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A TURONIAN CLAVAGELLID (BIVALVIA) FROM THE LADD FORMATION OF SOUTHERN CALIFORNIA

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ABSTRACT—*Stirpulina saulae* n. sp. is the first reported clavagellid from the Pacific Province of North America. Specimens of this clavagellid are from the Ladd Formation of the Santa Ana Mountains, Orange County, southern California. The age of these specimens is Late Turonian based upon the presence of the ammonite *Subprionocyclus* spp. both above and below the clavagellids in the section. These are, therefore, the oldest reported clavagellids from the western hemisphere, and they give positive support to the European Turonian reports of the genus *Stirpulina.* The deposits indicate an open-shelf habitat of shallow to moderate depth, and the associated fauna suggests a warm temperate to subtropical marine climate. This is consistent with the previously reported Cretaceous distribution for the group.

INTRODUCTION

CLAVAGELLIDS ARE a group of burrowing and boring bivalves that are free in youth and form an elongated tube in adulthood to which one or both valves are attached. The general temporal and geographic distribution of the clavagellids was described by Smith (1962b), and the detailed Cretaceous distribution was given by Pojeta and Sohl (1987). These authors give a reported age range for the clavagellids of Cenomanian to Holocene, with Cenomanian and Turonian occurrences restricted to Europe.

Previously described North American clavagellids are *Ascaulocardium armatum* (Morton, 1833) from upper Santonian to Maastrichtian rocks of the eastern Gulf Coast Plains (Pojeta and Sohl, 1987), "*Clavagella*" sp. A from the Santonian rocks of Mississippi (Pojeta and Sohl, 1987), and *Clavagella* sp. and possibly *Stirpulina* sp. from the Eocene rocks of Florida (Nicol, 1968; Jones and Nicol, 1989). The occurrence of *Stirpulina saulae* n. sp. from rocks of Turonian age in California extends the temporal range as well as the geographic range of clavagellids in North America.

The older reported clavagellid occurrences of Cenomanian and Turonian age from Europe are uncertain as to generic placement (Pojeta and Sohl, 1987). *Clavagella cenomanensis* d'Orbigny, 1850, from the Cenomanian of France was not illustrated, nor was *Clavagella* sp. indet., an internal mold, reported from Italy by Parona (1909). D'Orbigny and Parona described both their Cenomanian specimens as being similar to *Clavagella cretacea* d'Orbigny, 1845, which is placed in subgenus *C.* (*Clavagella*) Lamarck, 1818, by Smith (1962a). As Pojeta and Sohl (1987) pointed out, this species is unquestionably a clavagellid but its generic placement is uncertain. The two reports of clavagellids from the Turonian of Europe are also generically uncertain. *Clavagella ligerensis* d'Orbigny, 1850, was not illustrated and was described as similar to *C. cretacea.* Andert (1934, p. 345) reported *Clavagella elegans* Müller, 1859, from the Turonian of Saxony, which, if correctly identified, is the oldest reported *Stirpulina. Clavagella elegans* was described from the early Campanian Greensand of Vaals, west of Aachen, Germany (Pojeta and Sohl, 1987). Müller's species, assigned to *Clavagella* (*Stirpulina*) by Stoliczka (1870, p. 30), is a *Stirpulina* (Pojeta and Sohl, 1987).

STRATIGRAPHY AND LOCATION

The specimens described here are from the Ladd Formation (Popenoe, 1937, 1942) in the Santa Ana Mountains, Orange County, California (Figure 1). This formation crops out in the

