LARGE ASTRORHIZID FORAMINIFERA FROM OLIGOCENE - LOWER MIocene
DEEP-SEA SEDMENTS, NORTHERN APENNINES, ITALY: A NEW PERSPECTIVE
ON THE GENUS ASTRORHIZINOIDES STSCHERDBIN, 1969

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Abstract. *Nulliporites bongiocoides* Sacco, 1888 and *Nulliporites stellatus* Sacco, 1888 from the Oligocene - Lower Miocene deep-sea turbiditic sediments of Liguria and Piedmont (Monastero and Rocchetta formations) appear to be large, agglutinated astrorhizid foraminifers both assigned in this study to the genus *Astrorhizinoides* Stscherdbina, 1969 under a single species, *Astrorhizinoides bongiocoides* (Sacco, 1888). This foraminifer is characterized by a simple, straight to slightly curved or rarely branched test, which displays a thick, smooth, finely agglutinated wall, with constrictions, and a very thin chamber lumen. The test, partly crushed, is preserved mostly on the sole of thin turbiditic sandstones, where they may be aligned. Probably, the foraminifer was originally a semi-infaunal, free-standing form, the test of which was partly flexible.

Introduction

This paper concerns unique large, tubular, occasionally branched foraminiferids that occur in Oligocene deep-sea clastic sediments of the Monastero Formation, and rarely of the Rocchetta Formation (Upper Oligocene-Aquitianian), both cropping out on the edge of the foredeep Tertiary Piedmont Basin. These fossils were originally described by Sacco (1888) as *Nulliporites bongiocoides* and *Nulliporites stellatus*, at first considered as algae, later treated as trace fossils, and finally almost forgotten. Examination of their type material and new material from the type area allows us to reinterpret them as larger agglutinated foraminifera ascribed to the order Astrorhizida, having distinct morphological features.

Geological setting

The Monastero Formation (Bellinzona et al. 1971; Mutti et al. 1995; Marroni et al. in press) is an about 1000 m thick unit that overlies the Savignone Conglomerate in the lower part of the filling of the Tertiary Piedmont Basin on the northern edge of the Northern Apennines. The unit is dominated by turbiditic sandstones and mudstones, which overlie fan delta conglomerates of the Savignone Conglomerate (Gelati 1977; Gibbudo et al. 1985). In the lower part, the sandstones are locally coarse-grained and conglomeratic, while pelitic facies prevail in the upper part. Locally, pebbly mudstones and slump deposits are present. Calcareous nanoplankton dates this unit to the NP23/NP24 zones (late Rupelian-early Chattian; Marroni et al. in press).

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The studied foraminifers occur in the lower to middle part of the Monastero Formation in thin sandstone beds that show a sharp base transitioningally passing to mudstone at the top, graded bedding and ripple lamination. They display features of turbidites. The localities in which the studied foraminifers occur are shown in Fig. 1 and Tab. 1.

The Rocchetta Formation (Upper Oligocene-Aquitanian) is a clastic unit composed mostly of mudstones interbedded with sandstones or more rarely with
limestones, which were deposited as hemipelagic and turbiditic sediments (Gelati 1968). It overlies the Molare Formation, the basal unit of the Tertiary Piedmont Basin in the western part, and is followed by the Monesiglio Formation. The Rocchetta Formation is 100-550 m thick. The studied foraminifers occur in the upper part of the formation. The Rocchetta Formation is composed of hemipelagic and prodeltaic marls (Artoni et al. 1999). It is Rupelian-Chattian in age in the eastern part and Chattian-Aquitanian in the western part (Gelati 1968; Gelati et al. 1993; d’Atri et al. 1997). The Rocchetta Formation and the Monesiglio Formation are considered together as the Rocchetta-Monesiglio Group or the Rocchetta-Monesiglio Formation (Gelati et al. in press). The locality is shown in Fig. 1 and Tab. 1.

