CHITINOZOA FROM THE ORDOVICIAN SYLVAN SHALE OF THE ARBUCKLE MOUNTAINS, OKLAHOMA

by W. A. M. JENKINS

ABSTRACT. Chitinozoa referable to nine genera and twelve species (five new) are recorded from the Sylvan Shale of the Arbuckle Mountains in southern Oklahoma. They provide for the first time a means of dating, biostratigraphically subdividing, and correlating the entire formation. Its chitinozoan fauna indicates that the Sylvan Shale is of Upper Ordovician age throughout and confirms with additional fossil evidence the age of the lower beds. No *abrupt* changes break the general continuity of the chitinozoan succession but on the basis of *gradual* changes in the composition of its chitinozoan fauna the Sylvan Shale may be divided into three biostratigraphical units. The fauna occurs throughout the Arbuckle Mountains and is recognizable in the subsurface of western Texas and in the Maquoketa Formation of eastern Iowa. It differs strikingly from the fauna in the underlying Viola and Fernvale Limestones, and from the faunas in the overlying formations of the Silurian–Devonian Hunton Group. The occurrence of reworked Sylvan chitinozoans in upper Sylvan strata indicates that during late Sylvan time uplift (hitherto unsuspected) took place, at least locally, in the southern mid-continent.

The fauna is described systematically. *Clathrochitina* Eisenack 1959 is used in its original sense; *Plectochitina* Cramer 1964 is a junior synonym. *Sagenachitina* gen. nov. is proposed for species, hitherto referred to *Clathrochitina*, whose basal margins support finely divided networks. *Acanthochitina rashidi, Ancyrochitina merga, Clathrochitina sylvanica, Cyathochitina agrestis*, and *Sphaerochitina lepta* are new species.

THIS account of chitinozoans from the Sylvan Shale is the second of two investigations directed primarily at establishing an Upper Ordovician chitinozoan reference section in the Arbuckle Mountains of southern Oklahoma. In a stratigraphical sense it is the continuation of an earlier study (Jenkins 1969) devoted to chitinozoans from the underlying Viola and Fernvale Limestones. An incidental objective was to provide, for the first time, a means of dating and correlating the entire formation.

The Sylvan Shale is the youngest Ordovician formation in the Arbuckle Mountains, and rests unconformably upon the slightly older Viola–Fernvale limestone succession. It was chosen for this investigation primarily because it contains large numbers of well-preserved chitinozoans at practically all stratigraphical levels, but several additional factors also favoured its selection as a standard for stratigraphical reference. In particular, it is a distinctive lithostratigraphical unit separated by regional unconformities and by its sharply contrasting lithology from thick carbonate sequences above and below. In the subsurface the Sylvan Shale extends across most of Oklahoma into north-western Texas and southern Kansas and has been widely used as a marker horizon in the subsurface mapping of an otherwise unbroken sequence of Ordovician to Devonian limestones.

The formation crops out widely within the Arbuckle Mountains, for which reason the samples were collected there. It is particularly well exposed and free from faulting in a narrow outcrop 14 miles (22 km.) long, running west-north-west from Ravia to the Washita River along the steeply dipping southern flank of the Sycamore Creek Anticline (text-fig. 1). Chitinozoans from this outcrop form the basis of the present study.

In this paper, for reasons presented elsewhere (Jenkins 1969, pp. 5, 6), the base of the *Nemagraptus gracilis* Zone (or its correlatives) is taken as the lower limit of the Upper Ordovician. Thus defined, the Upper Ordovician includes the basal beds of the North

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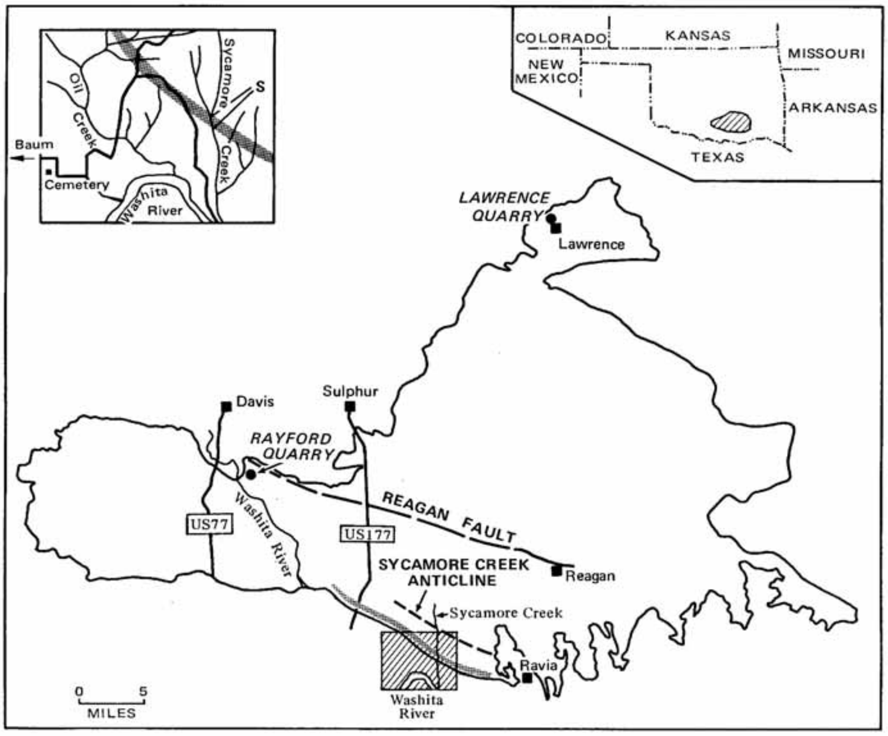


TEXT-FIG. 1. Showing the outcrop (outlined) and structural features of the pre-Pennsylvanian rocks in the Arbuckle Mountains. The shaded portion of the index map of Oklahoma delineates the area shown. The upper left inset map (represented by the shaded rectangle in the chart) shows the outcrop (stippled) of the Sylvan Shale exposed in the Sycamore Creek Anticline, and the road from Baum (on U.S. Highway 177) to the section (S) which provided the rock samples for this study. Compiled from Ham, W. E. 1955, *Geology of the Arbuckle Mountain Region*, Guide Book III; Ham, W. E. *et al.*, 1954, *Geologic Map and Sections of the Arbuckle Mountains, Oklahoma*, Guide Book III. Both published by the Oklahoma Geological Survey.