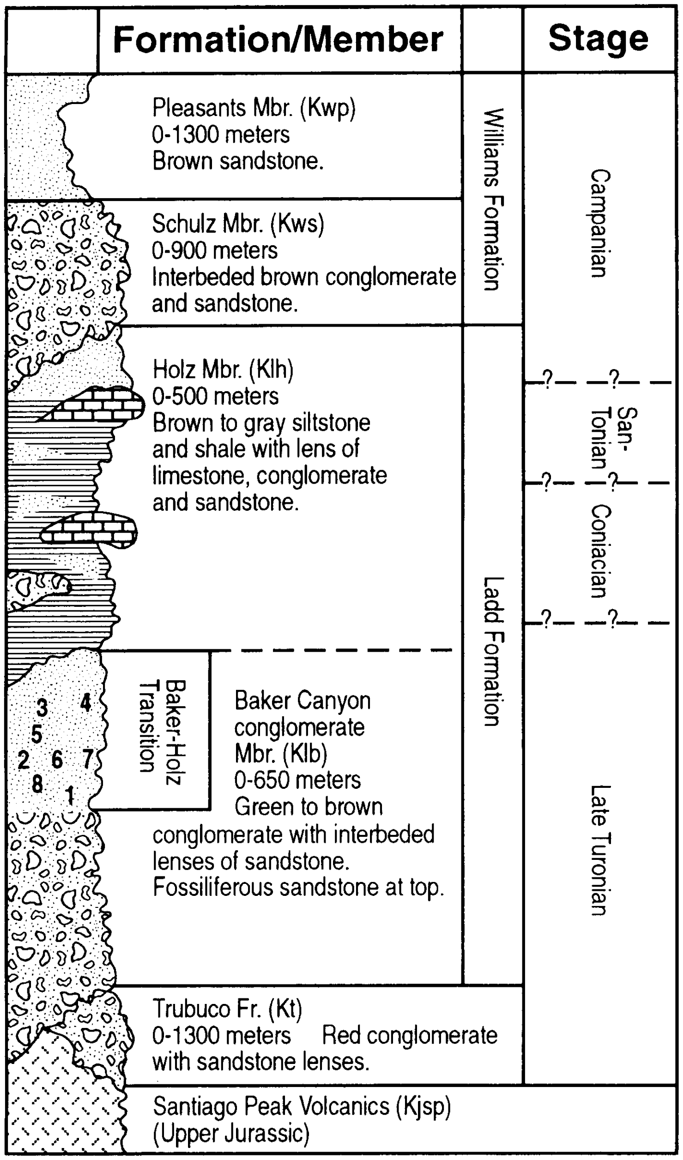

FIGURE 1—Upper Cretaceous stratigraphic column of Santa Ana Mountains with approximate position of fossil localities: 1, NHF-45; 2, CIT 1290; 3, CIT 301; 4, CIT 302; 5, UCLA 2952; 6, CIT 79; 7, CIT 1164; and 8, CIT 1062.

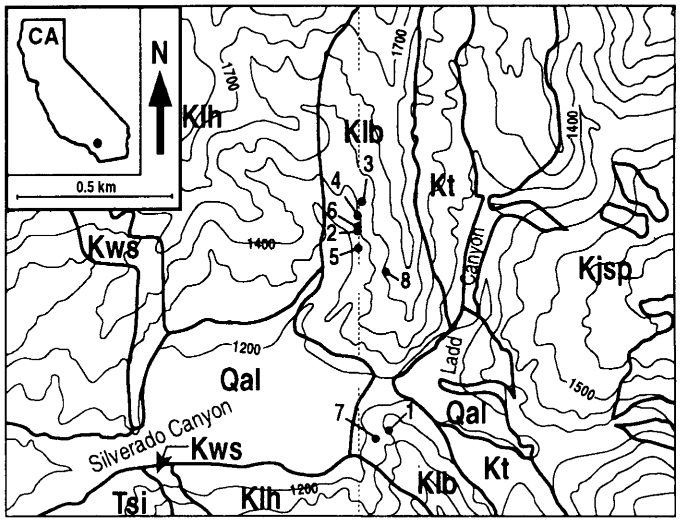

FIGURE 2—Map of fossil localities (numbered as in Figure 1). Sites 1 and 2 are localities yielding clavagellids. Sites 1 and 3–8 contain *Subprionocyclus*. (Map modified from Schoellhamer et al., 1981, sections 7–8, T5S, R7W, El Toro and Black Star Canyon quadrangles.)

northern and western slopes of the Santa Ana Mountains, and in the foothills to the west. It is divided into a lower Baker Canyon Conglomerate Member and an upper Holz Shale Member. The Baker Canyon Conglomerate Member as defined by Popenoe consists of interbedded conglomerate and sandstone and includes fossiliferous sandstone at the top. The overlying Holz Shale Member consists of shales and silty shales with conglomerate and limestone lenses, and, near the top, sandstone beds that are highly fossiliferous.

