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Spirotrypidae, A new family of Permian Bryozoans from the Wargal Limestone, Salt Range, Pakistan

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Abstract

Spirotrypidae, a new family of Rhabdomesida containing seven new genera and species, occurs in the Wargal Limestone (Permian) of the Salt Range in northcentral Pakistan. Based on conodonts, the age of this family ranges from Capitanian to earliest Changhsingian. The Wargal Limestone is considered to have been deposited on a shallow carbonate platform under normal marine conditions.

The small size of these bryozoans presents a challenge for their identification by normal methods of study of stenolaemate bryozoans (transverse, tangential, and longitudinal sections). It was necessary to prepare serial acetate peels of transverse sections of zoaria and produce tangential and longitudinal sections from these transverse sections.

Critical for producing tangential and longitudinal views is the constant central tube in the center of these bryozoans. The central tube serves as a known point of reference for aligning the serial transverse sections. This central tube is unique in the absence of any internal structures such as diaphragms. The tube does not branch to form additional tubes or produce new autozooecia from within the tube. Other structures unique to these bryozoans is the presence of indented tabular nodes in two of the genera and hook-shaped spines in two of the genera.

The seven new genera are classified by the type of autozooecial budding in the zoaria. The type of budding can be identified by examining the transverse sections. The new genera and species are *Didymotrypa multistylia, Tritrypa indentura, Tetratrypa hookia, Pentatrypa tabularia, Hexatrypa nammalia, Heptatrypa spinosa, and Spirotrypa spiralia.*

Keywords: Bryozoa, Wargal Limestone, Capitanian-Wuchiapingian-Changhsingian, Salt Range, Pakistan, Permian.

1. Introduction

During the senior author's tenure as a Fulbright Fellow at Peshawar University in 1980-81, he and two colleagues from the Department of Geology spent two months collecting samples of four sections of the Wargal Limestone in the Salt Range of Pakistan. While studying the bryozoans of the Wargal Limestone, the senior author discovered extremely small transverse sections of apparent bryozoans. These bryozoans contain a combination of features not described before and are considered to be a new family of the order Rhabdomesida. The size of these bryozoans is extremely small for stenolaemate bryozoans. The diameter of the transverse sections is the same as the diameter of a medium size sand grain. To visualize their size, realize that the diameter of the transverse section of these zoaria is about the same as the diameter of the period at the end of this sentence.

In this paper we describe the method of study of these bryozoans and present the taxonomy of a new family. In a separate new study of the Amsden Formation (Morrowan, Pennsylvanian) we have discovered two new species of bryozoans of similar size without the central tube. We believe that bryozoans of similar size will be found throughout the Paleozoic as workers begin to notice their presence.

Methods.--The method of study is critical for understanding and being able to recognize the different genera and species of this new family of Permian bryozoans. Because the size of these zoaria is so small compared to most bryozoans, and because they occur as allochemical fossil fragments in limestone, the techniques used to study them require a detailed description and discussion. This is especially true in the preparation of the tangential and longitudinal sections.

Zoarial diameters of these genera range from 0.204 to 0.450 mm. Attempting to locate these fragments and orient them to prepare tangential and longitudinal sections is next to impossible when working with pieces of limestone. Of the zoarial fragments of this new family located so far, only six oblique longitudinal sections have been found by the authors. No adequate tangential sections have been found. The outer wall of the exozone is too thin to produce a photograph of the surface of the zoarium. However, using a system of serial sectioning producing consecutive transverse sections, both tangential and longitudinal views of the zoaria can be generated.

Transverse serial sectioning through the zoarium.

In order to produce acceptable transverse peels through the zoarium, the zoarium must be perpendicular to the direction of growth. If the zoarium is oblique, the measurements of tangential and longitudinal sections will be distorted. In all the genera of this new family except for the spiral budding form, the sizes and symmetry of the autozooecia will indicate whether the transverse section is truly perpendicular.

Following is a discussion of the serial sectioning used in this study.

- View random acetate peels of limestone to locate a transverse peel of a zoarium.
- Taking the etched piece of limestone from which, the peel was produced, polish the etched surface for 45 seconds with cerium oxide polishing compound.
- Etch the polished surface in dilute formic acid (20 ml concentrated formic acid and 800 ml distilled water) for two seconds. Place sample in water to stop acid reaction.
- Dry the surface (we speed up the process with compressed air).
- Cover the etched surface with acetone.
- Place a piece of acetate (2 cm x 5 cm x 1.5 mm) 0n the etched surface.
- Allow peel to dry for at least ten minutes and remove acetate from limestone.

The serial peel is ready to observe under the microscope. We take a digitized image of the transverse peel with the microscope camera, place it in the numerical file in the computer, and prepare a hard copy for measuring with calipers to generate both tangential and longitudinal sections. The amount of specimen removed during each consecutive part of the process is 0.003mm. All measurements are plotted at a 2mm vertical interval. After the tangential and longitudinal views are produced on the 2mm scale, the sections are reduced to 63 percent to obtain the true relative size of the zoarium.

For this study, we generated over 4,000 transverse acetate peels of the studied bryozoans we encountered. Over 20,000 measurements of the morphological features in these 4,000 plus transverse sections were made to produce the tangential and longitudinal sections used for this taxonomic study. One of the most disappointing aspects of this research is to have an excellent transverse view of a specimen and see it disappear with each additional peel as one reaches the outer limits of the sand-sized allochemical particle.

2. General stratigraphy:

The Wargal Limestone is the middle formation of the Zaluch Group in the Salt Range of north-central Pakistan. The Wargal Limestone was named by Tiechert (1966) in his review of the nomenclature and correlation of the Permian "Produstus Limestone." The Wargal Limestone is equivalent to the Middle Productus limestone of previous workers (Waagan and Wentzel, 1886; Reed, Cotter, and Lahiri, 1930; Gee, 1947; Schindewolf, 1954). The Wargal Limestone is underlain by the Amb

Formation and overlain by the Chhidru Formation. The Wargal Limestone consists of a sandy and cherty skeletal wackestone in the lower part; mudstone and fine sandstone in the middle part; skeletal packstone wackestone and a packstone/wackestone with thin shale interbeds in the upper part. The entire formation contains abundant fossils including brachiopods, bryozoans, conodonts, foraminifers, gastropods, pelecypods, corals, and crinoidal debris.

3. Paleoecology and paleogeography

Wardlaw and Pogue (1995) describe the Wargal Limestone as deposited on a shallow carbonate bank with repeated subaerial exposure. They characterize the sequence of deposition of the Wargal as going from open marine carbonate deposition to shallow subtidal to supratidal mixed clastic and carbonate deposition. The conodont *Hindeodus* fauna is considered to be nearshore (Wardlaw and Pogue, 1995, p. 3).

Mertmann (2003) interpreted the Wargal Limestone as being deposited on a large carbonate platform. She reports a climate change causing higher water temperatures and decreased terrigenous input from the hinterland during the deposition of the Wargal. This climatic change was accompanied by the development of the carbonate platform with scattered coral patches on the Gondwana continental crust adjacent to the Indian Shield. This was followed by more coral patches and abundant crinoidal debris.

4. Location

Bryozoans described in this paper were collected by the senior author from the Wargal Limestone of the Salt Range, Pakistan during December 1980 and February to April 1981 (Haneef and others, 1981). All of the bryozoan specimens described in this paper were found in either the Nammal Gorge or the Chatuwala Nala sections (Fig. 1). Instructions for gaining access to these sections and detailed columnar sections are presented in Haneef and others (1981).

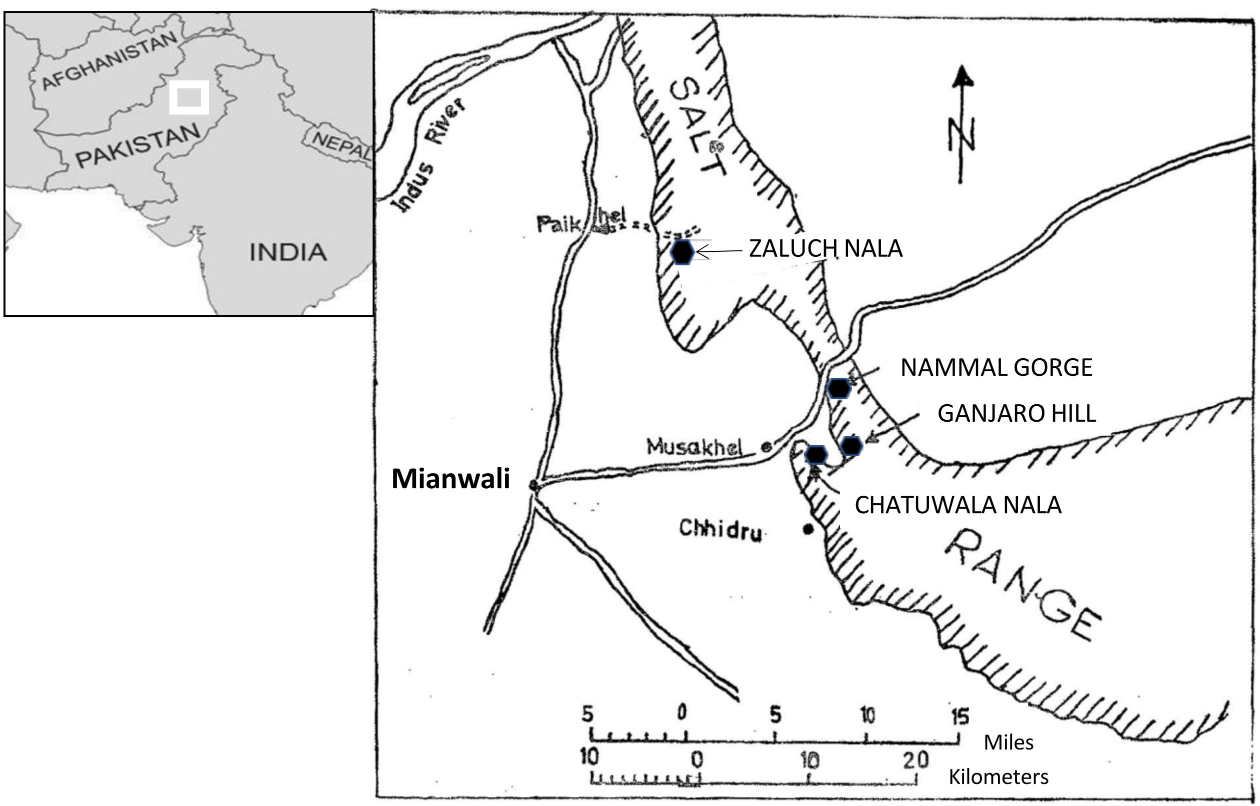


Fig. 1. Map showing location of study area.