American Black River Stage and their correlatives (Twenhofel *et al.* 1954; Berry 1960*a*, *b*; Kay 1960, p. 30) at the base of the Caradoc Series in Britain.

PREVIOUS RESEARCH

Previous publications concerned with chitinozoans from the Sylvan Shale are limited to two notes (Wilson 1958, Wilson and Hedlund 1964) and an abstract (Wilson and Hedlund 1962). The latter is from Hedlund's (1960) substantial account of chitinozoans, acritarchs, and scolecodonts, which was submitted as a thesis for the Master of Science degree to the University of Oklahoma. Although unpublished, Hedlund's work has remained for a decade the chief source of information about organic-walled microfossils in the Sylvan Shale, and the only attempt to describe them systematically.

The possibility exists, however, that chitinozoans were encountered in fossil residues of the Sylvan Shale as early as 1930. A short publication by Thomas (1930) contains (p. 87) not only a very early (perhaps the earliest) reference to organic-walled microfossils in the Lower Palaeozoic of Oklahoma, but almost certainly a passing reference to chitinozoans. I have been unable to ascertain whether or not this paper preceded Eisenack's of the same year, in which chitinozoans (though not named as such) were introduced to the scientific literature. On account of this paper's apparent obscurity outside North America the following relevant passage is reproduced.

> . . .I also have permission from Mr. S. W. Lowman, micropaleontologist for the Midcontinent Petroleum Corporation, to announce a discovery he has recently made concerning the Sylvan in Oklahoma and Kansas. He has found that after completely dissolving the shale in concentrated hydrochloric acid the residue will yield microfossils which are invisible upon ordinary microscopic examination. He discovered organisms similar to *Sporangites* found in the Woodford [Formation, which is Devonian–Mississippian]. One species is about as large as the disc-like *Sporangites huronense* and is found in the upper Sylvan from central Kansas to the Arbuckles. Another species about twice as large as the above has been found in the upper Sylvan on the outcrop and in wells near the Arbuckles. A few spindle-shaped forms have been found. There are reasons to believe that these are plant spores and there are also arguments in favor of the theory that they are graptolitic in nature (Thomas 1930, p. 87).

In all probability the 'spindle-shaped forms' are chitinozoans for, to my knowledge, no organic-walled microfossils in the Sylvan Shale other than certain chitinozoans (and possibly a few netromorph acritarchs) could be interpreted, however broadly, as spindle-shaped. It is interesting to learn from Thomas's paper that the speculation about the natural affinities of the Chitinozoa, which has continued to the present day, had already started before the group was formally established and named by Eisenack in 1931.

GENERAL STRATIGRAPHY

Lithology and fauna. Throughout the Arbuckle Mountains the lower part of the Sylvan Shale, up to *c.* 130 ft. (40 m.) thick, is a hard, splintery, very fissile, brown to dark grey shale containing graptolites which are particularly abundant near the base. By contrast, the upper part of the formation, up to 200 ft. (61 m.) thick, is mainly a soft, weakly fissile to concretionary, greenish-grey shale, and is apparently devoid of macrofossils. The topmost 30 ft. (9 m.) is a soft, massive, highly pyritic, light green claystone, which disaggregates completely in water and is, for this reason, only ever temporarily exposed. The Sylvan Shale is generally slightly calcareous, and may be highly calcareous locally, particularly in its upper 100 ft. (30 m). Dolomite beds a few inches thick occur irregularly throughout the formation, and in the lower part two beds of dense brown dolomite, each 1–3 ft. (0·30–0·91 m.) thick, extend laterally over a wide area. Outcrops of the Sylvan Shale are strikingly delineated by sharp changes in the topography, soil, and vegetation of the limestone country within which they are exposed.

The formation contains, in addition to one species of brachiopod (Cooper 1956, p. 244) and seven species of graptolites (Decker 1935, 1945; Ruedemann 1947, pp. 90–2, 100) in its lower part, a rich fauna of chitinozoans and acritarchs throughout. Generally, however, other fossils are lacking, and the upper Sylvan in particular is seemingly devoid of macrofossils.

The lithology and fauna of the Sylvan Shale indicate that it was laid down in tranquil waters, and suggested to Ham (1969, p. 11) that it was deposited in deeper waters than all other pre-Mississippian formations in the Arbuckle Mountains. It is the only pre-Upper Devonian shale unit, moreover, to persist throughout the Arbuckle Geosyncline and to extend beyond it over much of the southern mid-continent.

Pattern of deposition. Within the Arbuckle Mountains the Sylvan Shale's broad pattern of deposition is similar to that of the Viola Limestone (Jenkins 1969, p. 3). The Sylvan sediments in the south-western Arbuckle Mountains were laid down in the rapidly subsiding basin of the Arbuckle Geosyncline, whereas those to the north and east of a line now approximately followed by the Reagan Fault (text-fig. 1) were deposited on a slowly subsiding geosynclinal shelf. This led to the accumulation of less sediment in the north-east than in the south-west and explains the general thinning of the formation north-eastward across the Arbuckle Mountains from a maximum of 325 ft. (99 m.) in the basin to 150–175 ft. (45–53 m.) on the shelf (Ham 1969, p. 10).

Stratigraphical relations. Over a large part of Oklahoma, including the Arbuckle Mountains, regional unconformities separate the Sylvan Shale from a thick sequence of older Ordovician limestones below, and a succession of Silurian and Devonian carbonate formations above. The Sylvan lies everywhere upon the Fernvale Limestone, and the sharp contact is well exposed in Sycamore Creek (text-fig. 1), map reference SW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 27, T. 3 S., R. 4 E., Johnston County, Oklahoma. The dips of the two formations appear to be the same, but close examination reveals that the top of the Fernvale Limestone is an erosion surface that had been extensively weathered before the shale was laid down. A 2–3 in. (5–8 cm.) thick band of oxidizing pyritic 'rubble', containing phosphatized pebbles, locally marks the base of the shale, as at Sycamore Creek, and (Ham, personal communication, May 1969) is particularly well developed as a pyritic phosphate conglomerate, containing dolomite pebbles, in the road-cut entrance to Rayford Quarry (text-fig. 1), map reference NW$\frac{1}{4}$ NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 28, T. 1 S., R. 2 E., Murray County, Oklahoma. This and related late Ordovician unconformities are given some prominence, and discussed in a regional context, by Ham and Wilson (1967, pp. 350–2) in a comprehensive account of Palaeozoic tectonic disturbances in the central United States.