Systematic Palaeontology

Astrohrizidae Brady, 1881

Astrohrizoides Stschudrina, 1969

Type species: Astrohriza ornata Brady, 1879.

Diagnosis: Test free, consisting of a thick, simple or branched tube with constrictions, that branches at irregular intervals, not radiating from a central axis as in Astrohrizas. Wall firmly cemented. Apertures at the ends of the tube.

Remarks. In their description of the genus Astrohrizoides Stschudrina, 1969, Loeblich & Tappan (1987) stated that the test is made of coarse sand grains, with a rough exterior, and that a thick inner organic lining protrudes from the ends of the test. This description applies only to the type species Astrohrizoides comatus (Brady, 1879) illustrated by Brady (1884) from the modern Atlantic Ocean. The discussed specimens from the Oligocene of Italy are finely agglutinated, with a thick wall and they do not display any organic lining. The above-mentioned features of Astrohrizoides (i.e., the relative size of the agglutinated grains and whether or not an inner organic lining is preserved in fossil specimens) are considered herein as non-diagnostic at the genus level and therefore they are not mentioned in the diagnosis.

Astrohrizoides bombicoides (Sacco, 1888)

Figs 2-6

v³ Nulliporites bombicoides Sacc. - Sacco 1888, p. 19, pl. 1, fig. 22.

v³ Nulliporites stellari Sacc. - Sacco 1888, p. 19, pl. 1, fig. 23.

Types: As Sacco (1888) did not designate any holotype, therefore all specimens on slab 17476 (Museo Regionale di Scienze Naturali in Torino; Fig. 2A) are considered as syntypes.

Diagnosis: Test free, large for the genus, straight or gently curved, formed of a robust tube with constrictions and rare branches, with a very thin chamber lumen. Wall thick, finely agglutinated, with a smooth surface. Apertures at least at one of the terminal ends of the tube.

Description - general features. Test free, large (up to 15.5 mm in length and 2 mm in width), consisting of a robust straight or slightly curved tube that branches rarely. Branching may be dichotomous or side branches may diverge at angles up to 90°. The tube displays gentle swellings and constrictions, indicating the tube is partially subdivided into pseudochambers. Wall thick, of firmly cemented silt to very fine sand-sized grains, with a smooth exterior. The central chamber lumen is developed as a very thin tunnel. Terminations of the tubular branches, if not broken, are hemispherical, some possess an apical tip. Apertures, when present, are at the terminal ends of the branches. Some terminations

Fig. 2 - Type material of the discussed foraminifers housed in the Museo Regionale di Scienze Naturali in Torino, all ascribed to Astrohrizoides bombicoides (Sacco, 1888) in this paper. A) Nulliporites bombicoides Sacco, 1888, general view, Monastero Formation (Lower Oligocene), Cioccale, specimen 17476. All specimens are syntypes. B) Detail of A. C) Nulliporites stellari Sacco, 1888, general view, Monastero Formation (Lower Oligocene), Cioccale, specimen 17477. D) Close view of the type specimen.
Fig. 3 - New specimens of simple Astarhizinoides bombicoides (Sacco, 1888) in sandstone beds of the Monastero Formation (Lower Oligocene). A) Well-segmented, long and short morphotype, Grondona, INGUG175P54. B) Long, slightly curved form, slab 7303. C) A section through test within a sandstone bed, Grondona, INGUG175P53. D) Termination of test with well-visible entrance to a thin tunnel, Grondona, slab 7311. E) Termination of test with well-visible entrance to a thin tunnel, Cascina Emanuele, slab 6253. F) A club shaped test, Grondona, INGUG175P52. G) Two tests, the larger one with a nip at the termination, Grondona, INGUG175P70. H) Several tests of different shape, crushed test of Bathysiphon sp. (Ba), Grondona, slab 7288. I) Partly aligned tests of A. bombicoides and ?Bathysiphon sp. (?Ba), Costa Bergheige, INGUG175P56. J) A. bombicoides on the lower bedding plane with the trace fossils Paleodicotylospora (Pa) and Opbromorpha annulata (Oa), Grondona, slab 7289. K) A few tests of A. bombicoides crossed by the trace fossil Opbromorpha annulata (Oa), Grondona. L) A subvertically oriented ?A. bombicoides in a sandstone bed, with a broken upper part, Grondona slab 7310.
The original material. The type specimens of *Nulliporites bombicoides* Sacco, 1888 and *Nulliporites stellaris* Sacco, 1888, originally described by the same author, are housed in the Palazzo Carignano, in the part belonging to the Museo Regionale di Scienze Naturali in Torino. Sacco (1888) described them as new taxa of *Nulliporites* Heer, 1865, considered as algae, together with several trace fossils, which were commonly interpreted as algae at the time. They were found at Cioccale, 200–300 m from the village of Vallescara, about 40 km north of Genova (Fig. 1).