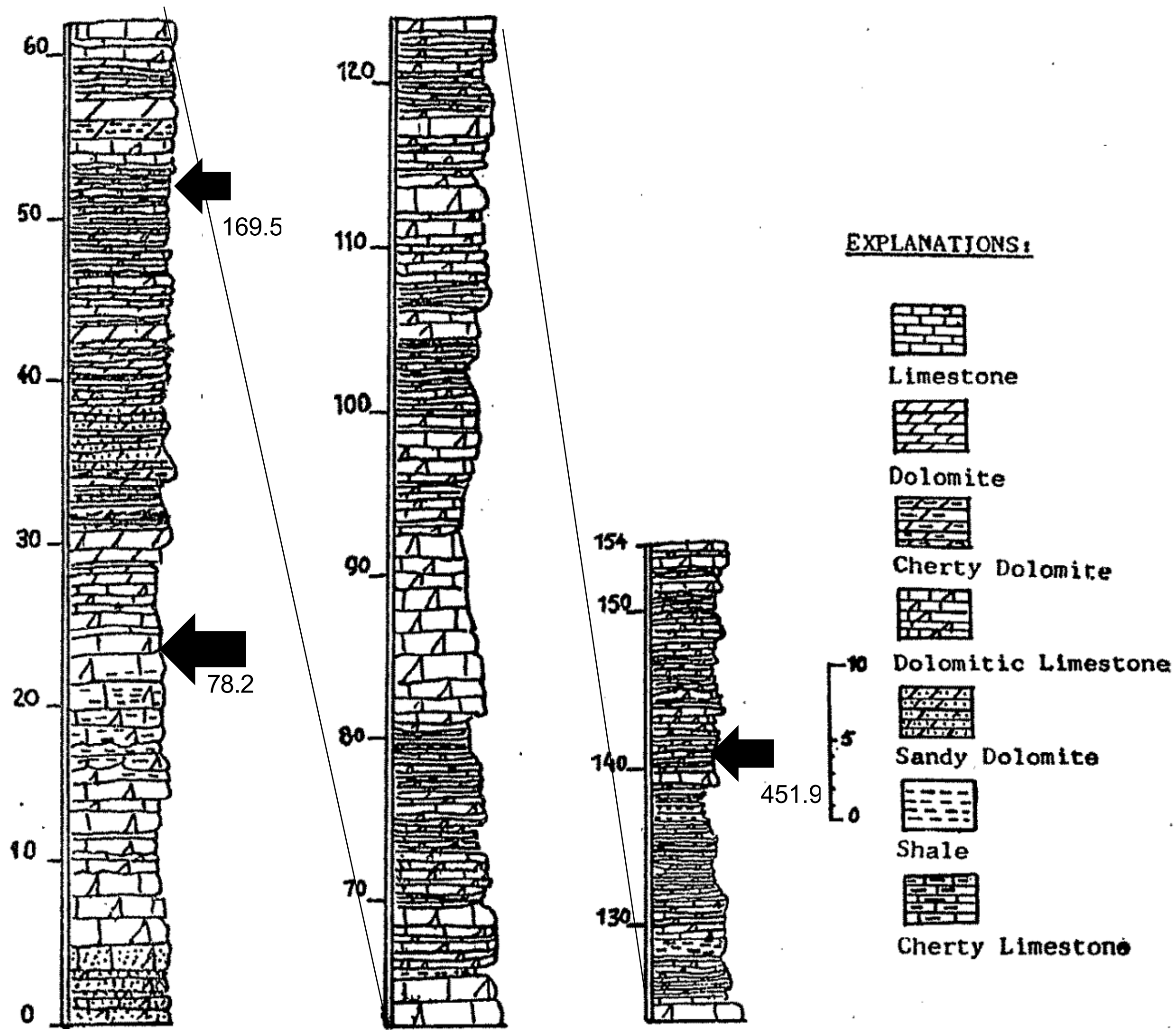


Fig. 2a. Section of wargal limestone at Nammal Gorge with bryozoan localities

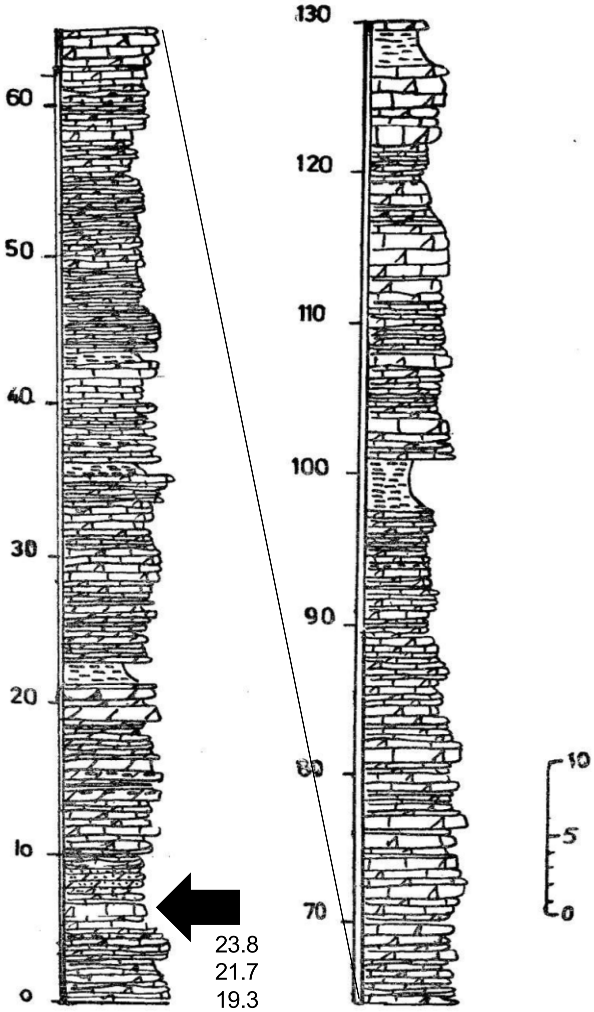


Fig. 2b. Section of Wargal limestone at Chatawala Nala with bryozoan localities

5. Age

Based on conodonts, the age of Spirotrypidae ranges from Capitanian to earliest Changhsingian (Wardlaw and Pogue, 1995). The genus *Didymotrypa ranges* from the uppermost *Hindeodus excavatus-Merrillina divergens* Zone 2 (Capitanian) to the uppermost *Hindeodus julfensis* B Zone 4B (earliest Changhsingian). *Tritrypa* occurs only in the uppermost *Hindeodus julfensis* B Zone 4B (earliest Changhsingian). *Tetratrypa, Pentatrypa, Hexatrypa, Heptatrypa,* and *Spirotrypa* range from middle to upper *Hindeodus excavatus-Merrillina divergens* Zone 2 (Capitanian). Specimens of these genera are very difficult to find in these rocks because of their size and these age ranges are minimal.

6. Systematic Paleontology

Bryozoans described or noted in the Wargal Limestone in this study constitute one new family and seven new genera. The suprageneric classification used in this study is a combination of Astrova and Morozova (1956), Morozova (1970) and Blake (1983). For definition of morphological terms used in diagnoses and descriptions, see Bassler (1953), Astrova (1960), Morozova (1970), and Boardman and Cheetham (1983).Illustrated holotypes and paratypes are housed in the Burke Museum of Natural History and Culture at the University of Washington (specimen numbers prefixed with UWBM IP). The Burke Museum location number for all of the specimens from this study is B9568. Other specimens studied are listed as "Other material" and are housed in the Eastern Washington University paleontological collection under Bz numbers.

Phylum BRYOZOA Ehrenberg, 1831

Class STENOLAEMATA Borg, 1926

Order RHABDOMESIDA Astrova and Morozova, 1956

Family Spirotrypidae new family

All the genera in this new family have a thin tube in the center of the zoarium (mean diameter ranges from 0.021 mm in *Didymotrypa* to 0.059 mm in *Heptatrypa*). This tube contains no diaphragms or structures; does not branch or divide into additional tubes; and does not produce new autozooecia from within the tube. The diameter of the central tube is constant in *Didymotrypa, Tritrypa, Heptatrypa,* and *Spirotrypa;* varible in *Tetratrypa;* and highly variable in *Pentatrypa* and *Hexatrypa.* Mean diameter of the zoaria in the family ranges from 0.227 to 0.440 mm. The variation in the mean diameter of the zoarium of any genus in this family is very low.

The genera of the family are determined by the type of autozooecial budding around the central tube. Seven genera named by the type of budding of autozooecia are described in the following descriptions. They are *Didymotrypa, Tritrypa, Tetratrypa, Pentatrypa, Hexatrypa, Heptatrypa,* and *Spirotrypa.* Presence of hemisepta, conical spines, tabular spines, indented tabular nodes, hook-shaped spines, ovicells, and canal areas within the wall structure are also features present in various genera of this family. No metapores are present.

Didymotrypa gen. nov.

Type species—Didymotrypa multistylia gen. et sp. nov., by monotypy; Wuchiapingian Changhsingian, Lopingian, Permian; Salt Range, Pakistan.

Diagnosis—Quadrate shape in transverse section (Fig. 3); central tube; autozooecia bud in two cycles at 180 degrees to each other (Figs. 3, 7-9). Indented tabular nodes present. Hemisepta on distal side of autozooecia near base of aperture.

Etymology—The generic name refers to budding pattern of two cycles of autozooecial budding at 180 degrees.

Discussion—*Didymotrypa* is distinguished from other genera of the Spirotrypidae by the two-cycle budding pattern and the presence of hemiphragms. *Didymotrypa* has indented tabular nodes similar to *Tritrypa*. *Tetratrypa* has hook-shaped spines not present in *Didymotrypa*. The diameter of the zoarium, diameter of central tube, and width of the autozooecial chamber are much smaller in *Didymotrypa* than *Pentatrypa*, *Hexatrypa*, *Heptatrypa*, and *Spirotrypa*. *Didymotrypa* and *Tritrypa* have twice as many spines around their apertures than other genera of Spirotrypidae.

Didymotrypa multistylia gen. et sp. nov.

figures 7-9; table 1

Table 1. Summary of numerical analysis of *Didymotrypa multistylia* gen. et sp. nov including number of zoarial fragments on which measurements were made (Nf), total number of measurements or counts (Nm), smallest observed value of measured or counted morphological variable (Xs), largest observed value of measured or counted morphological variable (Xl), arithmetic mean (X), standard deviation (SD), and coefficient of variation (CV). All measurements in millimeters.

	Nf	Nm	Xs	Xl	X	SD	CV
Diameter of zoarium	7	7	0.204	0.262	0.227	0.0209	9.20
Diameter of central tube	7	30	0.017	0.028	0.021	0.0027	12.96
Autozooecial chamber diameter proximal to aperture (long dimension)	3	22	0.084	0.126	0.112	0.0140	12.51
Autozooecial chamber diameter proximal to aperture (short dimension)	3	22	0.053	0.078	0.066	0.0077	11.70
Length of autozooecial chamber from central tube	5	12	0.320	0.692	0.470	0.1166	24.81
Thickness of outer wall of autozooecia	5	17	0.016	0.026	0.021	0.0033	15.70
Number of autozooecia per 2 mm	3	3	2.5	3.0	2.7	0.2887	10.82
Aperture length on surface	3	6	0.445	0.581	0.504	0.0561	11.14
Aperture width on surface	3	5	0.105	0.136	0.117	0.0125	10.68
Number of spines around autozooecial aperture	3	3	20	24	22.3	2.0817	9.33
Diameter of spines perpendicular to growth of zoarium	3	15	0.012	0.025	0.020	0.0035	17.54
Thickness of hemiphragms	5	11	0.009	0.017	0.012	0.0025	21.20
Length of hemiphragms	5	11	0.019	0.056	0.035	0.0115	32.76

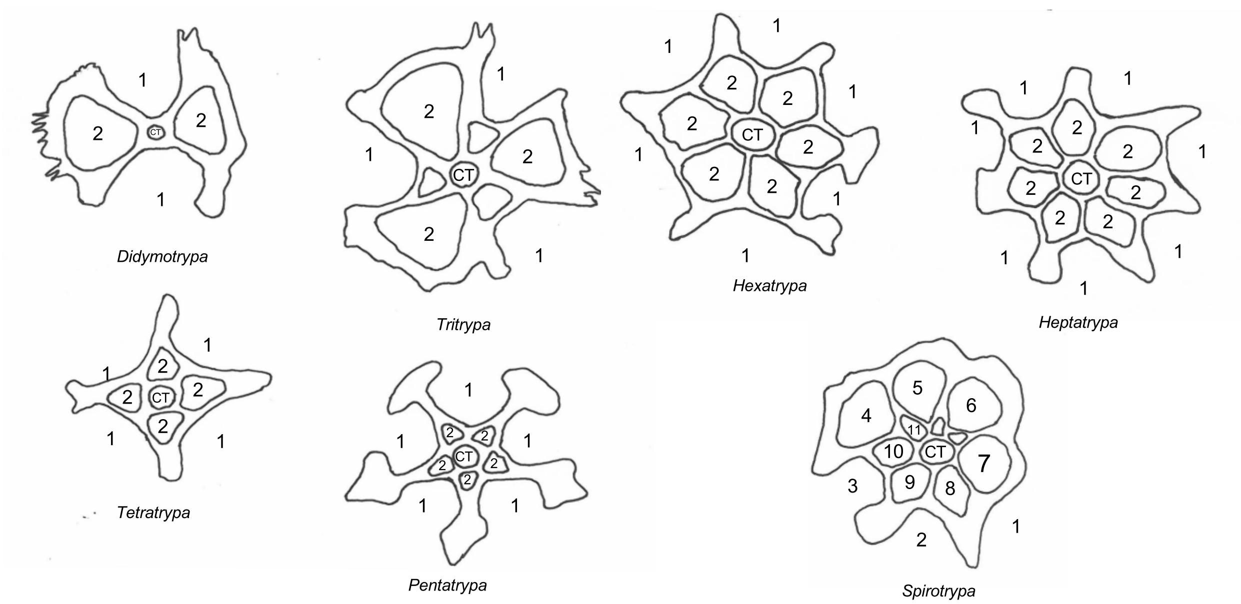


Fig. 3. Diagrams showing budding patterns and general outlines of genera of Spirotrypidae in transverse section. Higher number indicates budding of newest autozooecia. Central tube indicated by CT. The number of the transverse section used in creating the diagram is shown in parentheses following the generic name.

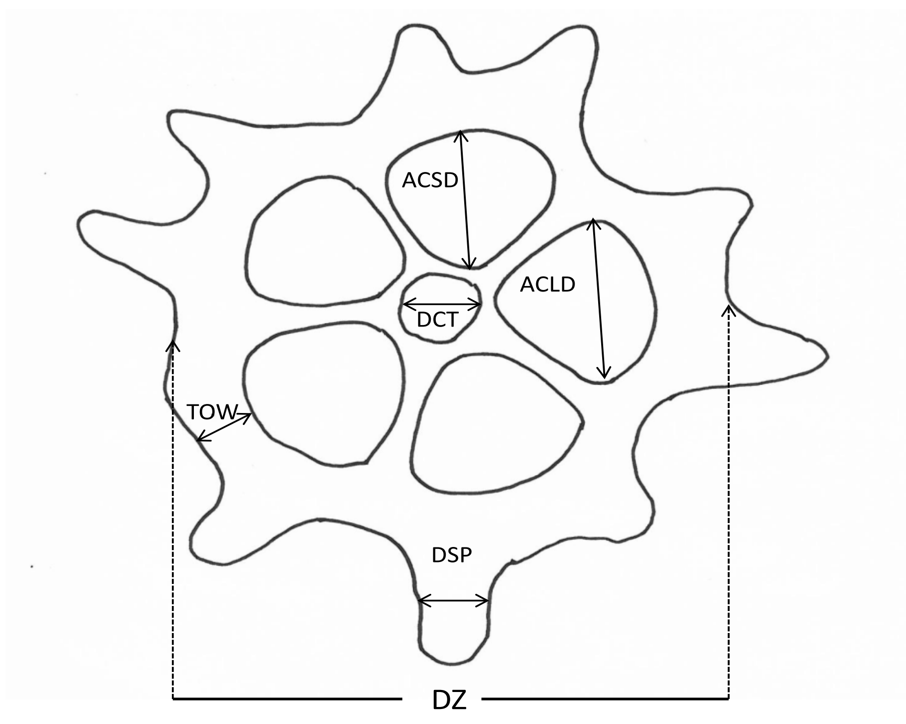


Fig. 4. Diagram showing points of measurements for Spirotrypidae. DZ is diameter of zoarium. DCT is diameter of central tube. ACLD is autozooecial chamber diameter proximal to aperture (long diameter). ACSD is autozooecial chamber diameter proximal to aperture (short diameter). TOW is thickness of outer wall of autozooecium. DSP is diameter of spines perpendicular to growth of zoarium.