Almost everywhere within the Arbuckle Mountains the Sylvan Shale is unconformably overlain by Silurian or Lower Devonian limestones (Amsden 1960, panel III). These are extremely thin within the Sycamore Creek Anticline, however, and locally, as at Sycamore Creek, they have been entirely removed by mid-Devonian erosion; the black shales and bedded cherts of the Upper Devonian–Mississippian Woodford Formation lie directly upon the Sylvan Shale. The Woodford Formation, which is 350–560 ft. (107–171 m.) thick in the Arbuckle Mountains, has been dated by conodonts as ranging in age from Frasnian (Upper Devonian) to Kinderhookian (Lower Mississippian); the Mississippian part of the formation generally is less than 1 ft. (0·30 m.) thick, and exceptionally at least 10 ft. (3 m.) thick (Hass and Huddle 1965).

Age and correlation. The Sylvan Shale was dated Upper Ordovician by Decker (1935), on the basis of graptolites confined to the lower part of the formation. The greater part of the Sylvan Shale has yielded no macrofossils, however, but was placed in the Ordovician on the basis of its association with the lower Sylvan. Although Decker's age determination for the lower graptolitic Sylvan has generally been accepted, the age of the overlying 'unfossiliferous' beds, at least 200 ft. (61 m.) thick in the south-western Arbuckle Mountains, has not hitherto been demonstrated.

Collection and preparation of material. Samples were collected at stratigraphical intervals of 20 ft. (6·10 m.) throughout the Sylvan Shale succession exposed in the bed and banks of Sycamore Creek (text-fig. 1), map reference SW¼ SE¼ sec. 27, T. 3 S., R. 4 E., Johnston County, Oklahoma, commencing 1 ft. above the Fernvale Limestone–Sylvan Shale contact. The latter serves as an easily recognizable reference datum, and samples are numbered according to their original stratigraphical positions (measured in feet) above it. For example, sample Sy280 is from a stratigraphical level 280 ft. above the contact, the prefix 'Sy' indicating that it is from Sycamore Creek. These samples are briefly described in the appendix.

The collection of regularly spaced samples was made easy at Sycamore Creek by the steep inclination of the beds and the absence of faulting. The relatively resistant shales in the lower part of the formation are well exposed in the bed and steep banks of the creek, and samples of these were collected without difficulty. To obtain samples of the softer shales and claystones near the top of the formation, however, it was necessary to dig through as much as 2 ft. (0·6 m.) of Recent alluvium. The total thickness of the Sylvan Shale at Sycamore Creek, from its sharp contact with the Fernvale limestone below, to its equally sharp contact with the Woodford Formation above, was carefully measured by Mr. J. A. Turnbull and myself, and found to be 305 ft. (93 m.), slightly less than Decker's (1935, p. 698) figure of 320 ft. (97·5 m.).

In order to determine how much the character of the Sylvan chitinozoan fauna varies regionally several samples were collected at widely scattered localities (q.v., p. 283) throughout the Arbuckle Mountains. A few figured specimens are from outcrops along U.S. Highway 77 about 4 miles (6·4 km.) south of Davis (text-fig. 1), map reference sec. 30, T. 1 S., R. 2 E., Murray County, Oklahoma. Their reference numbers are prefixed 'Da'.

The chitinozoans were prepared for microscopical examination according to the method outlined by Jenkins (1967, pp. 439–41), and furnished with reference numbers in the manner described for the Viola and Fernvale specimens of an earlier study (Jenkins 1969, p. 7). Most of the preparations, including all the type material, and portions of each rock sample, are housed in the Micropalaeontology Laboratory, Department of Geology, The University, Sheffield, England.

SYSTEMATIC PALAEONTOLOGY

Order CHITINOZOA Eisenack 1931
Genus ACANTHOCHITINA Eisenack 1931 emend. Jenkins 1967

Type species. Acanthochitina barbata Eisenack 1931 (by original designation), Ordovician, Baltic.

Acanthochitina rashidi sp. nov.

Plate 47, fig. 20; Plate 48, figs. 1, 2; text-fig. 2

Holotype. Plate 48, figs. 2*a*, *b*. Specimen Sy80/2/1/B; Sylvan Shale, 80 ft. (24·38 m.) stratigraphically above base, Sycamore Creek.

Diagnosis. Small conical to pyriform test. Maximum diameter about four-fifths total length; base convex, margin rounded. Neck weakly differentiated from chamber, short, tapering; commonly not developed. Aperture equal to, or slightly greater than, half maximum diameter. Numerous closely spaced slender processes; arms of adjacent processes united, forming a complete reticulum that stands as high as 12 μ above surface of test wall.

Dimensions (*in microns*). 25 specimens measured.

	Total length	*Maximum diameter*	*Apertural diameter*
Holotype:	128	89	53
Range:	105–158	81–106	40–63
Mean:	123	93	51

Remarks. Acanthochitina rashidi is considered as a separate species because it falls well outside Jansonius's (1964, p. 909) definition of *Kalochitina multispinata*. Wherever it has been found, however, *A. rashidi* makes up continuously intergrading populations with *K. multispinata* and many transitional forms occur. The two species are distinguished arbitrarily and solely on the basis of their ornaments. Their close relationship is not reflected in the strictly empirical system of classification followed here, however, and they are unavoidably referred to different genera.

TEXT-FIG. 2. *Acanthochitina rashidi* sp. nov. Lateral profile, ×400. For the sake of clarity only the ornament seen in profile is shown.

Comparison. In *Hercochitina downiei* Jenkins 1967 processes stand in longitudinal rows, and most frequently are connected only to those longitudinally adjacent to them. *A. rashidi* is much smaller than the type species (total length of 25 British examples 300–485 μ, mean 408 μ), and has a much more delicate ornament; processes on the basal margin do not differ appreciably from those elsewhere and, in particular, are not connected by a membrane.

Material. Several thousand single tests, and a dozen chains of two or three tests each.

Occurrence. Sy80–Sy200. *A. rashidi* is restricted to the middle of the Sylvan Shale, although forms transitional to it, but referable to *K. multispinata*, occur at the younger horizons Sy220, Sy240, and Sy260.