The original specimens of *Nulliporites bombicoides* Sacco, 1888 (No 17476) are preserved as simple, tubular bodies on the lower bedding surface of very fine-grained muscovitic sandstone (grain size mostly about 0.1 mm) sandstone (Fig. 2A, B). The lower bedding surface is uneven, sharp, with low, elongate elevations and depressions. Five more complete, and five less complete light-coloured tubular specimens are present. Most of the tubes are parallel to surface, attached or partly embedded into the rock, while others are gently inclined and plunging partly into the bed. The tubes are not oriented. All the specimens are considered here as syntypes. The more complete specimens are 10–15.5 mm long and 1.8–2 mm in maximal diameter. They are straight or curved in a gentle arc. The smallest ones are 2.5–5 mm long, 0.5–0.7 mm in maximal diameter. The diameter of the larger and smaller tubes is smaller towards the terminations, so the individuals display overall symmetrical or asymmetrical spindle-like shape. The terminations of the tubes, if not broken, are hemispherical, some of them show an apical nip. The larger tubes show gentle, distinct to indistinct swellings separated by constrictions, with 7–8 swellings per specimen. Locally, small, secondary elevations can occur on the surface. The face of the broken tube does not show macroscopically any trace of an entrance to the chamber interior. The tubes are built of light, hard, silt grains, without muscovite. The agglutinated grains are distinctly smaller than in the hosting sandstone bed.

The type specimen of *Nulliporites stellaris* Sacco, 1888 (No 17477) firstly described by Sacco (1888) is preserved on a fragment of muscovitic, very fine-grained (grain size mostly about 0.1 mm) sandstone, on its bedding surface. It is composed of a branched tube, circular in cross section, attached to the surface, but not embedded in the rock (Fig. 2C, D). The tube is 1.7–1.9 mm in diameter. It is composed of a straight segment, 2.5 mm long, with a broken end and two branches diverging from the other end under the angle of 110° and 113°, respectively. The branches are 3.5 and 4.1 mm long, respectively. Their termination is hemispherical. The diameter of the branches increases slightly and gradually toward the branching point, however no swelling or "central chamber" is observed at the junction. The face of the broken tube does not reveal macroscopically any trace of an entrance to a possible canal. The tube is built of light, hard, silt grains, without muscovite. The grains are distinctly smaller than those of the hosting sandstone bed. The arm with the broken end shows a transverse crack fissure in the proximity of the branch junction. One of the branches shows a low secondary elevation, almost circular in outline, with an apical nip. The elevations occupy about one third of the surface from the external side of the fossil, close to the junction area. The other branch is slightly curved at the end. Its surface shows very gentle swellings and constrictions.