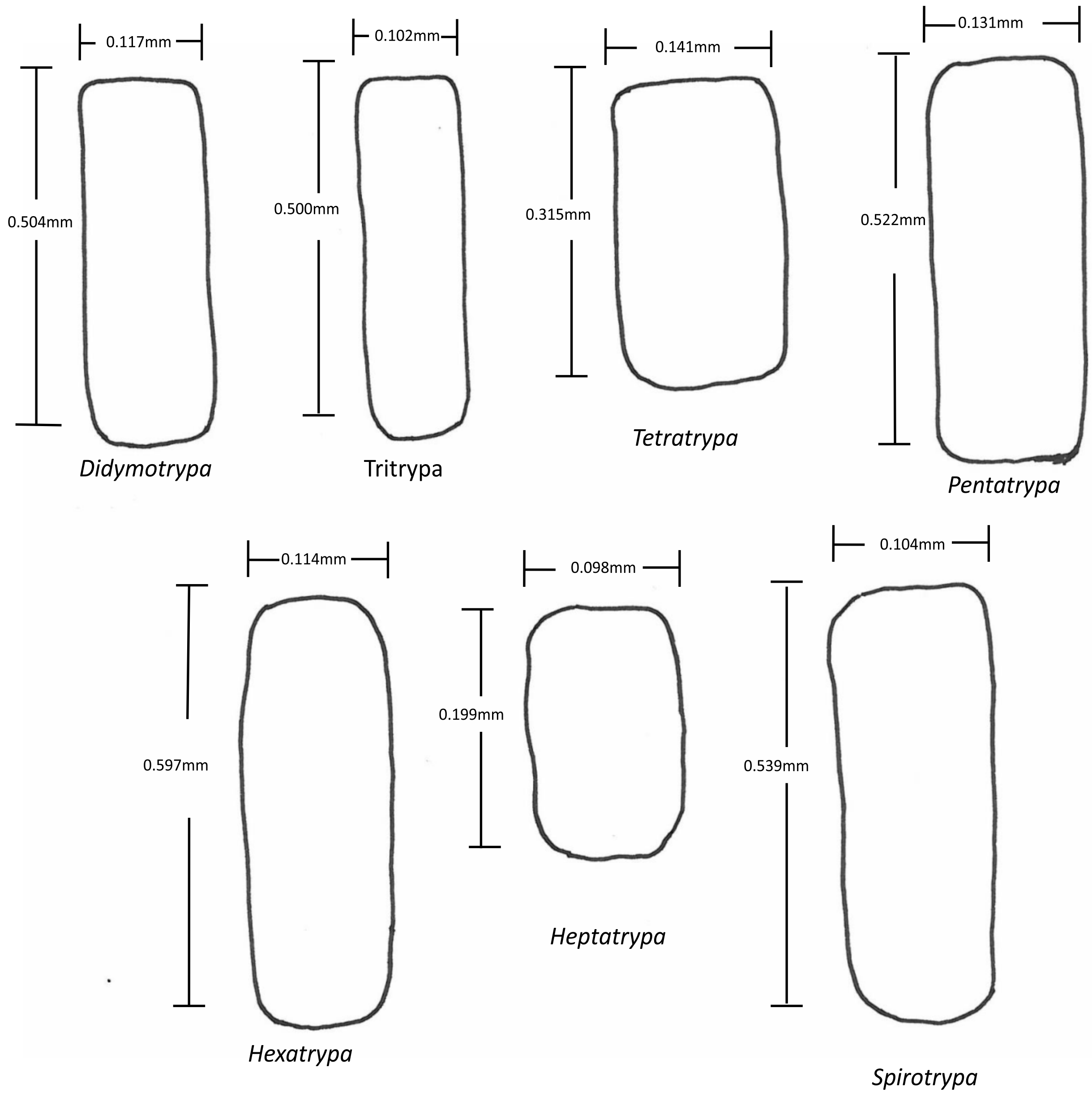


Fig. 5. Shapes and width/length dimensions of apertures in genera of Spirotrypidae.

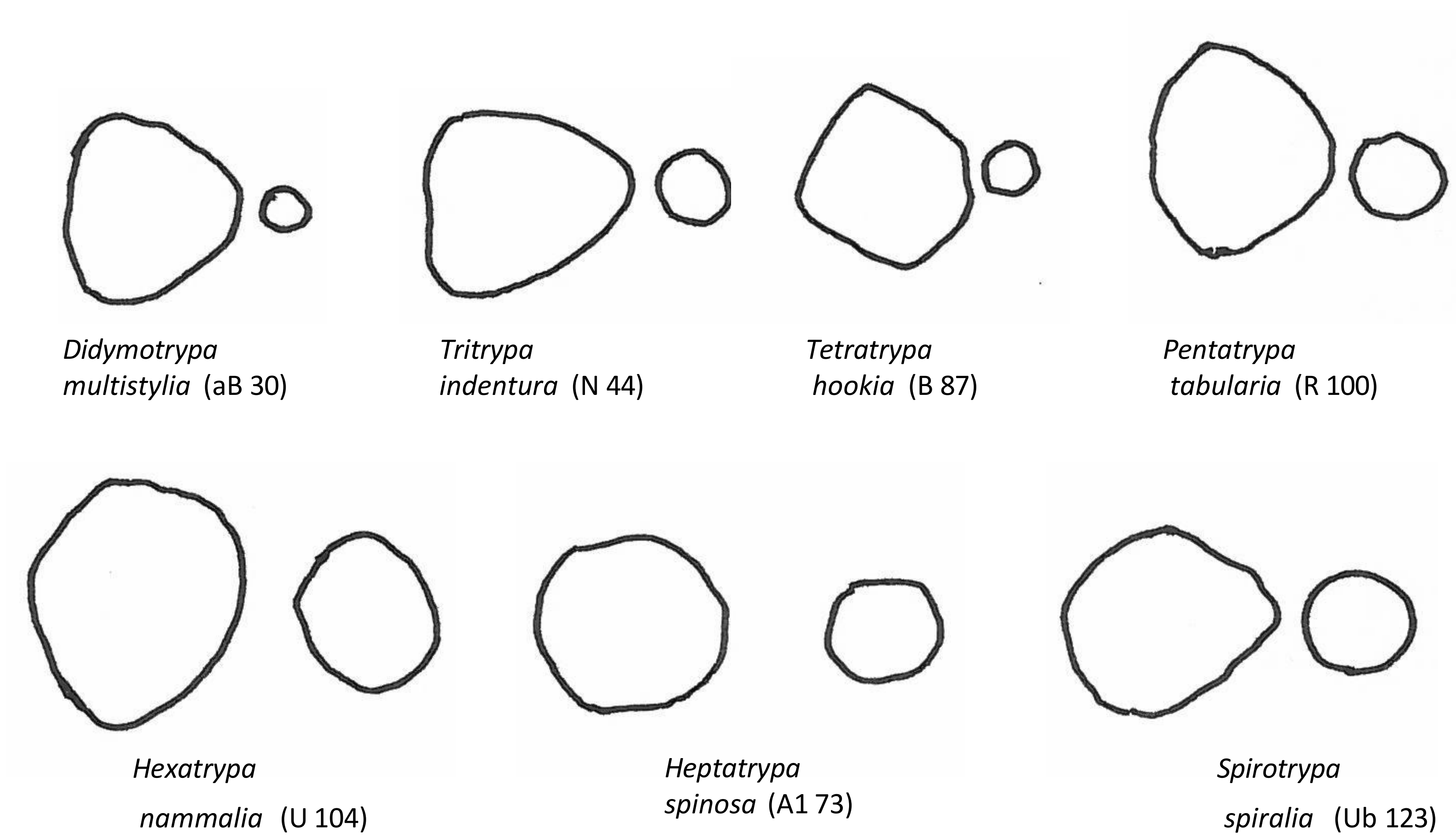


Fig. 6. Transverse views of autozooecia in species of Spirotrypidae proximal to opening of apertures. Smaller circles are size and location of central tubes. Size ratios of autozooecia consistent between taxa.

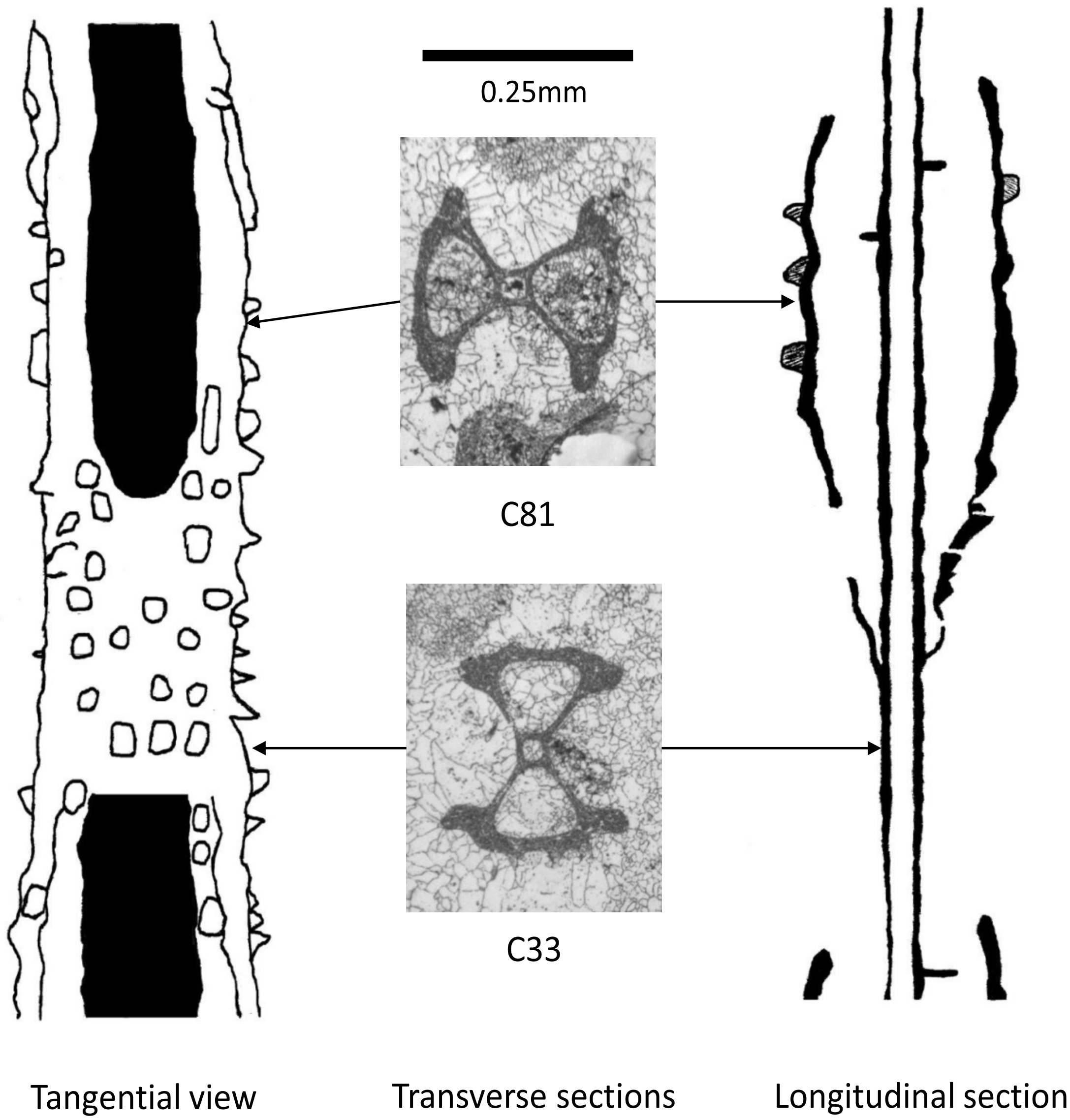


Fig. 7. Tangential, transverse, and longitudinal sections of holotype of *Didymotrypa multistylia* gen. et sp. nov Arrows indicate where transverse sections were used to produce tangential and longitudinal views. Designations under transverse sections refer to number of serial transverse section. Scale indicated by black line.

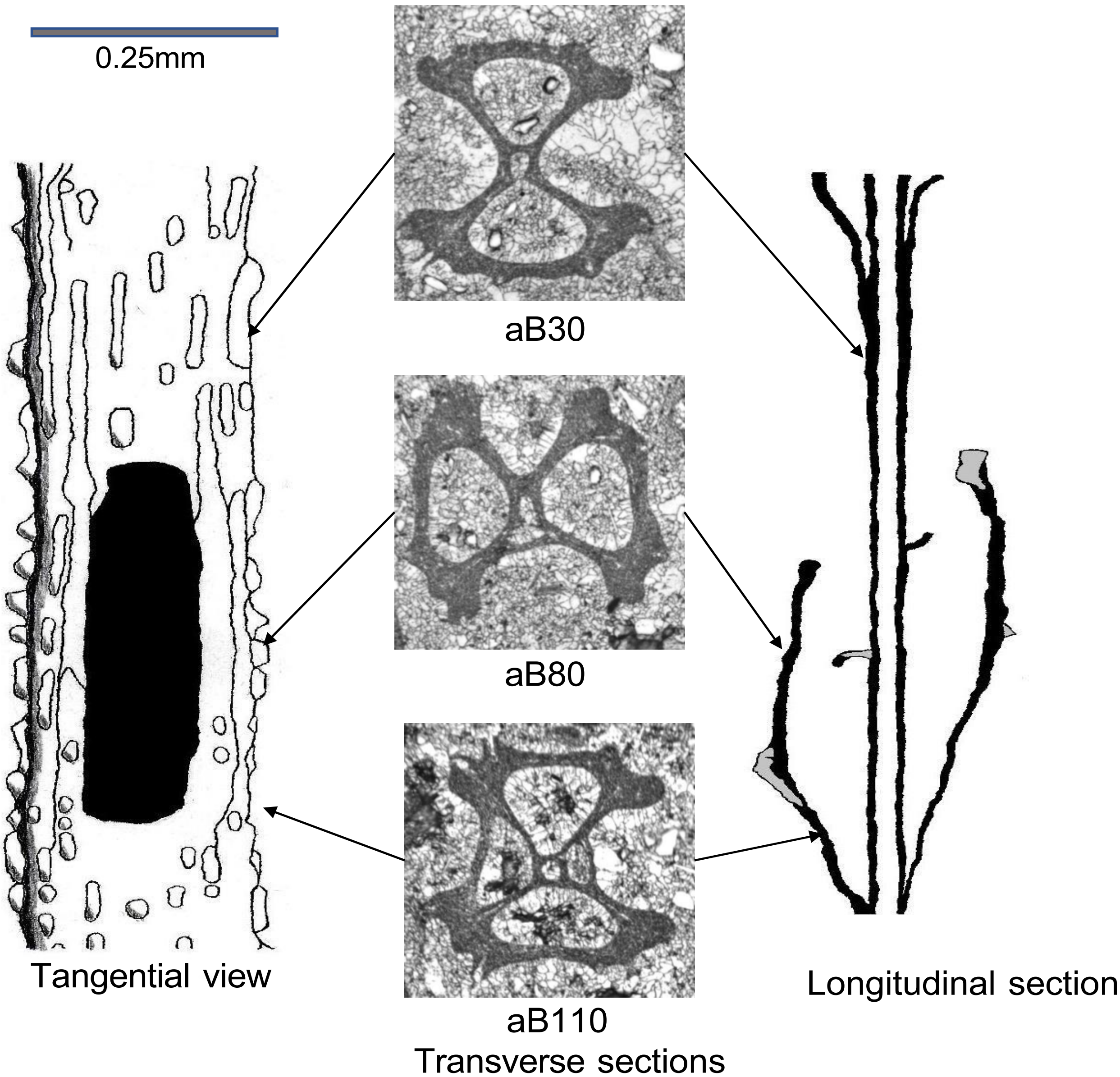


Fig. 8. Tangential, transverse, and longitudinal sections of paratype of *Didymotrypa multistylia gen. et sp. nov*. Arrow indications, designation of numbers, and scale same as in Figure 7.