EXPLANATION OF PLATE 47

Figs. 1–19. *Ancyrochitina merga* sp. nov., all but 19 ×250. 1–8, Sy80/1/1/B, Sy60/1/1/F, B, E, Sy80/1/1/A, D, C, and Sy60/1/1/H, respectively, bearing a variety of T- and Y-shaped appendices. 9–11, Sy60/1/1/D, Sy80/1/1/E and Sy60/1/1/A, respectively, with λ-shaped appendices. 12, 13, Sy80/1/1/F (holotype) and Sy60/1/1/C, respectively, each possessing T-, Y-, and λ-shaped appendices. 14–17, Sy40/1/1/A, C, B, and D, respectively, with ornaments of simple spines and λ-spines; this form represents the species near the base of the Sylvan Shale, whereas younger Sylvan strata contain only smooth-walled forms (figs. 1–13). 18, Sy60/1/1/G, cluster of three tests; two are in polar view, the upper right in lateral view. 19, Sy80/1/1/G, detail showing three simple appendices, and one with three orders of branching, in phase-contrast illumination ×400.

Fig. 20. *Acanthochitina rashidi* sp. nov., Sy100/2/1/B, in phase-contrast illumination, ×400.

Genus ANCYROCHITINA Eisenack 1955*a*

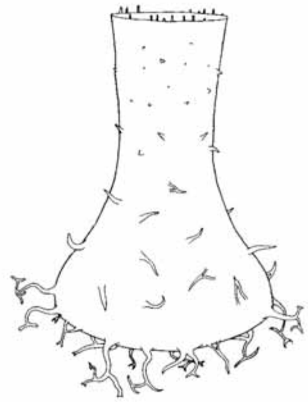
Type species. Conochitina ancyrea Eisenack 1931 (by original designation), Silurian, Baltic.

Ancyrochitina merga sp. nov.

Plate 47, figs. 1–19; text-fig. 3

Holotype. Plate 47, fig. 12. Specimen Sy80/1/1/F; Sylvan Shale, 80 ft. (24·38 m.) stratigraphically above base, Sycamore Creek.

Diagnosis. Small fungiform test. Chamber about half total length, wider than long; base slightly convex, margin rounded. 8–24, generally fewer than 15, simple or branching appendices up to one-third of the maximum diameter in length; generally 1–3, rarely 4, orders of Y– or T–shaped branching into 2 sharply diverging, equal distal limbs. Commonly, appendices divide (λ–shaped branching) in a transverse plane to form two proximal limbs which meet the basal margin abruptly. Oral tube cylindrical or slightly flaring, one-third to half maximum diameter in width; aperture fringed with hairs up to 5μ in length. Test smooth, or bearing slender, tapering, simple or λ–spines with pointed tips, up to one-sixth maximum diameter in length; thinly distributed, absent on base and basal margin.



TEXT-FIG. 3. *Ancyrochitina merga* sp. nov. Lateral view of test showing the appendices and the ornament of λ-spines and simple spines, $\times 400$.

Dimensions (in microns). 25 specimens measured.

	Total length	*Chamber length*	*Maximum diameter*	*Oral tube diameter*	*Apertural diameter*	*Appendix length*
Holotype:	125	70	91	35	*c.* 35	< 30
Range:	100–155	52–71	70–98	32–46	35–55	< 35
Mean:	128	64	81	36	44	—

Description. The flanks of the short, wide chamber are almost straight and taper rapidly, but with no abrupt change of curvature, into the neck. The maximum diameter generally is 120–140% of the chamber length. Where *A. merga* first occurs (horizon Sy40) it bears slender, simple spines and λ-spines up to $12\,\mu$ in length, distributed thinly over the test (Pl. 47, figs. 14–17). Throughout the remainder of the formation, however, forms with smooth walls, or forms with very few short spines ($< 2\,\mu$ in length) on the shoulder and neck, greatly predominate over the more ornate forms.

Comparison. A. merga is readily distinguished by the style and number of its appendices. *A. corniculans* Jenkins 1969 from the Viola and Fernvale Limestones is cylindro-conical rather than fungiform, and has only 4–6 appendices.

Material. Several thousand single tests.

Occurrence. Sy40–Sy305.

Genus CLATHROCHITINA Eisenack 1959

Type species. Clathrochitina clathrata Eisenack 1959 (by original designation), Wenlock, Gotland.

Diagnosis. 'Chitinozoans shaped like *Ancyrochitina ancyrea*, and furnished with appendices whose distal ends coalesce with a ring situated concentrically about the basal margin' (Eisenack 1959, p. 15).

Remarks. Clathrochitina Eisenack 1959 was conceived for cylindroconical chitinozoans possessing *distinct appendices* (generally discrete processes confined to the basal margin) that coalesce distally; *Plectochitina* Cramer 1964 is a junior synonym. Unfortunately, several species lacking distinct appendices have been referred inappropriately to *Clathrochitina* on the basis of *finely meshed networks* suspended from their basal margins, and *Plectochitina* has assumed the taxonomic role originally intended for *Clathrochitina*. Consequently, the genus *Sagenachitina* (q.v., p. 270) is here proposed for chitinozoans with *networks* suspended from their basal margins; and several species are transferred to it from *Clathrochitina*. The latter is considered to include, besides the type species, *Clathrochitina multiramosa* (Taugourdeau and Jekhowsky 1960) Taugourdeau 1967, *C. saharica* (Taugourdeau 1962) comb. nov., *C. carminae* (Cramer 1964) comb. nov., *C. rosendae* (Cramer 1964) comb. nov., and *C. combazi* (Cramer 1967*a*) comb. nov. It seems essentially a Silurian genus, being known only from the uppermost Ordovician (this paper), the Silurian (Eisenack 1959; Taugourdeau 1962, 1967; Cramer 1964, 1967*a*; Taugourdeau *et al.* 1967, p. 85, under *Plectochitina*), and, perhaps, the basal Devonian (Cramer 1964).