New material. Fragments of sandstone beds containing the studied foraminifers were collected from outcrops of the Monastero Formation at Grondona, Cerreto Ratti, Cascina Emanuele, Costa Bergheighe, Cioccale and Fontana (Tab. 1, Fig. 1). The lithology of the beds is very similar to that of the original material. The foraminifers are represented by tubular, simple, and rarely branched forms (Figs 3, 5, 6). Additional specimens were collected from an outcrop of the Rocchetta Formation (Upper Oligocene-Aquitanian) at Chiesa di Brovia near Dego (Tab. 1, Figs 1, 4). Some of the newly collected specimens are housed in the Jagiellonian Uni-
Fig. 5 - New specimens of simple and branched *Astrorhizinoides bombicoides* (Sacco, 1888) from sandstone beds of the Monastero Formation (Lower Oligocene). A) Simple and branched tests together, Ceretto Ratti, slab 7130. B) A detail of A showing a simple form with a side swelling interpreted as an initial branching. C) Branched form, Cascina Emanuele, 6252. D) Detail of A. E) Branched and simple test, some of them are broken, Cascina Emanuele, 6253. F) Detail of A. G) A test with short dichotomous branches, Grondona, 7301. H) A test with an almost right angle branch, Grondona, INGUJ175P57. I) Two tests and one with a side branch, INGUJ175P52.

The simple forms are the same as the type material of *Nulliporites bombicoides* Sacco, 1888. They occur almost exclusively on the lower surface of very fine- or fine-grained, thin-bedded, muscovitic, calcareous sandstones that show ripple cross lamination. Only at Cascina Emanuele, Costa Bergheighe and Ciocca, they can be found also in medium-grained, ripple laminated sandstones. The sandstone beds are up to 3.5 cm thick, exceptionally 5 cm thick at Ciocca. Their lower surface is erosive, sharp, and the upper surface shows a transition to the overlying grey, calcareous siltstone and mudstone. Rarely, fragments of the discussed foraminifers are found in the sandstones, within the few-millimetre-thick basal part.
The fossils are straight agglutinated tubes, 3-26.5 mm long (mean = 10.58 mm, n = 95), 0.8-2.8 mm (mean = 1.67 mm; n = 95) in diameter. The diameter changes slightly along the length of the tube, which shows gentle swellings and constrictions (Figs 3A-B, F-G, 4C). The endings, if preserved, are hemispherical, without any change in diameter, or they taper but without acute pointed tips (Figs 3F-G, 4A-B, 6C). In some cases, at least one ending is broken (Fig. 5E). The surface of the tube is smoothly finished.

Very rarely, an entrance to the tunnel is macroscopically visible at the face of the broken ends (Fig. 3D-E). Most of the broken faces look massive. However, computed tomography analysis and thin sections confirm the presence of a very thin, central, slightly winding tunnel running along the length of the tube (Fig. 6E). In specimen INGUJ17SP35, which is a simple cylinder, the tunnel is 74-139 μm in diameter. It shows some swellings and constrictions and disappears before the tapering end of the tube. The tunnel is also visible in thin section (Fig. 6A).

In the tests from the Monastero Formation, the wall of the tube is built of silt-size quartz grains, 5-40 μm in diameter (Fig. 6A-D). The grains are moderately well-sorted, mostly angular, well fitted, with small grains filling space between the larger ones. In the surrounding sandstone, grains are up to 100 μm in diameter. Subtle grain-size changes are observed along the tube, which appears to be constructed of fused segments (pseudochambers) that are 1-2 mm long (Fig. 6E). In the tests from the Rocchetta Formation (Fig. 4), the grains are coarser (very fine sand).

The branched forms (Fig. 5) are much rarer than the simple unbranched forms. Only 10 specimens have been found in almost all localities at which the simple forms occur. Both morphotypes co-occur in the same beds (Fig. 5A, E, I). The morphology of the branched forms shows the same features as the type specimens of *Nulliporites stellaris* Sacco, 1888. The branches are 2.5-6 mm long and 0.8-1.8 mm in diameter. They diverge at angles of 81°-184° (mean = 120°, n = 27). The external morphology of the tubes is the same as in the simple