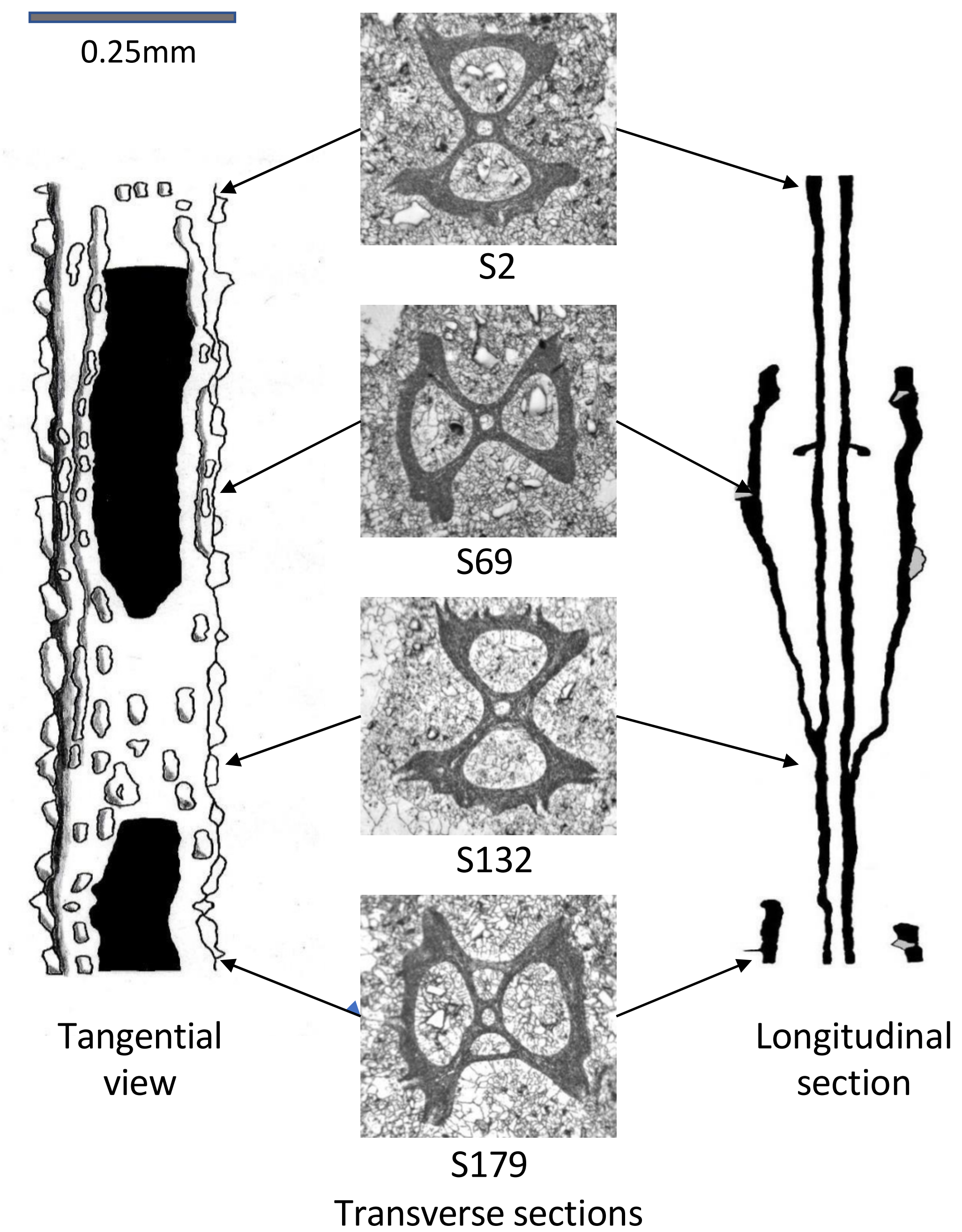
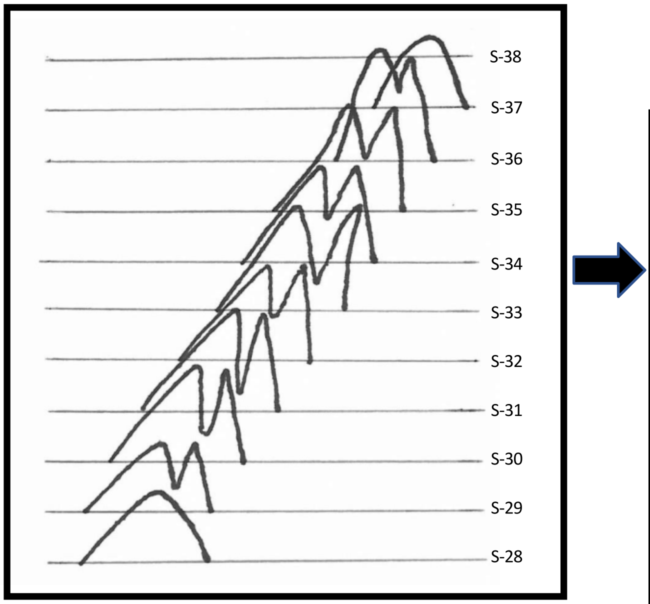
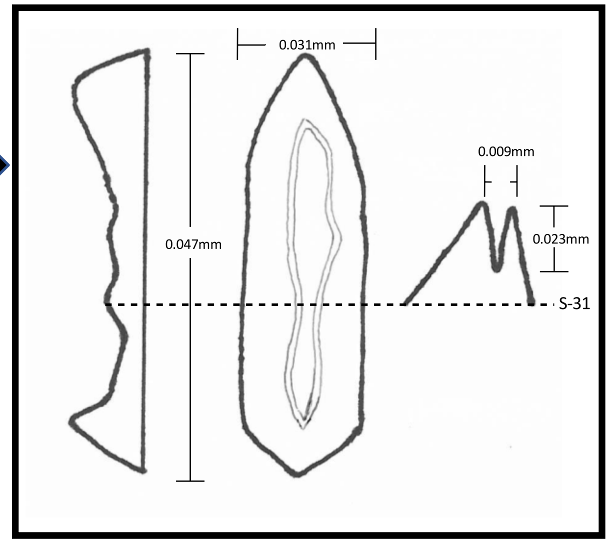


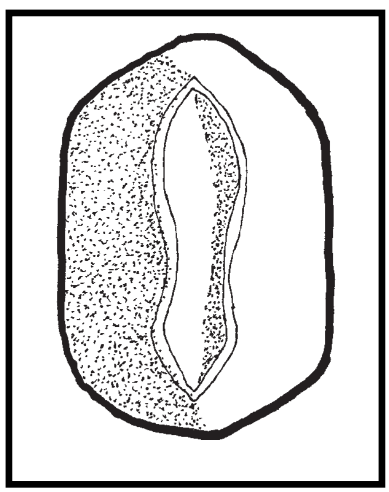
Fig. 9. Tangential, transverse, and longitudinal sections of paratype of *Didymotrypa multistylia* gen. et sp. nov. Arrow indications, designation of numbers, and scale same as in Figure 7.



A. DEVELOPMENT OF INDENTED TABULAR NODE FROM 11 PEELS (S 28-S38)



B. LONGITUDINAL, TANGENTIAL, AND TRANSVERSE VIEW OF INDENTED TABULAR NODE



C. TANGENTIAL VIEW OF NODE RECONSTRUCTION FROM 11 PEELS TO TRUE SCALE

Fig. 10. Detailed view of tabular node with indented surface characteristic of the genera *Didymotrypa and Tritrypa*. Eleven transverse sections were used to recreate a view of the indented tabular node. In B, the transverse cross section is the actual transverse section S 31. The final view (C) is corrected to scale.

Diagnosis—*Didymotrypa* with hemiphragms; longitudinal nodes with indented cavity in the center (Fig. 10); spines.

Etymology—Named for the abundant styles around the aperture.

Types—Holotype, UWBM IP 117915, 81-4-1-169.5 transverse sections C1-C121; paratype, UWBM IP 1117916, 81-4-3-451.9 transverse sections aB1-aB179; paratype, UWBM IP 117917, 81-4-3-451.9 transverse sections S1-S179.

Description—Small tubular zoaria (0.20 to 0.26 mm diameter) with moderately constant diameter central tube (0.017 to 0.028 mm diameter). Apertures rectangular with proximal end rounded or slightly pointed, ranging from 0.445 to 0.581 mm in length, 0.105 to 0.136 mm wide. In transverse section size of autozooecia proximal to aperture, parallel to surface ranges from 0.084 to 0.126 mm; perpendicular to surface ranges from 0.053 to 0.078 mm. Number of spines surrounding autozooecial aperture ranges from 20 to 24; 10 to 20 spines between apertures. Shape of hemiphragms is straight; or bend distally or proximally (Figs. 7-9).

Occurrence—Wargal Limestone (Wuchiapingian-Changhsingian), Permian; Nammal Gorge, Salt Range, Pakistan..

Tritrypa gen. nov.

Type species—*Tritrypa indentura* n. sp., by monotypy; Changhsingian, Lopingian, Permian; Salt Range, Pakistan.

Diagnosis—Zoaria cylindrical shaped in transverse section (Fig. 3); central tube; autozooecia bud in cycles of three autozooecia from central tube resulting in new autozooecia behind the apertures of previous autozooecia (Figs. 3, 11).

Etymology—The generic name refers to the budding of three autozooecia at the same level of zoarial growth.

Discussion—Differentiated from other genera of Spirotrypidae by budding three autozooecia each cycle (Fig. 3). Both *Tritrypa* and *Didymotrypa* have indented tabular nodes and large numbers of surface spines. *Tritrypa* doesn't have hemisepta like *Didymotrypa* or hook- shaped spines like *Tetratrypa*.

Tritrypa indentura gen. et sp. nov.
figure 11; table 2

Diagnosis—*Tritrypa* with tabular nodes with indented area in top of node.

Etymology—Named for indented tabular nodes on surface.

Types—Holotype, UWBM IP 117918, 81-4-3-451.9 transverse sections N1-N178.

Description—Tubular zoaria (0.319 to 0.326 mm diameter). Elongate apertures rounded at base (proximal end). In transverse section, size of autozooecia proximal to aperture, parallel to surface ranges from 0.107 to 0.114 mm; perpendicular to surface ranges from 0.082 to 0.105mm. Eighteen to 24 spines around autozooecial aperture; surface nodes elongate with indented areas at surface (Fig. 10).

Occurrence—Wargal Limestone (Changhsingian), Permian; Nammal Gorge, Salt Range, Pakistan.

Tetratrypa gen. nov.

Type species—*Tetratrypa hookia* by monotypy; Capitanian, Guadalupian, Permian; Salt Range, Pakistan.

Diagnosis—Quadrate shape in transverse section (Fig. 3); central tube; autozooecia bud in two cycles at 90 degrees to each other (Figs. 3, 12-13). No septa. Hook-shape spines present on surface of zoaria, pointing proximally or distally (Figs. 12-13).

Etymology—Generic name refers to quadrate shape of zoaria in transverse view and autozooecial budding pattern of two cycles at 90 degrees.

Discussion—Budding of autozooecia in two cycles at 90 degrees characterizes *Tetratrypa*. The lack of indented tabular nodes

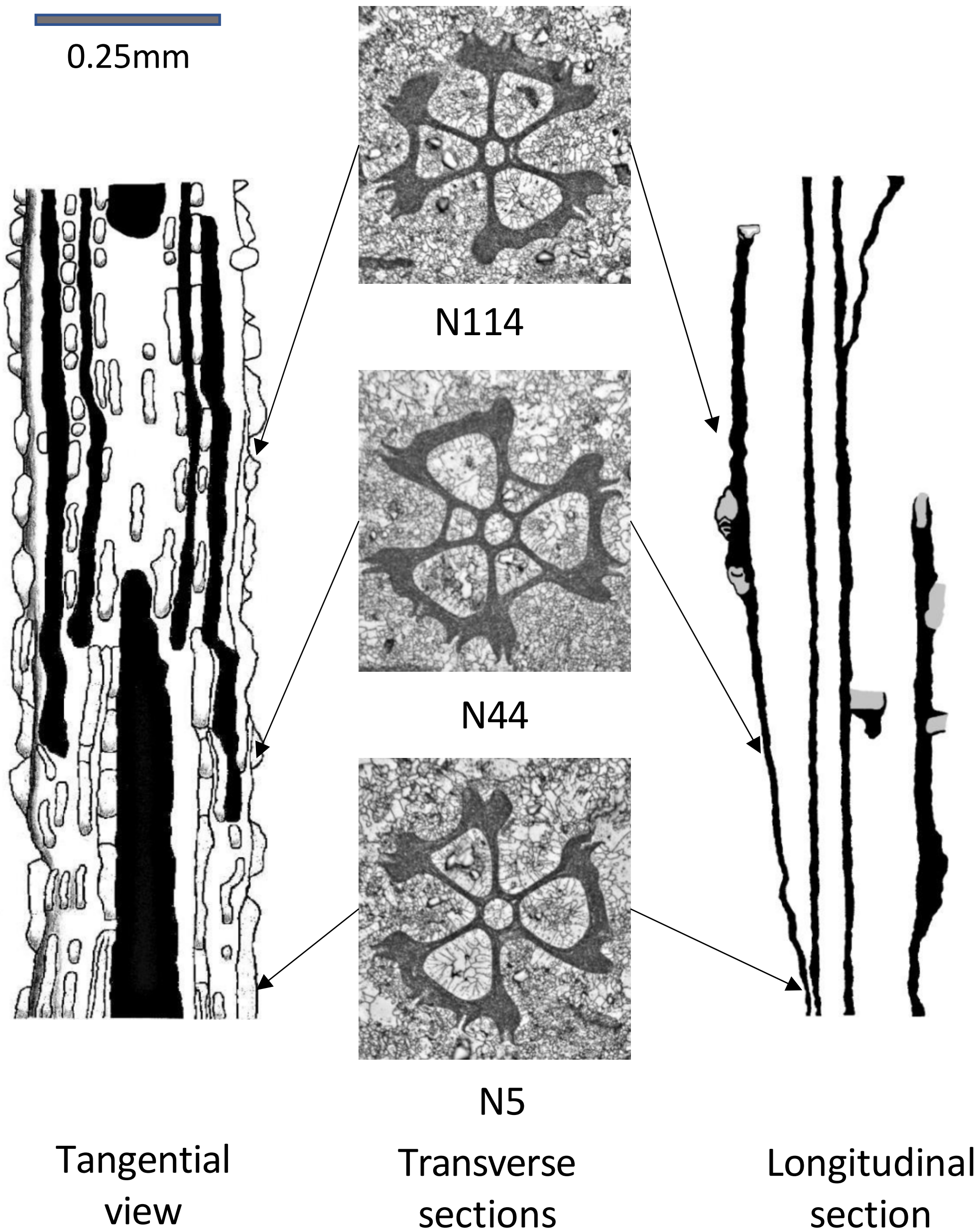


Fig. 11. Tangential, transverse, and longitudinal sections of holotype of *Tritrypa indentura* gen. et sp. nov. Arrow indications, designation of numbers, and scale same as in Figure 7.