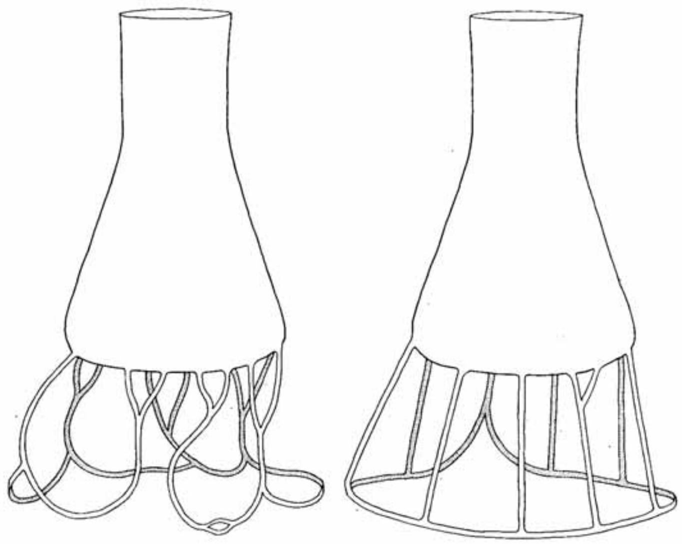
Cramer (1967*a*, pp. 84, 94; 1967*b*, p. 47) interpreted the structure on the basal margin of *C. clathrata* (type species of its genus) as a 'perforate cingulum' and, on the basis of this interpretation, transferred the species to *Cyathochitina* Eisenack 1955*b*. For species previously referred to *Clathrochitina*, which was abandoned through the loss of its type species, he proposed the genera *Clathrochitinella* and *Pseudoclathrochitina*. While Cramer's proposals may seem reasonable in the light of his structural interpretation, the latter is entirely inconsistent with Eisenack's (1959, p. 15, pl. 1, figs. 3, 4; text-fig. 4) clear illustrations and lucid, unambiguous description of the genus and its type species. Cramer's proposals and transfer of *C. clathrata* are, if only for this reason, unacceptable, and *Clathrochitinella* and *Pseudoclathrochitina* should be abandoned along with *Plectochitina*. Aside from the faulty interpretive basis upon which they rest, Cramer's proposals and transfer serve little more than to complicate and confuse a relatively straightforward issue, namely the generic placement of two groups of cylindroconical chitinozoans, one characterized by networks suspended from the basal margin (*Sagenachitina*), the other by appendices which coalesce distally (*Clathrochitina*). The existence of a few forms transitional between *Sagenachitina* and *Clathrochitina* is known (e.g. Taugourdeau 1967, pl. 1, fig. 9) but scarcely complicates the issue.

Clathrochitina sylvanica sp. nov.

Plate 48, figs. 3–13; text-fig. 4

Holotype. Plate 48, figs. 11*a*, *b*. Specimen Da50/12/1/A; Sylvan Shale, 50 ft. (15·24 m.) stratigraphically above base, in outcrop on west side of U.S. Highway 77, about 4 miles (6·4 km.) south of Davis, Oklahoma.

Diagnosis. Conical chamber slightly longer than oral tube, approximately as wide as long; base flat or slightly convex, margin rounded. Appendices of uniform thickness and texture, suspended at 6–15, generally 8–12, points on the basal margin; commonly anastomosing; occasionally discrete for their full lengths and connected at their tips by a continuous ring; equal to, or less than, maximum diameter in length. Oral tube cylindrical, half maximum diameter in width. Test wall smooth.



TEXT-FIG. 4. *Clathrochitina sylvanica* sp. nov. Lateral views of two variants with strongly developed appendices, ×400.

Dimensions (in microns). 25 specimens measured.

	Total length	*Chamber length*	*Maximum diameter*	*Oral tube diameter*	*Appendix length*
Holotype:	120	62	78	36	< 53
Range:	110–160	60–85	75–103	36–48	12–90
Mean:	131	76	84	40	—

Description. The flanks taper fairly uniformly, and the junction of the chamber and neck generally is clearly defined. The appendices are very strongly developed. Their pattern of branching and anastomosing varies considerably at each horizon, but the same, or closely similar, variants occur wherever the species has been found.

Comparison. Ancyrochitina merga is readily distinguished from *C. sylvanica* by its discrete, pitchfork-shaped appendices. Damaged specimens which have lost their appendices, however, may be exceedingly difficult to identify, but typical examples of *A. merga* are, nevertheless, fungiform rather than cylindroconical, and may bear simple or λ-spines. Four similar species of *Clathrochitina* differ from *C. sylvanica* as follows. *C. combazi* (Cramer 1967*a*) possesses 12–24 modestly branching appendices, whereas *C. rosendae* (Cramer 1964) bears only a few. The appendices of *C. clathrata* Eisenack 1959 are very short; those of *C. carminae* (Cramer 1964) branch elaborately and may extend as far as 130 μ from the basal margin. *C. multiramosa* (Taugourdeau and Jekhowsky 1960) Taugourdeau 1967 is readily distinguished by about 12 short processes attached immediately below the aperture, and connected at their tips by a continuous ring.

Material. Approximately 400 single tests.

Occurrence. ?Syl, Sy16–Sy180. *Clathrochitina sylvanica* is a distinctive element in approximately the lower half of the Sylvan Shale.

Genus SAGENACHITINA gen. nov.

Type species. *Clathrochitina oblonga* Benoit and Taugourdeau 1961 (by original designation), Arenig, Algeria.

Diagnosis. Chitinozoa with cylindroconical or campanulate tests and a network suspended from the basal margin.

Remarks. *Sagenachitina* gen. nov. is not represented in the Sylvan Shale, but is proposed for a group of closely similar species including 5 formerly referred inappropriately to *Clathrochitina* Eisenack 1959. These are *Sagenachitina oblonga* (Benoit and Taugourdeau 1961) comb. nov., *S. aquitanica* (Taugourdeau 1961) comb. nov., *S. eisenacki* (Taugourdeau 1961) comb. nov., *S. retifera* (Taugourdeau and Jekhowsky 1960) comb. nov., and *S. striata* (Benoit and Taugourdeau 1961) comb. nov. *Sagenachitina* differs from *Clathrochitina* (q.v., p. 268) in that its basal margin supports a finely divided network, rather than a relatively small number of distinct processes which coalesce distally. Apparently it is restricted to the Ordovician (Taugourdeau *et al*. 1967, p. 78), whereas *Clathrochitina* (*sensu* Eisenack 1959) seems essentially a Silurian genus.

Acknowledgement. *Sagenachitina* was introduced to the literature by Jansonius (1967, p. 352) as an informal manuscript name. It is validated here, in its original sense, with the permission and approval of Dr. Jansonius.

Genus CONOCHITINA Eisenack 1931 restr. 1955*b*

Type species. *Conochitina claviformis* Eisenack 1931 (by original designation), Silurian, Baltic.

Conochitina elegans Eisenack 1931

Plate 49, figs. 1–17

EXPLANATION OF PLATE 48

Figs. 1, 2. *Acanthochitina rashidi* sp. nov., ×400. 1, Sy100/2/1/D, in phase-contrast illumination. 2, Sy80/2/1/B, holotype; in bright-field (2*a*) and phase-contrast (2*b*) illumination.