![Fig. 6](image_url) - Microscopic features of *Astrorhizoides bombicoides* (Sacco, 1888) from Grondona. A) Thin section along the test showing a thin chamber lumen. B) Cross section of the test, Grondona. C) SEM image of the termination of the test. D) SEM image of test wall showing densely packed silt quartz grains. E) Computed tomography image of the test with well visible thin chamber lumen, INGUJ17SP35. F) Spatial view of specimen INGUJ17SP35 based on CT images. G-J) CT images of a branched test; H, I - view from the side; G, J - planar view; INGUJ17SP36. K) Spatial view of specimen INGUJ17SP36 based on CT images.
forms. There are no swellings or central "pseudocham-
bers" around the branching point. Computed tomogra-
phy of sample INGJ175P36 shows also a thin tunnel
as in the simple forms, which runs through all the
branches (Fig. 6G–J).

Discussion

Previous interpretations. The genus name *Nulli-
porites* was used independently by Krüger (1823) for a
Cretaceous coral (*N. nodulosus*) and by Heer (1865) for
algae (ten species; see also Heer 1877). Sacco (1888)
used *Nulliporites* Heer, 1865 and distinguished *Nulli-
porites bombicoides* and *Nulliporites stellaris*. These
two taxa have been included in the algal genus *Nulli-
pora* Lamarr, 1851 by Maschini & Squinabol (1892)
as *Nullipora lombrioides* (Sacco) and *Nullipora stellaris*
(Sacco). It is unknown whether Maschini & Squina-
bol (1892) corrected the original name of Sacco from
*bombicoides* to *lombrioides*, or if this is an unjustified
emendation. Heer's species of *Nulliporites* still exists
in the catalogue of algae (Guiry & Guiry 2014); however
Schimper (1879) already questioned this assignment.
Häntzsche (1965, 1975) considered *Nulliporites* Krüger,
1823 as *nomen nudum*, and included *Nulliporites* Heer,
1865 in *Chondrites* Sternberg, 1833. Also Chamberlain
(1977) included with a question mark *Nulliporites an-
gustus* Heer, 1877 and *N. granulosus* Heer, 1865 in
*Chondrites targonii* (Brongniart, 1828). Fu (1991) in-
cluded *Nulliporites angustus* Heer, 1877 in *Chondrites
targonii* (Brongniart, 1828). The similarity of *Nulli-
porites* Heer, 1865 to *Chondrites* was discussed by Heer
(1877), however he described them separately. Sacco
(1888) also noted the problem and invoked the opinion
by G. Saporta, who regarded *Nulliporites* as a synonym
of *Chondrites* and the opinion by G. Maillard, who
regarded them as burrows. Nevertheless Sacco (1888)
pointed to the difference in the filling material of *Chon-
drites* and his *Nulliporites* and suggested that they must
have been produced by different organisms.

In summary, neither *Nulliporites* Heer, 1865 as the
junior synonym of the trace fossil *Chondrites* Sternberg,
1833, nor *Nullipora* Lamarck, 1801 as an algal genus
can be used for the discussed material.

New perspective. The morphological features of
*Nulliporites bombicoides* Sacco, 1888 and *Nulliporites
stellaris* Sacco, 1888 in their types and the additional
material examined show that they are sparsely branched
agglutinated tubes with a central canal and some de-
velopment of pseudochambers. These features are typical
of protists, foremost of astorhizid agglutinated forami-
ifers (sensu Kaminski 2014). The distinctive feature of
the described fossils is the very thin central canal, thin-
ner than the wall, while most other astorhizid forami-
nifers show canals that are thicker than the wall. The
segments showing slightly different grain size are proba-
ably poorly developed pseudochambers connected by
the central canal. The protists selected silt grains and
packed them very tightly in the very thick agglutinated
wall.

The branched and unbranched forms co-occur
and they show the same morphological features (Fig.
5A, D, F). Also the smaller, unbranched forms show
the same features, except for their size and generally less
developed swellings and constrictions. This raises the
question if they belong to the same species or not. It
is probable that they belong to the same species, that
juveniles produced the smaller tubes, while adults pro-
duced the larger, occasionally branched tubes. This is
shown by curved forms with a side node that can be an
initial branching (Fig. 5B). One of the examined tests
shows short branches than can be interpreted as not
fully developed (Fig. 5G).