The boundary between the two members is gradational, laterally variable, and time transgressive. The fossiliferous sandstone at the boundary was referred to by Popenoe (1942, p. 178, fig. 4) as the Holz-Baker Transition, and as the Baker Canyon Sandstone by Cooper et al. (1982). These boundary definitions are subject to interpretation, and Sundberg (1980, p. 843, fig. 2, p. 855, fig. 22) considered that the lithologic changes reflected fan delta and lagoonal deposits whose outcrops span the time from late Turonian to possibly Santonian.

The presence of the ammonite *Subprionocyclus* spp. at or near the collecting sites (Figure 2) provides a Turonian age for all but one of the specimens. The Natural History Foundation of Orange County clavagellid specimen NHFOC cat. no. 1964 (Figure 3.1, 3.2) has little provenance other than it is from the Holz Shale. The Holz Shale crops out in the Santa Ana Mountains and western foothills. Matrix of specimen NHFOC 1964 and its preservation are similar to that of specimens from the other two sites. NHFOC site NHF-45 yielded seven nearly complete specimens and some fragments. NHF-45 is 18 m up the first draw south of the Silverado Narrows, SW¼, sec. 8, T5S, R7W, El Toro quadrangle, Orange County, California. This collection has not been completely identified and catalogued but does contain *Subprionocyclus* spp. indicative of late Turonian age. California Institute of Technology (CIT) loc. 1290 (=Natural History Museum of Los Angeles County, Invertebrate Paleontology Section (LACMIP) loc. 10135), near the top of the Baker Canyon sandstone on south side of hill west of Mustang Springs, NW¼, sec. 8, T5S, R7W, Black Star Canyon quadrangle, yielded a specimen of *Stirpulina saulae*. The locality, approximately 320 m north of the Holz Ranch house, is probably equivalent to CIT loc. 79 from which Matsumoto (1960, p. 65) listed *Subprionocyclus* sp. Other nearby localities (Matsumoto, 1960; Saul, 1982a, 1982b) reporting *Subprionocyclus* are also shown in Figures 1 and 2. An additional paratype is from University of California, Berkeley, Museum of Paleontology UCMP loc. 2137, 1⅜ mi. (2.2 km) N 75°E from B.M. 1271; at the contact between the red (Trabuco) and gray (Baker Canyon) basal conglomerates, between Harding and Williams Canyons, NW¼, sec.21, T5S, R7W, Santiago Peak quadrangle, Orange County. It is as complete as the holotype (Figure 3.1, 3.2).

MORPHOLOGY AND CLASSIFICATION

The classification used is that of Pojeta and Sohl (1987) in which *Stirpulina* Stoliczka, 1870, is treated as a separate genus rather than as a subgenus of *Clavagella* Lamarck, 1818. These are clavagellids with left valves fused to the crypt, free right valves internal to the adventitious crypt, and anterior branching tubes on a corona.

The morphological terminology used follows Savazzi (1982a, 1982b). The term crypt is used to include all hard parts, and the adventitious crypt is the hard parts added to the valves after the free stage. Siphonal sheath refers to the part of the adventitious crypt that covers the siphons. Shell or valve refers to the juvenile valves, and shell sheath that portion of the adventitious crypt and fused valves in area of valves. The corona refers to fringe at anterior end from which tubes protrude. The corona may have a short or elongated stalk attaching it to the shell sheath.

ENVIRONMENT AND EVOLUTION

The environment of deposition for the Cretaceous of the Santa Ana Mountains has been covered extensively in Bottjer et al. (1982) and Sundberg (1980). Sundberg's locality 12 (1980, p. 850, fig. 9) is approximately equivalent to NHF-45. Sundberg placed the fauna from this locality in the *Glycymeris-Astarte* Association of the *Inoperna-Glycymeris* Paleocommunity inhabiting normal marine waters at shallow depth. The collection from NHF-45 has a similar makeup to that reported by Sundberg at locality 12, including *Subprionocyclus* spp., *Inoperna bellarugosa* Popenoe, 1937, *Glycymeris pacificus* (Anderson, 1902), and *Alleinacin sulcata* (Packard, 1922) [*Astarte*]. Saul (1982a) indicated a moderate depth, shelf fauna in the area around CIT loc. 79, and possibly somewhat shallower around NHF-45. This shallow to moderate depth, warm water, shelf environment agrees with reported distributions of clavagellids for the Cretaceous (Pojeta and Sohl, 1987).