Figs. 3–13. *Clathrochitina sylvanica* sp. nov., illustrating variation in the size and complexity of the appendices, ×250. 3, Sy60/12/1/D. 4, Sy100/12/1/A. 5, Sy80/12/1/B. 6, Sy60/12/1/C, polar view. 7, Sy60/12/1/E. 8, Sy60/12/1/K. 9, Sy80/12/1/A. 10, Sy100/12/1/C. 11, Da50/12/1/A, holotype; in bright-field (11*a*) and phase-contrast (11*b*) illumination. 12, Sy60/12/1/H. 13, Sy60/12/1/A.

1931 *Conochitina elegans* Eisenack, p. 87, pl. 2, fig. 4 (holotype).
1934 *Rhabdochitina conocephala* Eisenack, p. 61, pl. 4, figs. 10–12; text-fig. 32.
1959 *Conochitina elegans* Eisenack; Eisenack, p. 3, pl. 2, figs. 4 (neotype), 5; text-fig. 1.
1960 *Rhabdochitina conocephala* Eisenack; Taugourdeau and Jekhowsky, p. 1230, pl. 9, fig. 131.
non 1962 *Conochitina elegans* Eisenack; Beju and Dăneţ, p. 531, pl. 1, figs. 31, 32.
non 1964 *Rhabdochitina conocephala* Eisenack; Cramer, p. 351, pl. 22, fig. 14; pl. 23, figs. 7, 11, 12.
1965 *Rhabdochitina hedlundi* Taugourdeau, p. 472, pl. 3, figs. 60, 66.
1965 *Conochitina elegans* Eisenack; Eisenack, p. 126, pl. 10, fig. 9.
1967 *Conochitina elegans* Eisenack; Jenkins 1967, p. 455, pl. 71, figs. 1–4.

Dimensions (*in microns*). 50 specimens measured.

		Total length	*Maximum diameter*	*Minimum diameter*	*Apertural diameter*
	Range:	204–904	62–96	50–78	61–78
	Mean:	403	78	61	69
26 specimens from Estonia (Eisenack 1959)	Range:	288–667	—	—	—
	Mean:	467	—	—	—
26 specimens from the Ostseekalk of south Finland (Eisenack 1965)	Range:	332–690	—	—	—
	Mean:	493	—	—	—
30 specimens from England (Jenkins 1967)	Range:	200–616	58–92	—	—
	Mean:	388	73	—	—

Remarks. Conochitina elegans Eisenack 1931 shows the same pattern of morphological variation in the Sylvan Shale as it does in the Caradocian Jewe and Kegel Beds, D_1–D_2, of Estonia (Eisenack 1959, p. 3, text-fig. 1), and in the Caradoc Series of England (Jenkins 1967). Throughout the Sylvan Shale, short conical or cylindroconical forms up to 400 μ in length (Pl. 49, figs. 8–15) predominate numerically over much longer cylindrical forms, up to 900 μ in length, which have pronounced aboral swellings (Pl. 49, figs. 1–7). The aperture is distinctively fringed by numerous, irregular, simple or branching processes up to 6 μ in length.

I am reasonably sure that *Conochitina elegans* and *Rhabdochitina hedlundi* Taugourdeau 1965 are conspecific. Well-preserved typical examples of *C. elegans* occur at several horizons in the Upper Ordovician Maquoketa Formation from Iowa, where Taugourdeau obtained the type material of *R. hedlundi*, but no other species comparable to *C. elegans* or *R. hedlundi* is represented.

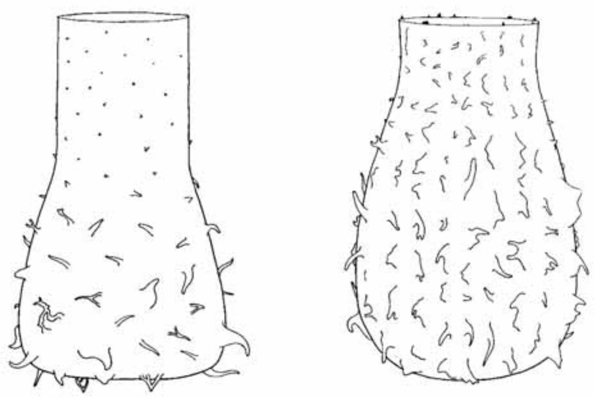
Material. Several thousand single tests, and clusters of up to 15 tests each.

Occurrence. Syl-Sy305. The species occurs in the Caradoc Series of Estonia (Eisenack 1959, 1962*b*) and Shropshire, England (Jenkins 1967), and in the Ostseekalk of north Germany and south Finland (Eisenack 1965). Taugourdeau and Jekhowsky (1960) record it, as *Rhabdochitina conocephala*, in Algerian sediments referred with reservations (op. cit., pp. 1205, 1230) to the lower Silurian. Eisenack (1964) refers to *C.* cf. *elegans* a group of forms from the Llandovery, Wenlock, and lower Ludlow of Gotland which, while closely similar to the Ordovician type material, are not certainly conspecific with it.

Conochitina cactacea Eisenack 1937

Plate 49, figs. 18–25; text-fig. 5

1937 *Conochitina cactacea* Eisenack, p. 222, pl. 15, figs. 14, 15 (holotype).
1959 *Conochitina cactacea* Eisenack; Eisenack, p. 10, pl. 1, figs. 12 (neotype), 13; text-fig. 2*a*, *b*.
non 1965 *Conochitina* cf. *cactacea* Eisenack *typica* Taugourdeau, p. 467, pl. 1, fig. 10.
1965 *Conochitina cactacea* Eisenack; Eisenack, p. 125, pl. 9, figs. 18, 19.
1967 *Conochitina cactacea* Eisenack; Laufeld, p. 299, fig. 9.



TEXT-FIG. 5. *Conochitina cactacea* Eisenack 1937. Lateral views illustrating (left) a typical cylindroconical example with randomly distributed spines, and (right) a pyriform test whose spines are expanded proximally and arranged in longitudinal rows, ×350.

Dimensions (*in microns*). 25 specimens measured.

