinally, some due to compressive agencies after death of the organism. But many specimens still retain the original shape and are also found mixed in the same assemblage of individuals. Some specimens are creased only in part, and the creasing may be hardly noticeable to strongly impressed. Creasing medially is also shown in many specimens of Terebellina illustrated by DANNER (1955) from the Neogene rocks of several localities in western Washington, U.S.A. This phenomenon is a common feature in specimens of the so-called Makiyama chitanii (MAKIYAMA) of wide distribution in Japan and recorded originally as a sponge from the Neogene rocks of the Sagara district in Shizuoka Prefecture (MAKIYAMA, 1931), and probably sometimes mistaken for the present new genus especially in Nagano Prefecture. Besides the tubular structures known to be creased medially and

Explanation of Plate 20

Figs. 1-7a. Yokoia kattoi (HATAI and SAITO).

(All figures ×3 excluding figs. 3-3a ×2)

All figures are different views taken with different focus depth. Figs. 3-3a, 4-4a, 5-5a, 6-6a and 7-7a show the pair of specimens photographed with different focus depths to show how different the surface features will appear. Identification of the worm tubes will arise from the magnification used, thus both natural and enlarged views are important for classification of the armored worms. Figs. 1-2, 6-6a, IGPS coll. cat. no. 92615-b; Figs. 3-3a, 4-4a, 5-5a, IGPS coll. cat. no. 92615-a; Figs. 7-7a, IGPS coll. cat. no. 92615-c.

Locality and Formation is mentioned in the text.
K. Kumagai photo.
longitudinally, there are several species of so-called worm tubes that have been described from the geological formation of Japan and of the North Pacific borderland. These are given in the list cited below.

**List of fossil armored worms from the North Pacific borderland**


*Terebellina kattoi* Hatai and Saito, 1962 [Misspelled as *Terebrellina*]. This is the type species of the genus *Yokoia*, n. gen., Japan. Jour. Geol. Geogr., vol. 31, nos. 2-4, p. 246, fig. 2. Type loc.—One kilometer east of Minamihina, Sakaki-cho, Hagishina-gun, Nagano Prefecture, Bessho Formation, Miocene.


All of the species given in the list above can be distinguished from the new genus described in this article by several important characters as, the strong concentric growth lines, periodic and irregularly spaced bulges or swellings that are especially noteworthy at and from the middle towards the anterior part of the tube. The tube may be straight, sigmoidal to slightly curved. The creasing medially and longitudinally is noticed on both large and small specimens. None of the tubes seem to be agglutinated as to consist of cemented grains of rock, shells, sand or other small objects as in *Terebellina*.

Observations on the known fossil worm tubes described from Japan reveal that the outstanding characteristics that are also of taxonomic importance are the strong growth lines, periodic and irregularly spaced bulges or swellings of the tube, irregular growth and non-agglutinated shell. The genus *Siphonites* Saporta, 1872 described and figured by Häntzsche (1962, p. 215) is stated to have the “Tubes about 1 cm in diameter with sandy lining, mostly washed out and collapsed on bedding planes.” This genus has been recorded from the Upper Triassic of France. The figure given by Häntzsche (1962, p. 216, figs. 135-4) shows specimens creased medially and longitudinally, and in this respect, resemblance is found with the broken specimens of *Yokoia*. However, the diameter of *Siphonites* is stated to be about 1 cm and in this respect it is much larger than any of the specimens of *Yokoia* in the present collection. The collapsed specimens of *Siphonites* also show a remote resemblance with the compressed and medially creased specimens of the Miocene and Pliocene so-called *Makiyama* distributed widely in Japan and with *Yokoia kattoi* (Hatai and Saito) from the Miocene of Nagano Prefecture. *Makiyama* is in need of detail study to confirm its true characteristics and relation with similar forms. *Siphonites* differs from the two just mentioned in the
much larger diameter, much shorter and stouter tube. Among the species given in the list, *Terebellina shikokuensis* Katto, 1960, from the Eocene Naharigawa and Muroto Formations of Kochi Prefecture is the first record to the genus *Terebellina* from Japan. *Terebellina shikokuensis* is characterized by the wall being composed of “fine grained sands firmly cemented”. Subsequent study of the holotype of *T. kattoi* shows that its wall is not composed of “minute siliceous grains” as in *Terebellina*, and in this respect, *kattoi* should be referred to a genus other than *Terebellina*. Examination of some of the tubes called *Terebellina shikokuensis* Katto, taken from the original mass of specimens illustrated by Katto (1960), shows that the external shell is composed of minute grains and that the matrix also consists of minute grains. There is no periodic irregularly spaced concentric swellings as in *Yokoia*, and from the characteristics just mentioned its reference to the genus *Terebellina* is without doubt. *Shikokuensis* can be retained in the genus *Terebellina* and the genus is represented in the Cenozoic rocks of Japan by the single species, *shikokuensis*.

The wall of *Yokoia*, n. gen. proposed in this article is calcareo-siliceous, and in this respect it reference to the family Serpulidae. Burmeister, 1837 (Howell, 1962, p. 155) seems to be justified it the original tube was calcareous but subsequently changed into silica. And it is characterized by the shape of the tube, its longitudinal creased structure, and with characteristic concentric, periodically arranged swellings.