Pojeta and Sohl (1987, p. 72) suggested the derivation of *Ascaulocardium* from *Stirpulina*. The similar shell sheaths and siphonal sheaths of *S. saulae* and *A. armatum* (Morton, 1833) add credence to this inference. The similarities are an oval siphonal sheath that connects to the shell sheath with a marked inflection, siphonal sheaths that have a tendency to have lateral grooves, juvenile valves that are rounded at the ends, and right free valves having finer growth striations (Figure 3.5) than the left valves. The posterior adductor muscle scars are high along the hinge line, but the anterior adductor muscle scars and pallial lines of *S. saulae* are not known. The relative positions of the anterior and posterior adductor muscles in *A. armatum* compared to those of the pholadomyids indicate a phylogenetic relationship (Pojeta and Sohl, 1987).

SYSTEMATIC PALEONTOLOGY

Phylum MOLLUSCA Cuvier, 1797
Class BIVALVIA Linnaeus, 1758
Subclass ANOMALODESMATA Dall, 1889
Order PHOLADOMYOIDA Newell, 1965
Superfamily CLAVAGELLACEA d'Orbigny, 1844

Definition.—Juvenile shell nacreous, free when young, one or both valves cemented wholly or partially to adventitious elongated crypt in adult; anterior end of adventitious crypt sealed by perforated plate, tubules, or tubes; adult with two subequal adductor muscles, or adductor muscles absent; pedal retractor muscles reduced, nonfunctional; pallial and siphonal muscles