	Total length	*Maximum diameter*	*Oral tube diameter*	*Apertural diameter*	*Spine length*
Range:	118–240	80–123	52–77	53–73	< 15
Mean:	165	97	63	62	—
Neotype (Eisenack 1959):	123	72	42	43	—

EXPLANATION OF PLATE 49

Figs. 1–17. *Conochitina elegans* Eisenack 1931, ×100. 1–7, Sy60/4/1/A, D, K, Da3/4/1/B, Sy60/4/1/R, G, and Sy100/4/1/C, respectively, long cylindrical tests with conspicuous aboral swellings. 8–10, Sy60/4/1/S, H, and J, respectively, shorter tests with neck and chamber differentiated. 11–17, Sy40/4/1/C, D, F, A, Sy60/4/1/T, Da3/4/1/D and Sy60/4/1/P, respectively, short to very short tests illustrating some of the very considerable variation that is expressed in both the large and small size-fractions of populations of *C. elegans*.

Figs. 18–25. *Conochitina cactacea* Eisenack 1937, all except 19*b* ×250. The figured specimens have been chosen to illustrate the ornament; most are distorted and none shows the typical shape of this well-known species. 18, Sy60/6/1/A. 19, Sy16/6/1/A; 19*a*, showing exceptionally well-preserved ornament in upper right quadrant of photograph; 19*b*, detail of proximally-expanded spines, in phase-contrast illumination ×1600. 20, Sy16/6/1/D. 21, Sy16/6/1/B. 22, Sy16/6/1/F. 23, Sy60/6/1/B. 24, Sy16/6/1/E. 25, Sy16/6/1/C.

Description. The chamber is conical with straight or swollen flanks, and makes up more than half the total length. The base is flat, with a broadly rounded margin. The oral tube, which occasionally is not developed, is cylindrical and approximately two-thirds of the maximum diameter in width. The aperture is straight, or fringed with irregularly spaced processes up to 3 μ in length. Short spines, most of which are simple, cover the entire test. Branching spines with two distal limbs, and λ-spines with two or three discrete bases, however, are common. Spines may taper uniformly, or their proximal portions may be widely expanded in a plane parallel with the test's longitudinal axis. Commonly the spines show some tendency to loosely align themselves in longitudinal rows, and in some examples the expanded proximal portions of longitudinally adjacent spines occasionally coalesce, forming very short ridges up to 3 μ in height. Such ridges tend to be less strongly developed, though no less common, toward the aperture. In general, spines are largest on the basal margin and become smaller orally.

Material. Approximately 200 single tests.

Occurrence. Syl-Sy305. *C. cactacea* occurs throughout the Sylvan Shale, but nowhere is it common. The species occurs in the Ostseekalk of north Germany and Gotland (Eisenack 1965), and in the Caradocian Dalby and Slandrom Formations of central Sweden (Laufeld 1967). A few atypical examples are known from the Wesenberg Beds, E, of Estonia (Eisenack 1962*b*, 1965).

Genus CYATHOCHITINA Eisenack 1955*b*

Type species. *Conochitina campanulaeformis* Eisenack 1931 (by original designation), Ordovician, Baltic.

Cyathochitina agrestis sp. nov.

Plate 50, figs. 11, 18

Holotype. Plate 50, figs. 11*a*, *b*. Specimen Syl/8/1/A; Sylvan Shale, 1 ft. (0·3 m.) stratigraphically above base, Sycamore Creek.

Diagnosis. Large test. Chamber conical to swollen cylindrical, about two-thirds total length; maximum diameter in lower half or middle of chamber, about one-third chamber length; base flat, about three-quarters maximum diameter in width. Carina attached some distance aborally of maximum diameter. Oral tube cylindrical or slightly flaring, about four-fifths maximum diameter in width; aperture straight. Test wall rough.

Dimensions (*in microns*). 6 specimens measured.

	Total length	*Chamber length*	*Maximum diameter*	*Oral tube diameter*	*Apertural diameter*	*Carina width*
Holotype:	980	660	192	148	172	< 20
Range:	592–980	376–660	176–192	128–152	136–172	< 25
Mean:	784	549	184	142	153	—

Comparison. In general shape this species closely resembles *Acanthochitina barbata* Eisenack 1931 and *Cyathochitina stentor* (Eisenack 1937), but lacks the diagnostic ornament of either (Jenkins 1967, pp. 443–5; Laufeld 1967, p. 318, respectively). It is much larger than *Cyathochitina calix* (Eisenack 1931), 57 Baltic examples of which (Eisenack 1962*a*) average 299 μ in total length (min. 190 μ, max. 450 μ).

Material. 10 single tests.

Occurrence. Syl.

Cyathochitina ontariensis (Jansonius 1964) comb. nov. emend.

Plate 50, figs. 1–9

1964 *Tanuchitina ontariensis* Jansonius, p. 910, pl. 1, figs. 5, 6 (holotype).

Emended diagnosis. Elongate, cylindroconical, or campanulate test. Chamber approximately two-thirds total length; base almost flat; margin drawn out into a short sharp carina, generally directed aborally, and situated slightly below the maximum diameter. Neck cylindrical, half to two-thirds maximum diameter in width; collarette flaring; aperture serrate or fimbriate, generally 8–12 μ wider than neck. Wall smooth.

Dimensions (*in microns*). 25 specimens measured.

	Total length	*Maximum diameter*	*Neck diameter*	*Apertural diameter*	*Carina width*
Range:	268–740	102–180	56–88	64–106	< 3
Mean:	475	142	69	79	—
Holotype (Jansonius 1964):	310	—	—	—	—

Description. The flanks may taper uniformly or be slightly swollen (Pl. 50, figs. 1, 2, 4, 5), in which cases the chamber and neck are more or less clearly distinguishable. Occasionally the test is trumpet-shaped, having concave flanks which merge with the neck (Pl. 50, figs. 3, 7). Originally the base probably was flat or almost so; in most specimens, however, perhaps owing to compression, it is convex in the centre and concave toward the margin. The carina is a continuous, uniformly wide, knife-edge rim which, in lateral view, rarely protrudes more than 3 μ beyond the general silhouette of the test.

Remarks. This species was designated type species of *Tanuchitina* by Jansonius (1964), but is here considered to fall well within the scope of *Cyathochitina* Eisenack 1955*b*.

Comparison. C. agrestis sp. nov. has a much larger carina than *C. ontariensis* and the shape of its test is quite different. *C. stentor* (Eisenack 1937) is furnished with a strongly developed, skirt-like carina (up to 85 μ in width; Laufeld 1967, p. 318) and an ornament of strongly defined longitudinal ridges.

Material. Several thousand single tests.

Occurrence. Sy80-Sy305. The type material is from the subsurface Upper Ordovician of Ontario.