Because of their branching morphology and rela-
tively large size, these species are best placed into the
genus *Astorhizoides* Stschedrin, 1969 [type species
*Astorhiza cornuta* Brady, 1879], which consists of a
thick tube that branches at irregular intervals, not ra-
diating from a central area as in *Astorhiza*, and not
possessing a swollen central pseudochamber as in *Rhab-
dammna*. The type species of *Astorhizoides*, *A. cor-
nuta* (Brady, 1879), is reported from Challenger Sta.
122, SE of Pernambuco (about 320 m depth), in the
western Atlantic. It has an agglutinated wall made of
firmly cemented coarse sand grains with a rough exter-
ior. The analysed specimens from Italy are more finely
agglutinated and likely have a thinner wall than the type
species. Because of the page priority in the original de-
scription of Sacco (1888), the species *Nulliporites bom-
bicoides* is here placed in the genus *Astorhizoides*, and
*Astorhizoides bombicoides* (Sacco, 1888) regarded to
be the valid name, with *Nulliporites stellaris* Sacco, 1888
as its synonym.

Loeblich & Tappan (1987) reported the strati-
graphic range of *Astorhizoides* as "Holocene". Our
finding of *Astorhizoides* in the Oligocene of Italy is the
first fossil record of the genus. Their deep-sea oc-
currence is proven by sedimentological interpretations
(see Geological setting) and co-occurrence with trace
fossils typical of the Paleodictyon ichnosubfacies of the
Nereites ichnofacies, e.g. *Paleodictyon* (Fig. 3J),
which is typical of thin- to medium-bedded turbiditic
sediments in different parts of deep-sea fans (e.g., Uch-
man & Wetzel 2012).

Their life position is not certain, but it is likely
that they were erect forms, possibly semi-infaunal, si-
milar to *Bathyopion* (see Gooday et al. 1992), with
which they co-occur in some slabs (Fig. 3H, I). Some
specimens have been found in vertical position in a sandstone bed, with broken upper parts (Fig. 3L), suggesting they protruded above the muddy sea floor. The tests do not show any traces of attachment to objects.

The fossil specimens show some distinct taphonomic features. They are partially fragmented (Fig. 5E). They occur mostly on the lower bedding surface of turbiditic sandstones, being locally oriented (Fig. 3I, J). Some of them occur within the lower part of the bed (Fig. 3C). These features suggest that the tubes are transported or at least aligned by a turbidity current, however if they were transported, it was a rather short distance. Otherwise, the branched forms should be more crushed. The fragmentation of some tests suggests that they were rigid before final deposition. Some tests, however, are truncated by the trace fossil Ophiomorpha annulata (Fig. 3K) proving that some tests were enough soft to be abraded by appendages of the crustacean producer. Therefore, it seems that the test was originally partly flexible. Such a feature would have provided better resistance against current action.

Conclusions

This work revises the species Nulliporites bombicoides and Nulliporites stellaris, previously described as algal remains and now both attributed to the genus Astrobizinoides and to the single species A. bombicoides.

The agglutinated, large, astrobizinoid foraminiferid Astrobizinoides bombicoides (Sacco, 1888) is the first reported fossil species of the genus Astrobizinoides Stschudrina, 1969. It is characterized by a simple or rarely branched test formed of a thick-walled, smooth, finely agglutinated tube with constrictions. It displays a very narrow chamber lumen, with apertures at least at one of the terminal end of the tubes. It is found in Oligocene - Lower Miocene deep-sea turbiditic sediments, where its tests are preserved mostly on the lower bedding surfaces of thin turbiditic sandstones. Astrobizinoides bombicoides was probably a semi-infaunal, freely standing form, which apparently survived being transported for short distances. Its preserved tests are partly crushed.

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