Table 2. Summary of numerical analysis of *Tritrypa indentura* gen. et. sp. nov. Abbreviations as in Table 1. All measurements in millimeters.

	Nf	Nm	Xs	Xl	X	SD	CV
Diameter of zoarium	1	4	0.319	0.326	0.322	0.0040	1.26
Diameter of central tube	1	4	0.033	0.039	0.036	0.0024	6.80
Autozooecial chamber diameter proximal to aperture (long dimension)	1	6	0.107	0.114	0.110	0.0030	2.72
Autozooecial chamber diameter proximal to aperture (short dimension)	1	6	0.082	0.105	0.091	0.0076	8.29
Length of autozooecial chamber from central tube	1	1	1.28	1.28	1.28	0.0	0.0
Thickness of outer wall of autozooecia	1	4	0.019	0.027	0.023	0.0035	15.22
Number of autozooecia per 2 mm	1	1	1.3	1.3	1.3		
Aperture length on surface	1	1	0.50	0.50	0.50	0.0	0.0
Aperture width on surface	1	2	0.097	0.107	0.102	0.0070	6.93
Number of spines around autozooecial aperture	1	4	18	24	21.2	2.7538	12.96
Diameter of spines perpendicular to growth of zoarium	1	10	0.011	0.026	0.019	0.0051	26.84
Length of spines parallel to growth of zoarium	1	10	0.032	0.130	0.079	0.0350	44.27

Table 3. Summary of numerical analysis of *Tetratrypa hookia* gen. et. sp. nov. Abbreviations as in Table 1. All measurements in millimeters.

	Nf	Nm	Xs	Xl	X	SD	CV
Diameter of zoarium	10	10	0.211	0.273	0.241	0.0202	8.36
Diameter of central tube	5	35	0.024	0.044	0.034	0.0059	17.04
Autozooecial chamber diameter proximal to aperture (long dimension)	5	45	0.097	0.156	0.126	0.0108	8.60
Autozooecial chamber diameter proximal to aperture (short dimension)	5	45	0.068	0.105	0.084	0.0080	9.47
Length of autozooecial chamber from central tube	3	7	0.308	0.762	0.483	0.1675	34.67
Thickness of outer wall of autozooecia	5	12	0.019	0.037	0.024	0.0045	18.68
Number of autozooecia per 2 mm	3	3	4.0	4.0	4.0		
Aperture length on surface	2	8	0.242	0.378	0.315	0.0504	15.99
Aperture width on surface	4	8	0.133	0.148	0.141	0.0045	3.18
Number of spines around autozooecial aperture	4	11	8	15	12.4	2.3779	19.24
Diameter of spines perpendicular to growth of zoarium	3	14	0.016	0.029	0.023	0.0042	18.06

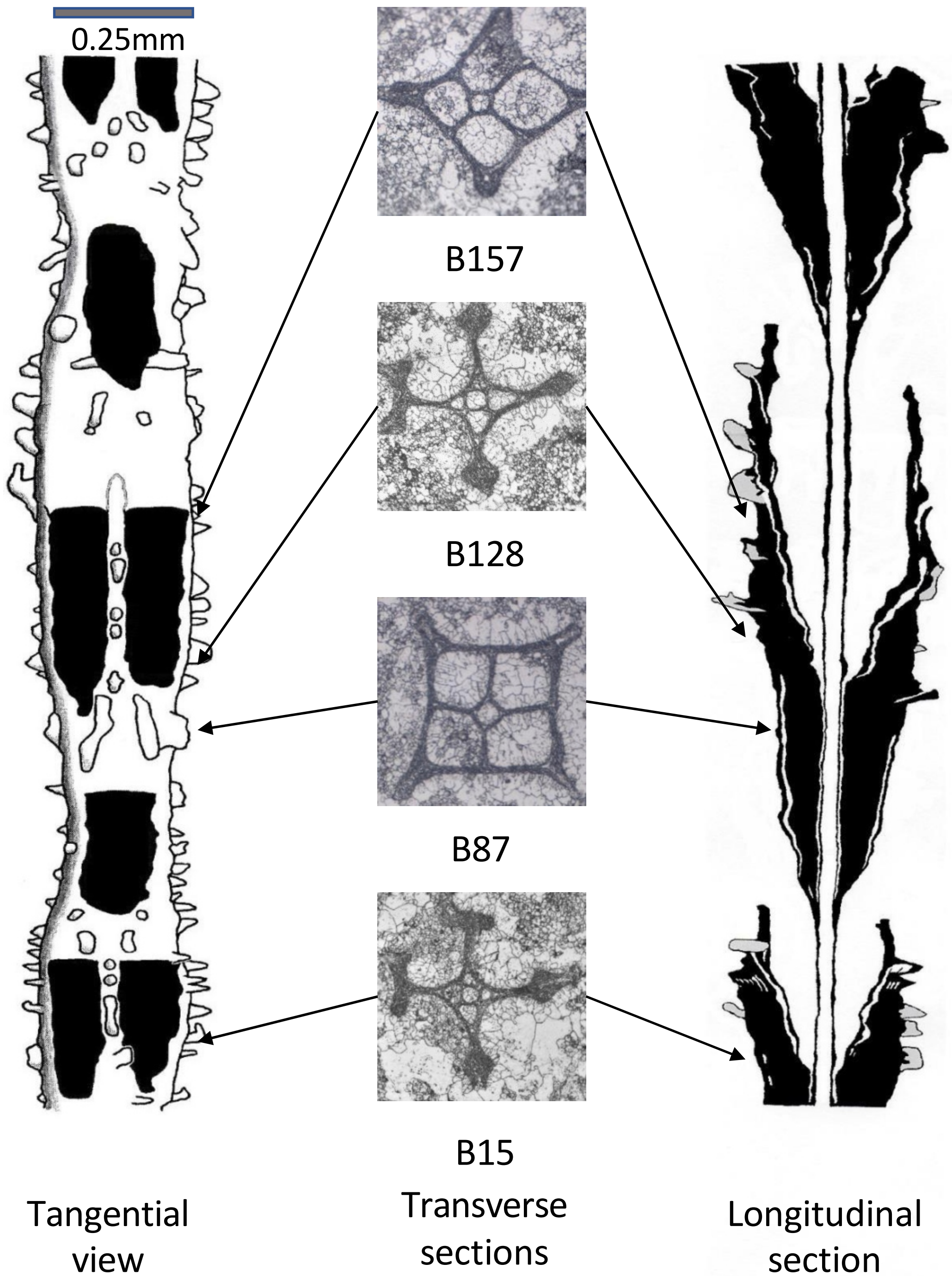


Fig. 12. Tangential, transverse, and longitudinal sections of holotype of *Tetratrypa hookia* gen. et sp. nov. Arrow indications, designation of numbers, and scale same as in Figure 7.

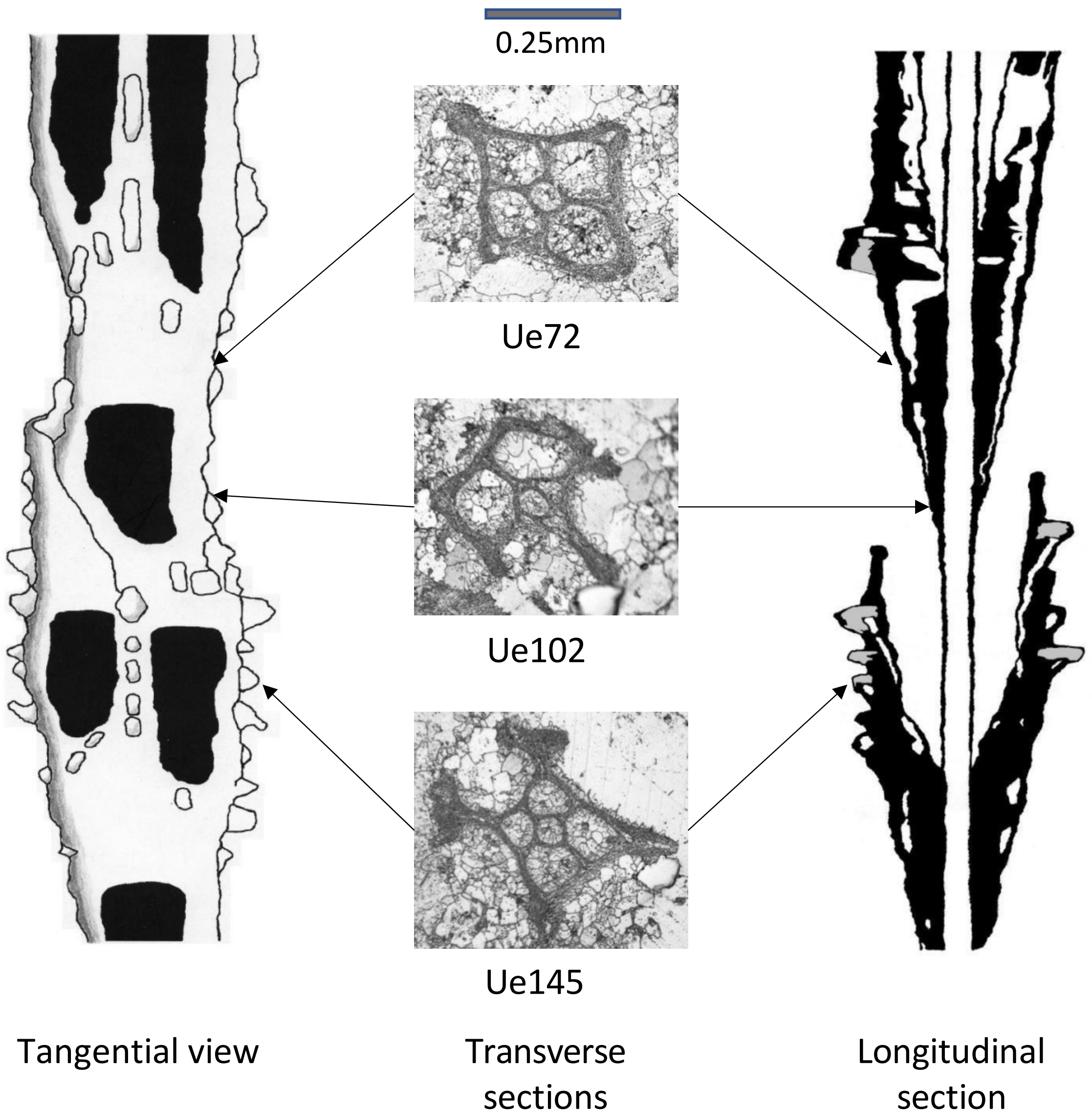


Fig. 13. Tangential, transverse, and longitudinal sections of paratype of *Tetratrypa hookia* gen. et sp. nov. Arrow indications, designation of numbers, and scale same as in Figure 7.

and hemiphragms separate *Tetratrypa* and *Didymotrypa. Tetratrypa* has hook-shaped spines not found in other genera of Spirotrypidae except for *Hexatrypa.*

Tetratypra hookia gen. et sp. nov.
figures 12-13; table 3

Diagnosis—Tetratrypa with proximally pointed apertures and hook-shaped surface spines.

Etymology—Named for the hook-shaped spines found in this species.

Types—Holotype, UWBM IP 117919, 81-3-10-23.8 transverse sections B1-B291; paratype, UWBM IP 117920, 81-3-16-78.2 transverse sections Ue1-Ue204.

Other material—EWUBz 371, 81-3-16-78.2 transverse sections A41-A468; EWUBz 372, 81-2-10-21.7 transverse sections X1-X39.

Description—Small tubular zoaria (0.211 to 0.273 mm diameter) with variable central tube (0.024 to 0.044 mm diameter). Apertures at surface rectangular with proximal end sharply pointed to rounded, ranging from 0.242 to 0.378 mm in length, 0.133 to 0.148 mm in width. In transverse section size of autozooecia proximal to apertural opening, parallel to surface ranges from 0.097 to 0.156 mm, perpendicular to surface ranges from 0.068 to 0.105 mm. Number of spines surrounding aperture ranges from eight to 15. Two to six spines between apertures longitudinally. Shape of spines variable; cone-shaped, tabular, and hook-shaped.

Occurrence—Wargal Limestone (Capitanian) Permian; Nammal Gorge, Chatawala Nala, Salt Range, Pakistan.

Pentatrypa gen. nov.

Type species—Pentatrypa tabularia by monotypy; Capitanian, Guadalupian, Permian; Salt Range, Pakistan.

Diagnosis—Zoaria cylindrical with pentagonal outline in transverse section (Fig. 3); central tube; autozooecia bud in cycles of five autozooecia from central tube resulting in new autozooecia behind apertures of previous autozooecia (Figs. 14-17).

Etymology—The generic name refers to budding of five autozooecia at the same level of zoarial growth.

Discussion—Pentatrypa is distinguished from other genera of Spirotrypidae by budding cycles of five autozooecia from central tube. Large central tube similar to *Hexatrypa, Heptatrypa,* and *Spirotrypa. Pentatrypa* lacks hemiphragms and hook-shaped spines. Number of autozooecia per 2mm similar to *Tetratrypa, Hexatrypa,* and *Spirotrypa.* Aperture length large and highly variable similar to *Spirotrypa*.

Pentatypra tabularia gen. et sp. nov.
figures 14-17; table 4

Diagnosis—Pentatrypa with four to five tabular spines between autozooecial apertures; large highly variable central tube; abundant canals in zooecial walls.

Etymology—Named for the row of tabular spines oriented vertically between the autozooecia.

Types—Holotype, UWBM IP 117921, 81-3-10-19.3 transverse sections Ud1-Ud272; paratype, UWBM IP 117922, 81-3-10-19.3 transverse sections R1-R210; paratype, UWBM IP 117923, 81-3-10-19.3 transverse sections G1-G162; paratype, UWBM IP 117924, 81-3-16-78.2 transverse sections A3 1-A3 75.