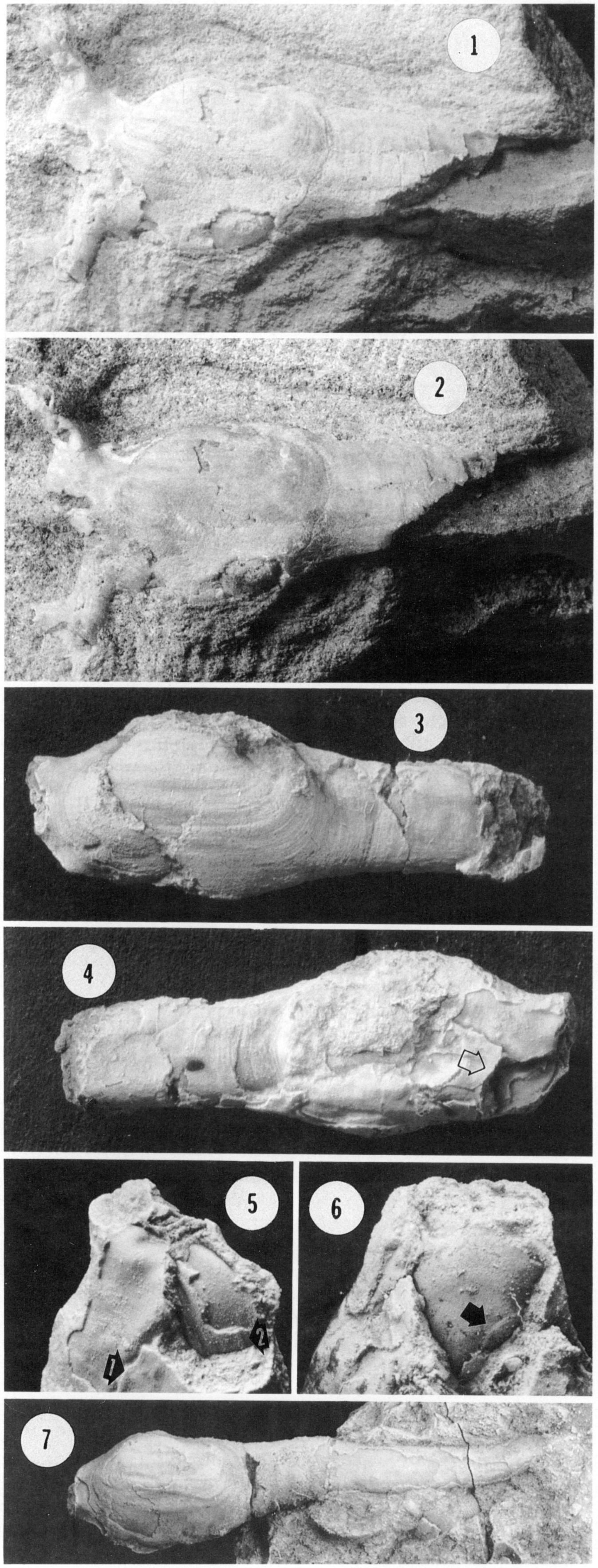

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FIGURE 3—*Stirpulina saulae* n. sp. *1, 2,* holotype, NHF 1964, left side, ×2.8. *3–5,* paratype, NHF 2016. *3,* left side, ×3.8; *4,* right side, arrow indicates area of figure *3.5,* ×3.8; *5,* anterior end at angle, arrow 1 indicates broken edge of adventitious crypt, arrow 2 indicates exposed portion of right juvenile valve, ×6.8. *6,* paratype, NHF 2017, posterior at angle, arrow indicates mold of posterior adductor muscle scar, ×6.8. *7,* paratype, NHF 2020, ×2.2. All specimens whitened except 2 which is wet to show tubes.

well developed; siphons long, fused; ligament external, or internal and supported by chrondrophores; hinge teeth absent.

Family CLAVAGELLIDAE d'Orbigny, 1844
Genus STIRPULINA Stoliczka, 1870

Definition.—Siphonal end simple or periodically expanded into fringe; left valve fused to adventitious crypt, other free; anterior end with tubes on corona or pedestal.

Type species.—*Stirpulina coronata* (Deshayes, 1824).

STIRPULINA SAULAE n. sp.
Figure 3

Diagnosis.—*Stirpulina* with elongated inflated juvenile valves; siphonal sheath elliptical in cross section and noticeably smaller than shell sheath, sheaths joining with a marked inflection; anterior corona close to anterior end of juvenile valves with a small number of branching tubes.

Description.—Siphonal sheath elliptical in cross section with simple growth lines and occasional lateral grooves; siphonal sheath smaller than shell sheath both laterally and vertically, siphonal and shell sheaths joining with marked inflection; juvenile valves elongated, well inflated, and well rounded at both ends; average length of juvenile valve 12.0 mm ± 0.5 mm. Left fixed valve with moderately heavy growth lines, and right valve free, internal to adventitious crypt, with finer growth lines; anterior corona having a short stalk and four to six branching tubes.

Remarks.—Because of the small number of specimens and their preservation no attempt was made to expose internal features. However, some features have been exposed during collecting or cleaning. Figure 3.5 shows a portion of the right free valve which had fine unserrated growth lines and the exposed internal mold of which indicates a rounded end. Figure 3.6 shows the posterior end of the right valve mold. In the lower right corner of this mold is a mark of part of the posterior adductor muscle scar (indicated by arrow). The muscle scar is small and well incised. No pallial lines have been detected.

The anterior tubes are missing from all but the holotype (Figure 3.1, 3.2). The number of primary tubes is estimated by the swellings on the edge of the corona (Figure 3.3). The siphonal sheaths are all broken at the posterior end. The longest is shown in Figure 3.7. The presence or absence of fringes on the siphonal sheath is unknown as this specimen has its external sheath abraded. The right shell crypts (Figure 3.4) are slightly crushed but appear to be smooth and have no indication of adventitious tubes, triple junctions, or crown of tubes.