Among the abundant specimens of tubular structures found in the black mudstone in the Sakaki area, there were many without the external shell that could be identified with *Terebellina kattoi* described by Hatai and Saito. Under the circumstances, it was decided that the tubular shells are identical with the mould specimens described and illustrated by Hatai and Saito. The presence of abundant siliceous material in the matrix of both specimens, that is to say in the ones described by Hatai and Saito and in the ones newly found is noteworthy as stated already. Chemical and X-ray analyses of both of them are also identical.

**Remarks in the paleoecology of the worm**

As mentioned already the tubes of *Yokoia kattoi* were all found in black colored siltstone, and in association with some strongly and laterally compressed shells of the cephalopod genus *Eutrephoceras*, some thin shelled pelecypods, many small detached fish scales arranged at random and also with some fragments of plant leaves which are now under examination by Professor Hidekuni.

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**Explanation of Plate 21**

Figs. 1–7. *Yokoia kattoi* (Hatai and Saito).

(All figures ×35 excluding fig. 7, ×87)

Microscopic figures show some vertical sections and longitudinal sections (figs. 1–4). Spiculate structures shown in figs. 5, 6 and 7 (enlarged in part from figs. 5 and 6). Shell material and spiculate structure composed of silica (analysed by EPMA and X-ray operations). (IGPS coll. cat. no. 92616–a).

Locality and Formation is mentioned in the text.
K. Kumagai and S. Ohtomo photo.
Matsuo of the Kanazawa University. Among the several kinds of fossils, only the worm tubes are abundant whereas the nautiloid shells are common only locally, the fish scales are rather common and of wider distribution than the cephalopod but only of a few types a feature that does not point to that the original fish were abundant, and the fragmental remains of plant leaves are very rare, probably because of being drifted to their place of burial. From the massive nature of the black colored siltstone, kind of fossils and their resemblance to the present day marine bottom sediments as well as bathymetric environment of the Recent Hyalinocia tubicola recorded by Heezen and Hollister (1971) and by Wigley and Emery (1967) and which resembles Terebellina shikokuensis serve to bring forth the following interpretation on the paleoecology of Yokoia kattoi.

The paucity of benthic and planktic (Martinsson, 1975) and the abundance of only worm tubes of the benthic community and the common occurrence of nautiloids locally all serve for the following interpretation. During and after deposition of the dark colored bottom muds (Black siltstone) it is thought that the bottom conditions were oxygen-poor and sulphurous gas have generated in the soft, dark colored, bottom muds. Under the conditions probably of low temperature, issuing sulphurous gas and oxygen-poor environment, the possibility of benthic life was probably restricted to armored worms that devoured debris and planktic to pelagic invertebrates that settled to the bottom. The nautiloids that were swimming in the surface waters or drifted to the area underlain by the dark muds were probably affected or paralysed by the sulphurous gas issuing from the bottom muds and thus died and then sank to the bottom to become buried there. This seems to be an analogue to the graptoloids (Twenhofel, 1931) occurring in black shales. Also from the occurrence of abundant broken worm tubes, it may be probable that the nautiloids were predators of the worms.

Judging from the foregoing, it is thought that the bottom condition of the sea was influenced by oxygen-poor water contrary to the warm surface waters in which the vagrant nautiloids wandered. The association of fish scales with the armored worms and nautiloids may not mean the existence there of a rich fish fauna because a single fish can supply many scales. Some fish bones occurred in association with some different types of scales (Tanaka et al., 1966) or even in the black siltstone adjacent to the armored worm remains, they probably were either destroyed by bacteria, decay or devoured by the armored worms or some other cause. The rare occurrence of fragmental plant leaves may point to the distance from the land. They were wind transported or current carried to the sea area of their burial. Their presence in the marine fauna is of no use for interpretation of the paleoecological conditions of the armored worms. That no planktic protozoans were found in the black siltstone suggests that after death they sank to sea bottom to become the food of the armored worms on one hand and the oxygen-poor and sulphur gas generated bottom conditions may have accelerated chemical destruction of the protozoan test, thus explaining their absence in the bottom muds.

References cited

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Shimizu, T., 1975 (MS), Geology of the northern part of Ueda City, Nagano Prefecture. (in Japanese). Graduation Thesis of the Institute of Geology and Paleontology, Faculty of Science, Tohoku University.


Explanation of Plate 22

Fig. 1. Yokoia kattoi (Hatai and Saito) x9.

Vertical sections to show the mode of occurrence of Yokoia kattoi (Hatai and Saito). The specimens are arranged along the lamination dominantly. The most dominant part contained 70-80 specimens per 2 cm³. Figure shows the medial impression, thickness of the wall, irregular bulges and arrangement to the bedding plane (longitudinal of plate). (IGPS coll. cat. no. 92616-a).

Locality and Formation is mentioned in the text.

IGPS coll. cat. no. is of abbreviation for the collection catalogued number of the Institute of Geology and Paleontology, Faculty of Science, Tohoku University, Sendai, Japan.
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