Other material—EWUBz 373, 81-3-16-78.2 transverse sections A5 1-A5 78; EWUBz 374, 81.3-10-21.7 transverse sections M1-M114; EWUBz 375, 81-3-16-78.2 transverse sections
V3 1-V3 47.

Description—Large tubular zoaria (0.276 to 0.374 mm diameter) with highly variable diameter central tube (0.031 to 0.078 mm diameter). Apertures rectangular with proximal end rounded to irregular shaped, ranging from 0.261 to 0.859 mm in length, 0.111 to 0.160 mm in width. In transverse section, size of autozooecia proximal to apertural opening,

Table 4. Summary of numerical analysis of *Pentatrypa tabularia* gen. et. sp. nov. Abbreviations as in Table 1. All measurements in millimeters.

	Nf	Nm	Xs	Xl	X	SD	CV
Diameter of zoarium	19	19	0.276	0.374	0.341	0.0265	7.77
Diameter of central tube	7	57	0.031	0.078	0.051	0.0127	24.86
Autozooecial chamber diameter proximal to aperture (long dimension)	7	69	0.093	0.147	0.116	0.0096	8.27
Autozooecial chamber diameter proximal to aperture (short dimension)	7	69	0.072	0.117	0.095	0.0115	12.13
Length of autozooecial chamber from central tube	5	8	0.502	0.909	0.613	0.1274	20.78
Thickness of outer wall of autozooecia	6	14	0.028	0.050	0.040	0.0076	19.08
Number of autozooecia per 2 mm	5	5	2.7	6.0	3.8	1.2817	33.73
Aperture length on surface	6	20	0.261	0.859	0.522	0.1586	30.39
Aperture width on surface	6	8	0.111	0.160	0.131	0.0149	11.39
Number of spines around autozooecial aperture	5	14	10	15	11.6	1.6458	14.19
Diameter of spines perpendicular to growth of zoarium	5	25	0.018	0.038	0.024	0.0047	19.66
Length of spines parallel to growth of zoarium	9	13	0.038	0.072	0.050	0.0077	15.43

Table 5. Summary of numerical analysis of *Hexatrypa nammalia* gen. et. sp. nov. Abbreviations as in Table1. All measurements in millimeters.

	Nf	Nm	Xs	Xl	X	SD	CV
Diameter of zoarium	3	15	0.300	0.419	0.354	0.0406	11.48
Diameter of central tube	3	15	0.039	0.071	0.051	0.0106	20.77
Autozooecial chamber diameter proximal to aperture (long dimension)	3	19	0.091	0.141	0.118	0.0180	15.29
Autozooecial chamber diameter proximal to aperture (short dimension)	3	19	0.085	0.131	0.103	0.0142	13.77
Length of autozooecial chamber from central tube	3	7	0.308	0.762	0.483	0.1675	34.67
Thickness of outer wall of autozooecia	3	13	0.016	0.024	0.019	0.0023	12.34
Number of autozooecia per 2 mm	2	3	4.0	4.0	4.0		
Aperture length on surface	1	5	0.512	0.681	0.597	0.0662	11.09
Aperture width on surface	3	18	0.094	0.138	0.114	0.0103	9.01
Number of spines around autozooecial aperture	2	5	8	12	10.0	1.871	18.70
Diameter of spines perpendicular to growth of zoarium	3	17	0.019	0.032	0.024	0.0039	16.45

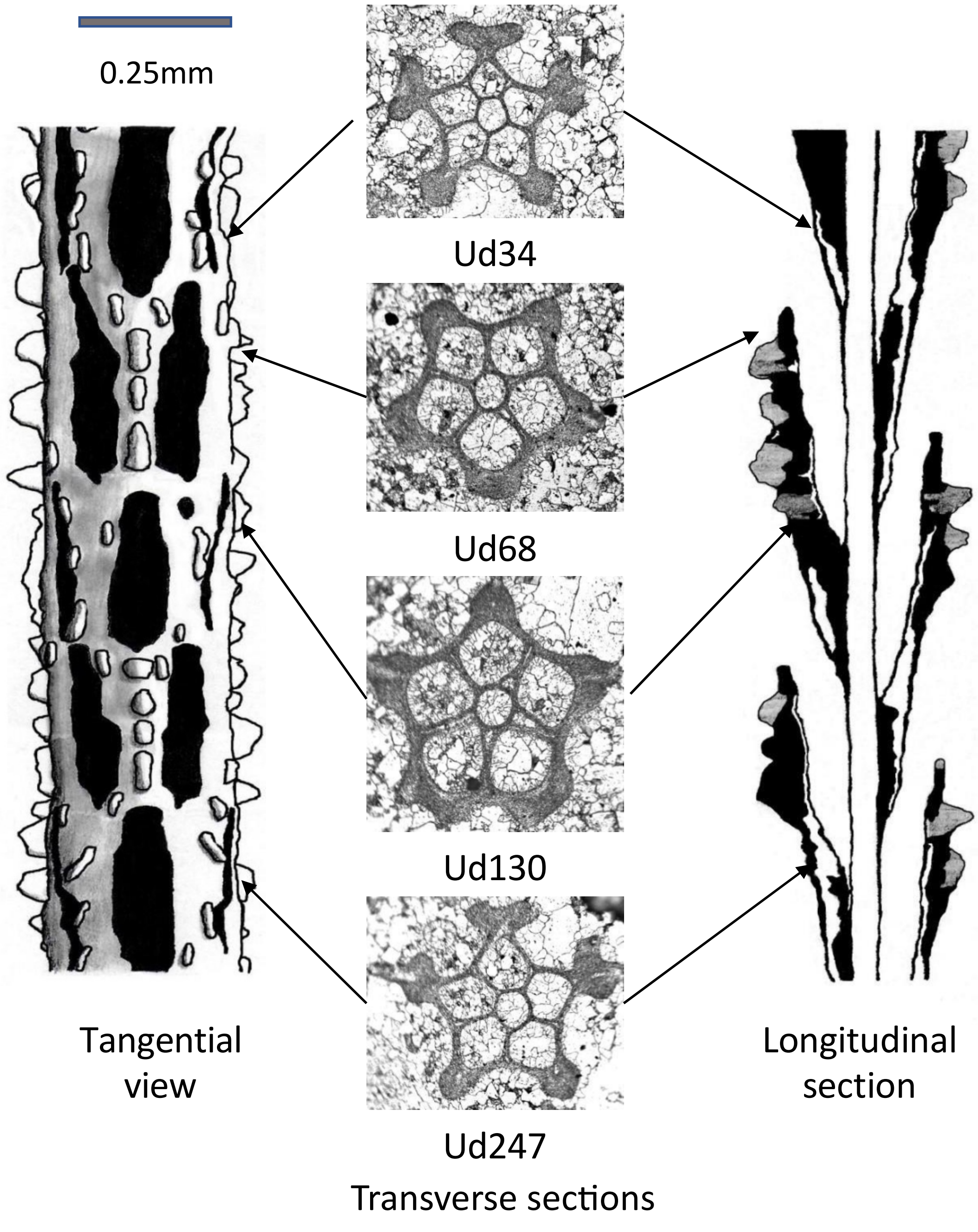


Fig. 14. Tangential, transverse, and longitudinal sections of holotype of *Pentatrypa tabularia* gen. et sp. nov. Arrow indications, designation of numbers, and scale same as in Figure 7.

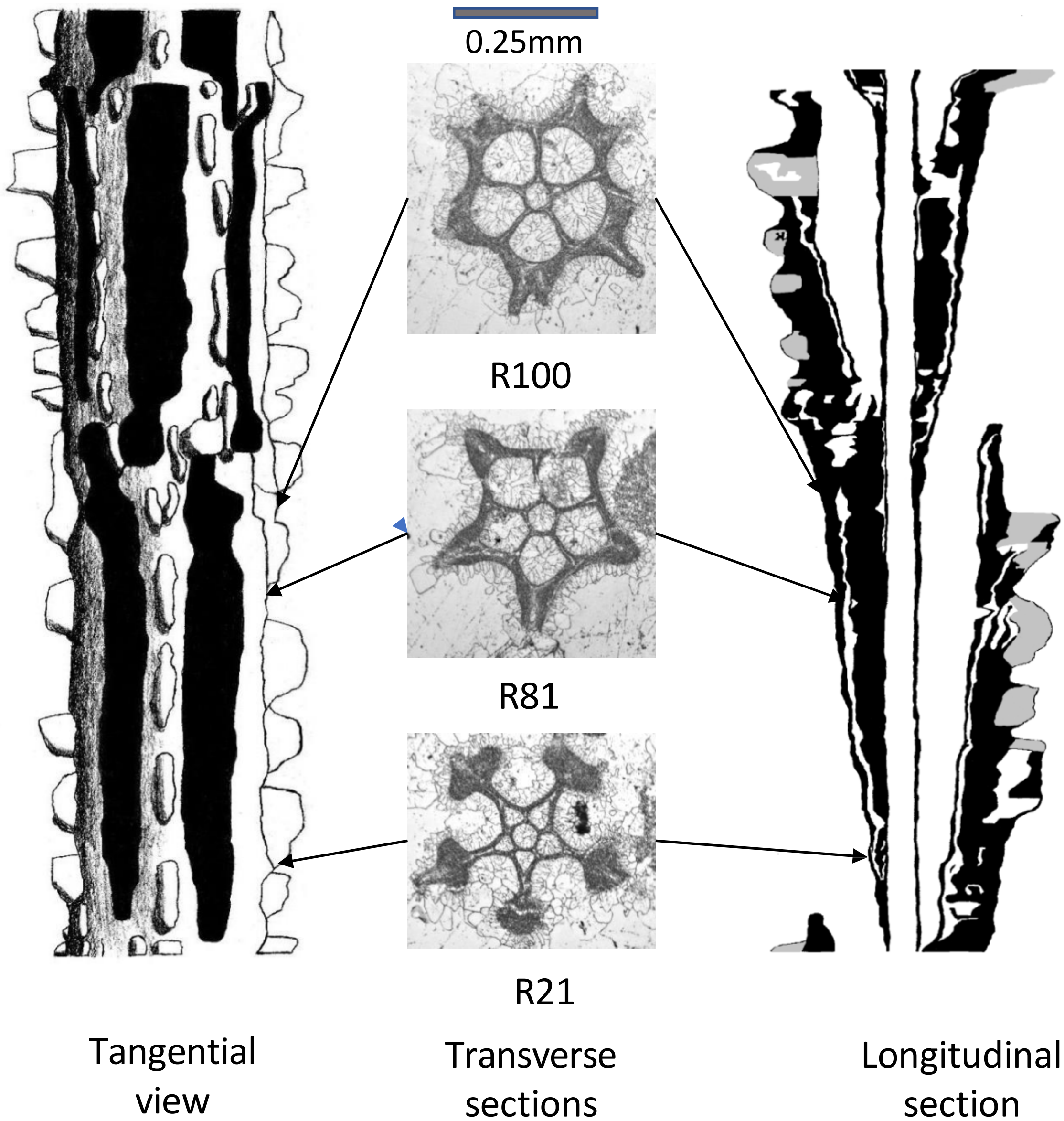


Fig. 15. Tangential, transverse, and longitudinal sections of paratype of *Pentatrypa tabularia* gen. et sp. nov. Arrow indications, designation of numbers, and scale same as in Figure 7.

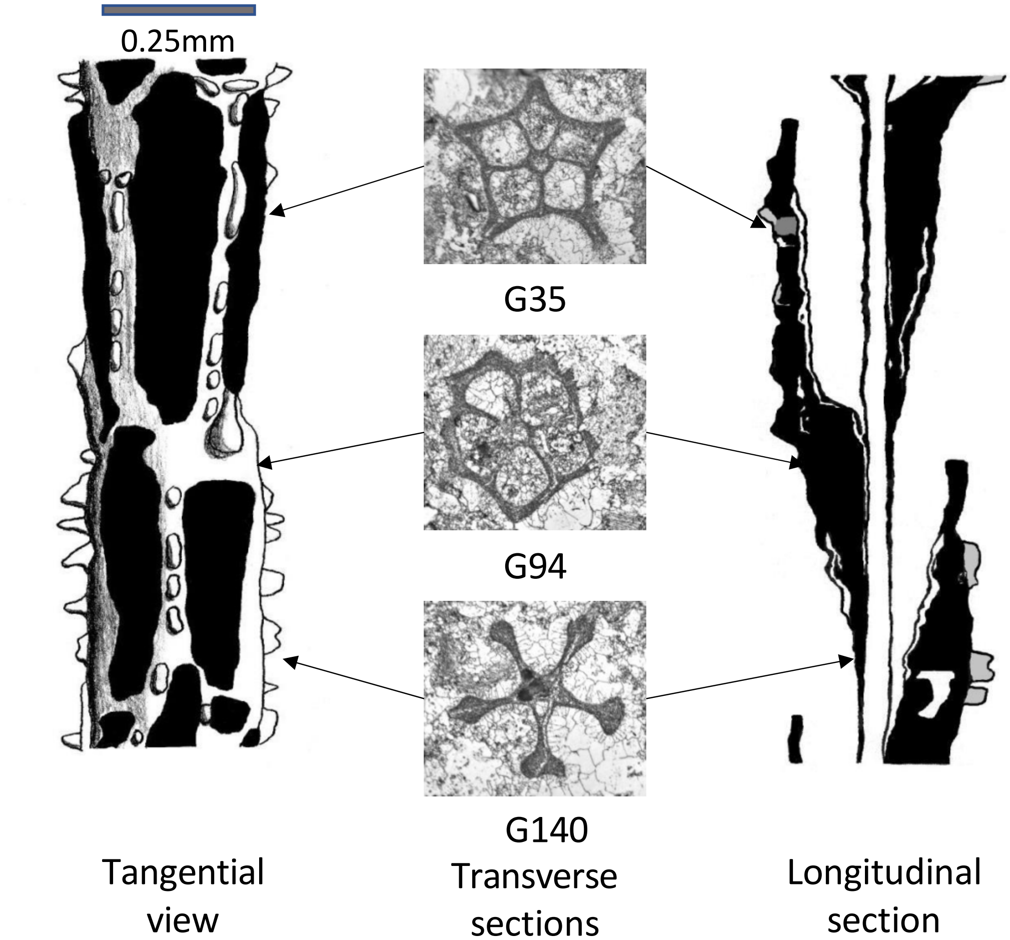


Fig. 16. Tangential, transverse, and longitudinal sections of paratype of *Pentatrypa tabularia* gen. et sp. nov. Arrow indications, designation of numbers, and scale same as in Figure 7.