This species can be differentiated from other reported *Stirpulina* spp. by the shape of the juvenile shell, the relative size of the siphonal sheath to the shell sheath, the short coronal stalk, and the number of primary tubes. The siphonal sheath of most previously described *Stirpulina* join the shell sheath with a smooth continuous taper (see Appendix for list of *Stirpulina* spp.). The exception is *Stirpulina caillata* (Deshayes, 1866), which tends to have a smaller siphonal sheath that is not as strongly demarked as that of *S. saulae*. Whereas *S. saulae* has elongated, inflated juvenile valves, *Stirpulina oblita* (Michelotti, 1861), *Stirpulina vicentina* (Savazzi, 1982a), *Stirpulina bacillum* (Brocchi, 1814), and *Stirpulina bacillum bacillaris* (Deshayes, 1830) have juvenile valves that are posteriorly truncated.

Ascaulocardium armatum lacks a corona, and the corona stalk is very short on *Stirpulina saulae*. *Stirpulina saulae* lacks adventitious tubes or a crown of tubes and has no indication of a triple junction. The triple junctions are, however, not always evident on *A. armatum.*

Etymology.—The species is named after L. R. Saul in recognition of her work on Cretaceous mollusks.

Types and repositories.—The material from the Natural History Foundation of Orange County is being moved to the Interpretive Center at Ralph B. Clark Regional Park, Orange County, California. This includes the holotype, NHF cat. no. 1964, from the Ladd Formation of the Santa Ana Mountains (Figure 3.1, 3.2), and paratypes NHF cat. nos. 2011–2015 (unfigured), 2016 (Figure 3.3–3.5), 2017 (Figure 3.6), 2118–2019 (unfigured) from NHFOC locality NHF-45. Paratype LACMIP cat. no. 12276 (unfigured) from LACMIP loc. 10135 is at the Natural History Museum of Los Angeles County. Paratype UCMP 39836 (unfigured) from UCMP loc. 2137 is at the University of California, Berkeley, Museum of Paleontology.

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APPENDIX

The following modifies and extends the list in Smith (1962a, p. 170) of previously described species of the genus *Stirpulina.*

Stirpulina aspergillum (Bronn, 1828) [*Clavagella*], p. 5 =*Stirpulina bacillum* (Brocchi, 1814).
Stirpulina bacillum (Brocchi, 1814) [*Teredo*], p. 273, Pl. 15 [not Pl. 14 as given in text]. Miocene, Austria.
Stirpulina bacillum bacillaris (Deshayes, 1830) [*Clavagella*], p. 239. Pliocene, France.
Stirpulina caillati (Deshayes, 1866) [*Clavagella*], p. 88, Pl. 1, Eocene, France.
Stirpulina clavata (Roemer, 1841) [*Teredina*], p. 76. ?Cretaceous, Germany.
Stirpulina cornigera (Schafhäutl, 1863) [*Clavagella*], p. 179, Pl. 65a. Late Cretaceous, Bavaria.
Stirpulina coronata (Deshayes, 1824) [*Clavagella*], p. 8, 1837 [plates], Pl. 5. Late Eocene, France.
Stirpulina digitata (Bivona-Bernardi, 1832) [*Tubelana*], p. 56, Pl. 1 = *S. bacillum bacillaris* (Deshayes, 1830). ?Pliocene, Italy.
Stirpulina elegans (Müller, 1859) [*Clavagella*], p. 17, Pl. 8. Late Cretaceous, Germany.
Stirpulina goldfussi (Philippi, 1846) [*Clavagella*], p. 44. Early Oligocene, Germany.
Stirpulina maniculata (Philippi, 1836) [*Aspergillum*], p. 1, Pl. 1 ?=*S. bacillum bacillaris* (Deshayes, 1830).
Stirpulina oblita (Michelotti, 1861) [*Clavagella*], p. 53, Pl. 5. Late Oligocene (Tongrian) Hungary–Egypt.
Stirpulina ramosa (Dunker, 1882) [*Clavagella*], p. 172, Pl. 16. Recent, Japan.
Stirpulina veronensis (Savazzi, 1982a) [*Clavagella*], p. 87, Pl. 1. Middle Eocene, Italy.
Stirpulina vicentina (Savazzi, 1982a) [*Clavagella*], p. 88, Pl. 2. Lower Oligocene, Italy.