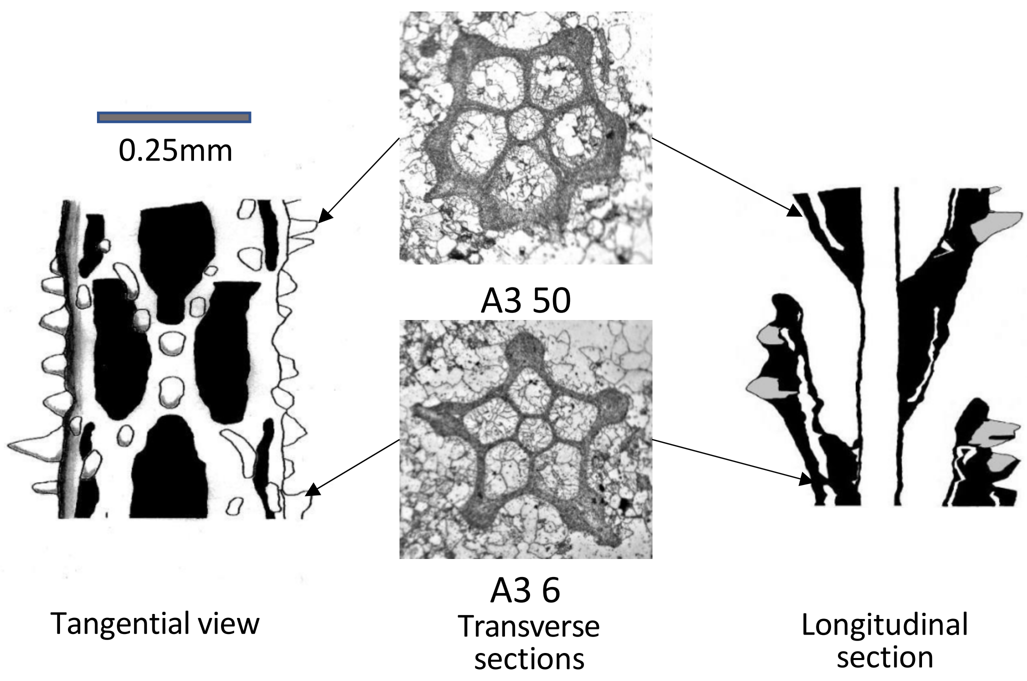


Fig. 17. Tangential, transverse, and longitudinal sections of paratype of *Pentatrypa tabularia* gen. et sp. nov. Arrow indications, designation of numbers, and scale same as in Figure 7.

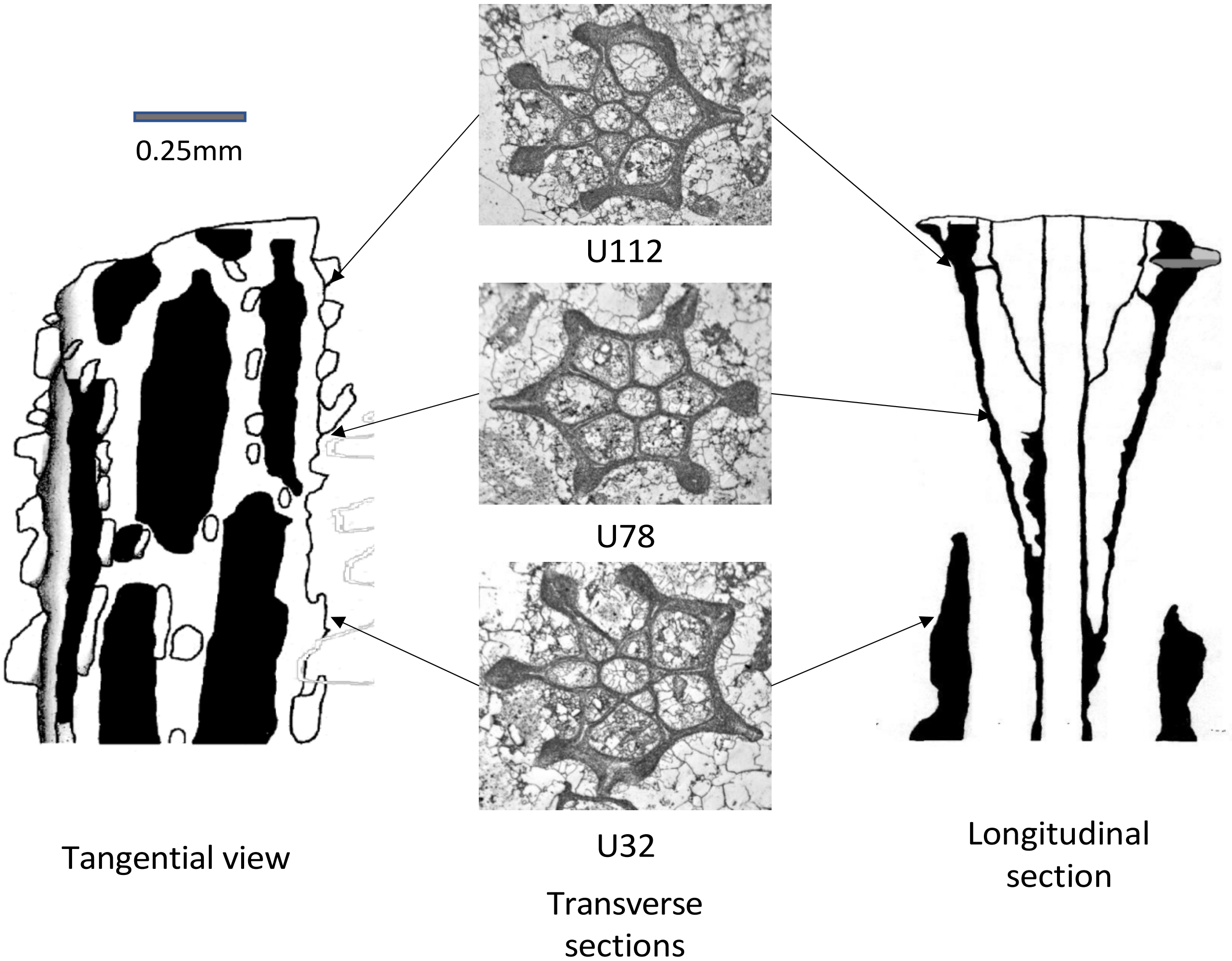


Fig. 18. Tangential, transverse, and longitudinal sections of holotype of *Hexatrypa nammalia* gen. et sp. nov. Arrow indications, designation of numbers, and scale same as in Figure 7.

parallel to surface ranges from 0.093 to 0.147 mm; perpendicular to surface ranges from 0.072 to 0.117 mm. Number of spines surrounding apertures ranges from 10 to 15 with a row of four to five tabular spines between each pair of apertures. Clear calcite filled canals present in zooecial walls (Fig. 14-17; longitudinal sections).

Occurrence—Wargal Limestone, (Capitanian), Permian; Nammal Gorge, Chatawala Nala, Salt Range, Pakistan.

Hexatrypa gen. nov.

Type species—Hexatrypa nammalia by monotrypy; Capitanian, Guadalupian, Permian; Salt Range, Pakistan.

Etymology—The generic name refers to budding of six autozooecia at the same level of zoarial growth.

Diagnosis—Zoaria cylindrical with hexagonal outline in transverse section (Fig. 3); central tube; autozooecia bud in cycles of six autozooecia from central tube resulting in two new autozooecia behind apertures of previous autozooecia (Fig. 18-19).

Discussion—Hexatrypa has autozooecial budding in cycles of six autozooecia. No hemiphragms, indented tabular nodes, or hook-shaped spines. Diameter of zoaria and central tube larger than *Didymotrypa* and *Tetratrypa.* Shape of autozooecia proximal to aperture circular (Fig. 6). Aperture length uniformly large.

Hexatrypa nammalia gen. et sp. nov.
figures 18-19; table 5

Etymology.—Named for occurrence in Nammal Gorge.

Types.—Holotype, UWBM IP 117925, 81-3-16-78.2 transverse sections U1-U125; paratype, UWBM IP 117926, 81-3-16-78.2 transverse sections Ui235-Ui328.

Other material.—EWUBz 376, 81-3-16-78.2 transverse sections V1 1-V1 41.

Diagnosis.—*Hexatrypa* with irregular rectangular apertures; irregular distribution of spines around aperture; rare hook-shaped surface spines.

Description.—Moderate tubular zoaria (0.300 to 0.419 mm diameter) with highly variable central tube (0.039 to 0.071 mm diameter). Aperture length and width constant; shape irregular with proximal end usually pointed. In transverse section size of autozooecia proximal to apertural opening, parallel to surface ranges from 0.091 to 0.141 mm; perpendicular to surface ranges from 0.085 to 0.131. Number of spines surrounding aperture ranges from eight to 12. Shape of spines variable; cone-shaped, tabular, and rare hook-shaped pointed distally.

Occurrence.—Wargal Limestone, (Capitanian), Permian; Nammal Gorge, Salt Range, Pakistan.

Heptatrypa gen. nov.

Type species— *Heptatrypa spinosa* by monotrypy, Captanian, Permian; Salt Range, Pakistan.

Etymology—The generic name refers to the budding of seven autozooecia at the same level of zoarial growth.

Diagnosis—Zoaria cylindrical with seven-sided outline in transverse section (Fig. 3); central tube; autozooecia bud in cycles of seven autozooecia from central tube resulting in two autozooecia behind apertures of previous autozooecia (Fig. 20). Thin eleongate spines surrounding the apertures.

Discussion—Budding of autozooecia in *Heptatrypa* occur in a cycle of seven autozooecia. No hemiphragms or indented tabular nodes present in *Heptatrypa.* Possible hook- shaped spine.

Heptatrypa spinosa gen. et sp. nov.
figures 20; Table 6

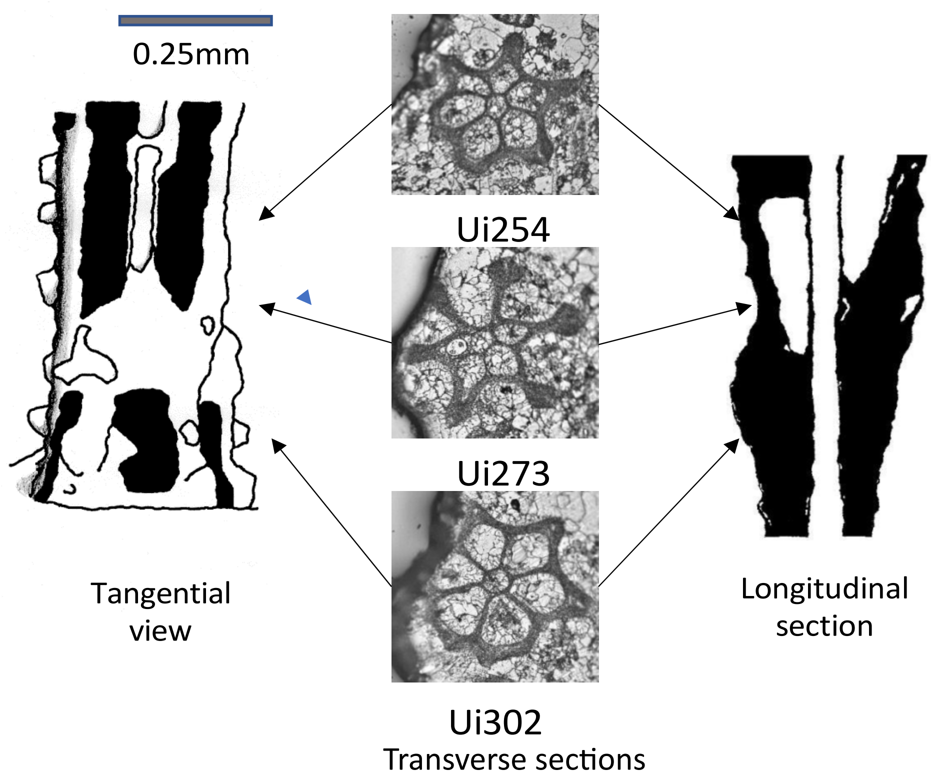


Fig. 19. Tangential, transverse, and longitudinal sections of paratype of *Hexatrypa nammalia* gen. et sp. nov. Arrow indications, designation of numbers, and scale same as in Figure 7.

Table 6. Summary of numerical analysis of *Heptatrypa spinosa* gen. et. sp. nov. Abbreviations as in Table1.All measurements in millimeters

	Nf	Nm	Xs	Xl	X	SD	CV
Diameter of zoarium	1	5	0.431	0.450	0.440	0.0072	1.63
Diameter of central tube	1	11	0.054	0.063	0.059	0.0028	4.82
Autozooecial chamber diameter proximal to aperture (long dimension)	1	17	0.091	0.122	0.104	0.0098	9.43
Autozooecial chamber diameter proximal to aperture (short dimension)	1	17	0.081	0.128	0.102	0.0144	14.14
Length of autozooecial chamber from central tube	1	2	0.270	0.388	0.329	0.0834	25.36
Thickness of outer wall of autozooecia	1	4	0.016	0.026	0.022	0.0043	19.64
Number of autozooecia per 2 mm	1	3	10.0	10.0	10.0		
Aperture length on surface	1	7	0.161	0.261	0.199	0.0370	18.58
Aperture width on surface	1	5	0.084	0.166	0.098	0.0134	13.66
Number of spines around autozooecial aperture	1	5	5	8	6.4	1.402	17.82
Diameter of spines perpendicular to growth of zoarium	1	7	0.019	0.028	0.024	0.0034	13.97

Etymology—Species named for thin elongate spines surrounding apertures.

Types—Holotype, UWBM IP 117927, 81-3-16-78.2 transverse sections A1 1-A1 84.

Diagnosis—*Heptatrypa* with abundant elongate spines between apertures

Description—Moderate tubular zoaria (0.431 to 0.450 mm diameter) with constant central tube (0.054 to 0.063 mm diameter). Apertures rectangular with proximal end blunt to pointed, ranging from 0.161 to 0.261 mm in length, 0.084 to 0.116 mm in width. In transverse section size of autozooecia proximal to apertural opening, parallel to surface ranges from 0.091 to 0.122 mm; perpendicular to surface ranges from 0.081 to 0.128 mm. Number of spines surrounding apertues ranges from five to eight.

Occurrence—Wargal Limestone, Capitanian, Guadalupian, Permian; Nammal Gorge, Salt Range, Pakistan.

Spirotrypa gen. nov.

Type species—*Spirotrypa spiralia*, by monotypy, Capitanian, Guadalupian, Permian; Salt Range, Pakistan.

Etymology—The generic name refers to the spiral budding of autozooecia in the development of the zoarium.

Diagnosis—Zoaria cylindrical with five to seven autozooecia around circumference (Fig. 3); central tube; autozooecia bud spirally from central tube in sequence resulting in increasingsize of autozooecia until opening to surface of zoarium (Figs.21-22); two autozooecia behind apertures of previous autozooecia.

Discussion—Autozooecia bud in a spiral arrangement. Autozooecia develop in a cloakwise direction. Each new autozoocium is positioned slightly distally in the zoarium (Figs.

Table 7. Summary of numerical analysis of *Spriotrypa spiralia* gen. et. sp. nov. Abbreviations as in Table1.All measurements in millimeters

	Nf	Nm	Xs	Xl	X	SD	CV
Diameter of zoarium	3	14	0.238	0.338	0.285	0.0248	8.71
Diameter of central tube	3	15	0.038	0.052	0.044	0.0047	10.59
Autozooecial chamber diameter proximal to aperture (long dimension)	3	26	0.086	0.132	0.110	0.0149	13.51
Autozooecial chamber diameter proximal to aperture (short dimension)	3	26	0.078	0.109	0.091	0.0077	8.51
Length of autozooecial chamber from central tube	2	6	0.512	1.050	0.805	0.2520	31.31
Thickness of outer wall of autozooecia	3	8	0.044	0.097	0.076	0.0190	24.93
Number of autozooecia per 2 mm	2	5	2.5	4.0	3.4	0.822	24.16
Aperture length on surface	2	14	0.300	0.838	0.539	0.1795	33.30
Aperture width on surface	3	11	0.070	0.138	0.104	0.0229	21.98
Number of spines around autozooecial aperture	3	13	7	12	8.9	1.4412	16.19
Diameter of spines perpendicular to growth of zoarium	3	14	0.019	0.038	0.024	0.0062	25.82

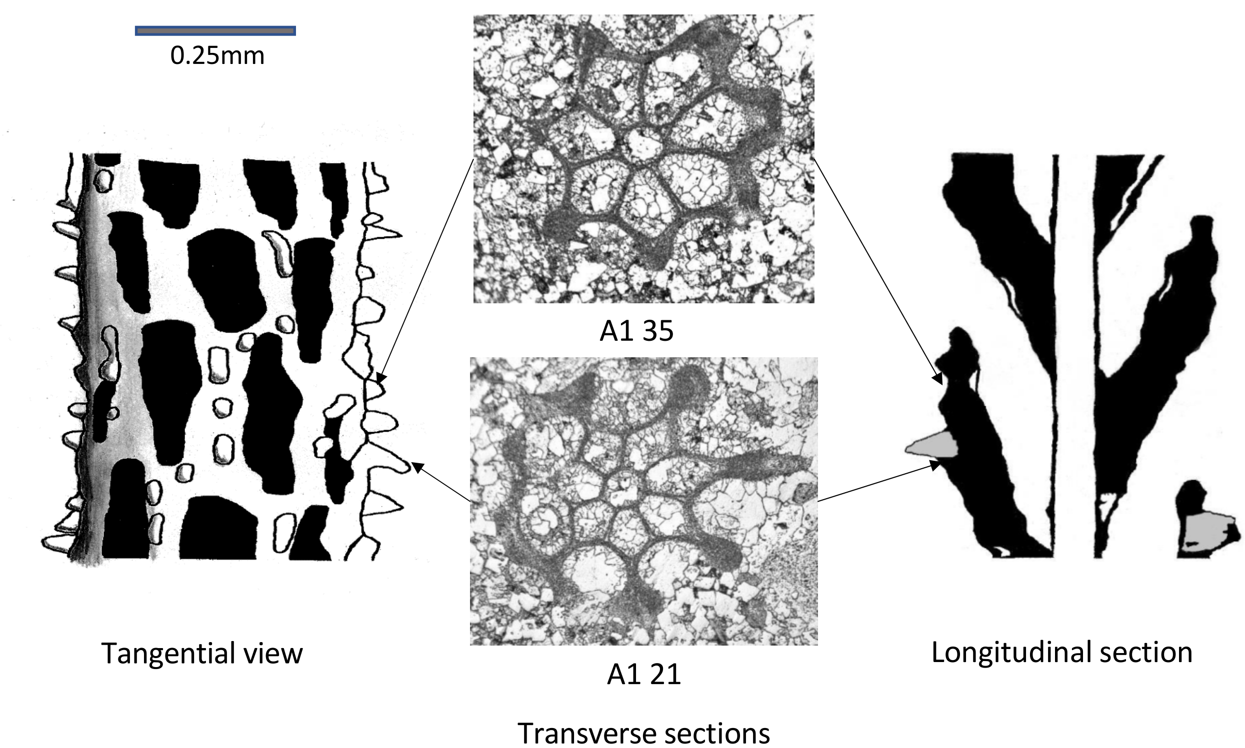


Table 7. Summary of numerical analysis of *Heptatrypa spinosa* n. gen., n. sp. Abbreviations as in Table1.All measurements in millimeters

21-22). No hemiphragms, indented tabular nodes, or hook-shaped spines. Large variable apertues.

Spirotrypa spiralia gen. et sp. nov.
figures 20-1; table 7

Diagnosis—Spirotrypa with spirally developed autozooecia in transverse and tangential view; abundant spines around apertures; abundant clear calcite canals in exozonal wall.

Etymology—species named for spiral appearance of autozooecia in tangential view from proximal to distal direction (Fig. 19).

Types—Holotype, UWBM IP 117928, 81-3-16-78.2 transverse sections Ub1-Ub310; paratype, UWBM IP 117929, 81-3-10-21.7 transverse sections D1-D233.

Other material—EWUBz 377, 81-3-10-21.7 transverse sections W1-W43.

Description—Moderate tubular zoaria (0.238 to 0.338 mm diameter) with constant diameter central tube (0.038 to 0.052 mm diameter). Apertures rectangular to elongated proximally, ranging from 0.300 to 0.838 mm in length, 0.070 to 0.138 mm wide. In transverse section, size of autozooecia proximal to apertural opening, parallel to surface ranges from 0.086 to 0.132 mm; perpendicular to surface ranges from 0.078 to 0.109 mm. Number of spines surrounding the apertures ranges from seven to 12. Shape of spines cone-shaped or tabular.

Occurrence—Wargal Limestone, Capitanian, Guadalupian, Permian; Nammal Gorge, Chatawala Nala, Salt Range, Pakistan.

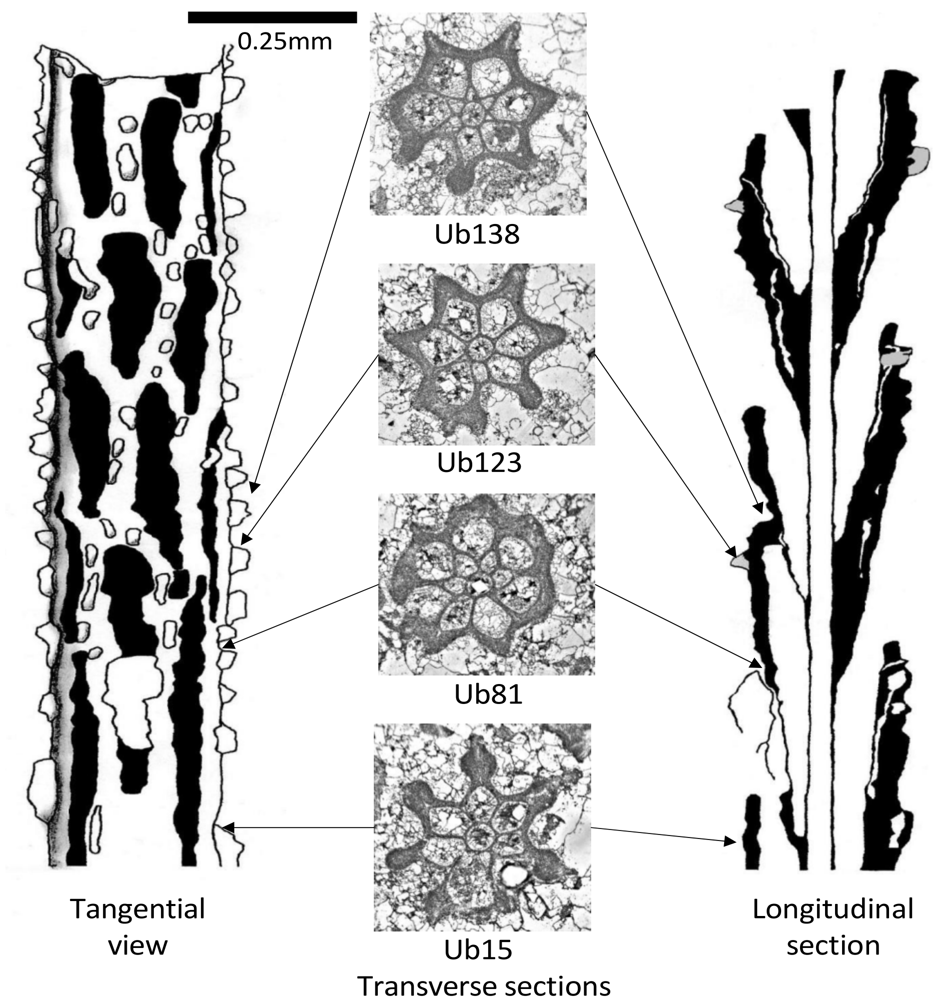


Fig. 21. Tangential, transverse, and longitudinal sections of holotype of *Spirotrypa spiralia* gen. et sp. nov. Note the spiral increase in size of autozooecia in anticlockwise direction. Arrow indications, designation of numbers, and scale same as in Figure 7.

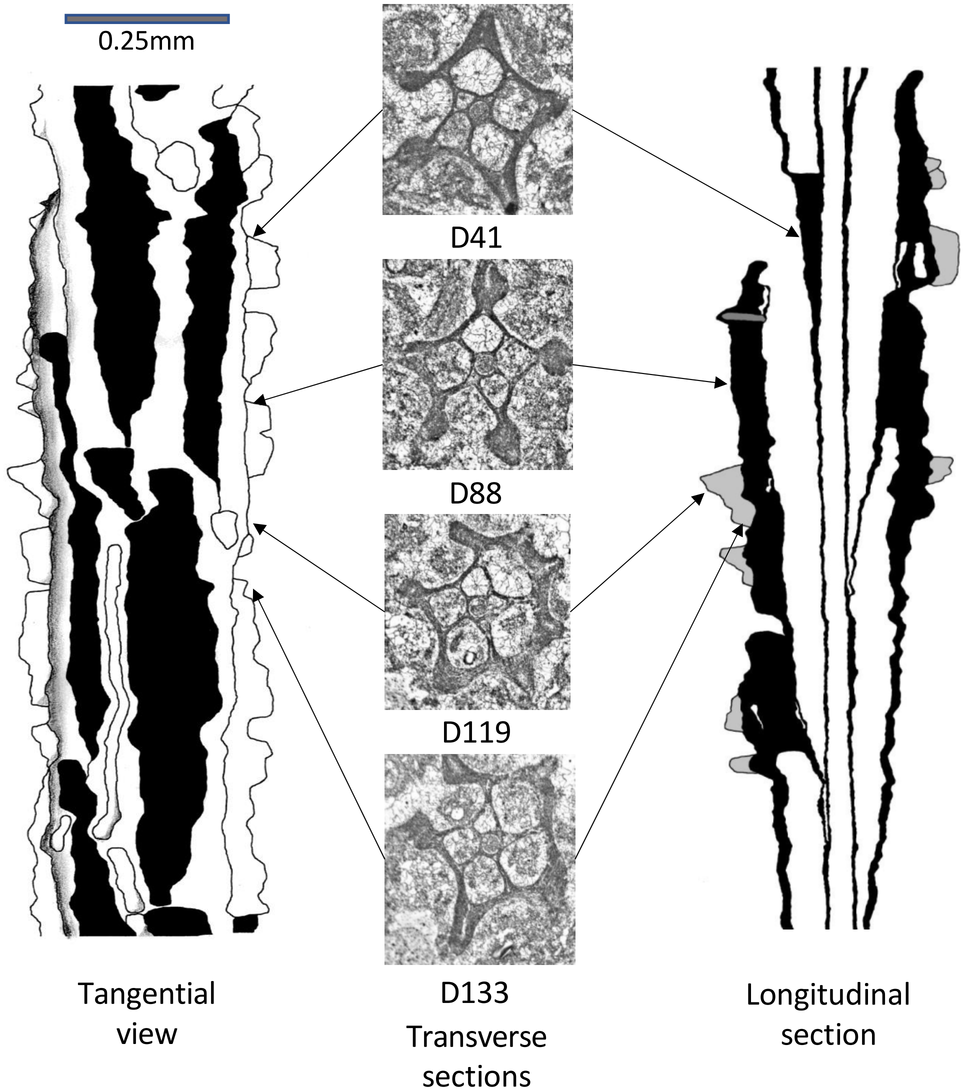


Fig. 22. Tangential, transverse, and longitudinal sections of paratype of *Spirotrypa spiralia* gen. et sp. nov. Arrow indications, designation of numbers, and scale same as in Figure 7.

7. Conclusion

The amount of time required to produce the series of acetate peels; to measure and plot the data points to create the longitudinal and tangential sections; and to measure the morphological structures of these microbryozoans is extensive. Other workers question why we haven't used digital analyses by allowing computers to take the transverse sections and recreate three dimensional views of these microbryozoans. In fact, we have provided sequences of transverse sections to three different computer learned people who have all failed in this attempt. Since the rock matrix surrounding the bryozoan wall material is difficult for the computer to recognize the difference in these peels, the time required to "clean" them up is very time consuming. Up to this point, we have not been able to find anyone who has been able to computerize our photographs and produce the desired results. Critical to our reconstructions of the microbryozoan zoaria is the central tube in the Spirotrypidae. In order to tie each additional peel to the reconstruction, the continuous central tube is the constant point of reference. In the microbryozoans noted in the Amsden Formation previously, there is no central tube for reference. Therefore, the reconstruction of zoaria in the Amsden material is more tenuous and probably less accurate by trying to use various morphological features of the previous peels.

8. Acknowledgments

This study would never have been possible without the assistance of Mohammad Haneef and Obaid-Ur-Rahman in collecting the samples of the Wargal Limestone from the Salt Range of Pakistan in 1980-81. Haneef and Obaid spent many days helping the senior author measure and collect samples under very difficult and trying conditions.

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