EXPLANATION OF PLATE 50

Figs. 1–9. *Cyathochitina ontariensis* Jansonius 1964, $\times 100$. 1, 2, Sy100/7/1/A and B, respectively, typical examples with slender campanulate tests and weakly developed carinae. 3, Sy80/7/1/B, trumpet-shaped test. 4, 5, Sy80/7/1/A and Sy100/70/1/C, respectively, with well-developed carinae. 6–7, Sy80/7/1/C and Sy100/7/1/D, respectively, very short tests. 8, Sy80/7/1/E. 9, Sy80/7/1/D.

Figs. 10, 12–17, 19, 20. *Desmochitina minor* Eisenack 1931. 10, 14, 15, 19, 20, Sy100/9/1/A, Sy80/9/1/A, B, C, and Sy100/9/1/B, single tests each with an operculum firmly attached at the base, $\times 250$. 12, Sy40/9/1/A, single test lacking an operculum at its base (presumably one was once present and has since been lost), but having retained the operculum sealing its own aperture (this is set squarely in the throat of the specimen), $\times 250$. 13, 16, 17, Sy60/9/1/B, H, and Sy100/9/1/C, respectively, chains of tests connected aperture-to-base, $\times 100$.

Figs. 11, 18. *Cyathochitina agrestis* sp. nov. 11, Syl/8/1/A, holotype; 11*a*, $\times 100$; 11*b*, carina, $\times 250$. 18, Syl/8/1/B, $\times 100$.

Fig. 21. *Desmochitina scabiosa* (Wilson and Hedlund 1964), Sy60/10/1/D, cluster of four tests, $\times 250$.

Genus DESMOCHITINA Eisenack 1931 emend. 1962*a*

Type species. Desmochitina nodosa Eisenack 1931 (by original designation), Ordovician, Baltic.

Remarks. For the present I share Eisenack's (1968, pp. 155, 185) view that *Hoegisphaera* Staplin 1961 is superfluous, and would place it (and its junior synonym *Calpichitina* Wilson and Hedlund 1964) in synonymy with *Desmochitina* Eisenack 1931 emend. 1962*a*. *Hoegisphaera* was established by Staplin (1961) for 'a new type of Paleozoic microfossil possibly allied to the Chitinozoa' (op. cit., p. 392), in which 'The colour and texture of the wall are similar to those of Chitinozoa, but the analogy cannot be carried farther' (op. cit., p. 419). However, it is clear that the species assigned to *Hoegisphaera are* chitinozoans, and they have been widely recognized as such in the literature (Jansonius 1964, p. 913; 1967, p. 350; Taugourdeau *et al.* 1967, p. 61; Laufeld 1967, pp. 319–20, 327–8; Jenkins 1967, p. 462; Eisenack 1968, pp. 155, 185). Three years after *Hoegisphaera* had been established, Wilson and Hedlund (1964) described the genus *Calpichitina* with its type species *C. scabiosa*. This generic name, however, was proposed for a species (*C. scabiosa*) which clearly fell within Staplin's (1961) concept of *Hoegisphaera*, and was closely similar in size and shape to *Desmochitina complanata* Eisenack 1932 (for dimensions see Eisenack 1959, p. 16). Very shortly after the establishment of *Calpichitina*, Wilson and Dolly (1964), doubting its validity, abandoned it by transferring the type species (*C. scabiosa*) to *Hoegisphaera*.

Desmochitina minor Eisenack 1931

Plate 50, figs. 10, 12–17, 19, 20

1969 *Desmochitina minor* Eisenack; Jenkins, pp. 20, 21, pl. 6, figs. 1–18 (q.v. for further synonymy).

Dimensions (in microns). 25 specimens measured.

	Total length	*Chamber length*	*Maximum diameter*	*Minimum (neck) diameter*	*Apertural diameter*
Range:	72–120	60–108	66–86	46–60	54–64
Mean:	92	84	76	53	58

Remarks. Eight informal infraspecific taxa have been referred to *Desmochitina minor* by Eisenack (1958, 1962*a*). The form recorded here corresponds exactly to the informal taxon *D. minor* forma *typica* Eisenack 1958 but is considered to merit recognition as a separate species. It occurs widely within North America and Europe, where it is generally quite distinct. The remaining seven infraspecific taxa, and forms transitional to them, are apparently lacking in the Sylvan Shale.

Most specimens are indistinguishable from many of the examples from Bohemia (Eisenack 1948, text-figs. 14, 15), the Ordovician Rhenish Schiefergebirge (Eisenack 1939, text-figs. 1–3, 6), and the Swedish and British Caradoc (Laufeld 1967, fig. 25; Jenkins 1967, pl. 71, fig. 18). They differ appreciably, however, from Eisenack's Baltic material (1962*a*, pl. 16, figs. 1–8, 10; 1965, pl. 10, figs. 16, 17) and the Viola–Fernvale specimens recorded in an earlier study (Jenkins 1969), in that the general shape of the chamber in lateral view tends to be spherical rather than quadrangular; the oral tube is smaller and less sharply flaring; and chains of up to 20 tests are common.

In marked contrast to its broad pattern of morphological variation in the Viola and Fernvale Limestones (Jenkins 1969, p. 21, pl. 6, figs. 1–18), the species is represented within the Sylvan Shale by a conservative form which, throughout the formation, varies little in size, shape, or surface texture.

Material. Many thousand single tests, and several hundred chains of up to 20 tests each. Clusters of up to 60 tests are common at horizon Sy60.

Occurrence. Sy16-Sy260. In the lower half of the formation (Sy16-Sy140) *D. minor* is a numerically important element in the chitinozoan fauna and occurs in long chains; thereafter its numbers are drastically reduced, and the species is missing or extremely scarce near the top of the formation (Sy280-Sy305). Its occurrence outside North America is given elsewhere (Jenkins 1969, p. 21).

Desmochitina scabiosa (Wilson and Hedlund 1964) Jenkins 1969

Plate 50, fig. 21

1958 *Desmochitina* sp. 2 Wilson, pl. 1, fig. 7.
1962*a* *Desmochitina* sp. Eisenack, p. 304, pl. 16, figs. 11, 12.
1964 *Calpichitina scabiosa* Wilson and Hedlund, p. 164, pl. 1, figs. 1 (holotype), 2–12.
1965 *Desmochitina lecaniella* Eisenack, p. 131, pl. 10, figs. 21, 22 (holotype).
1967 *Desmochitina lecaniella* Eisenack; Laufeld, p. 326, fig. 24.
1969 *Desmochitina scabiosa* (Wilson and Hedlund); Jenkins, p. 23.

Dimensions (*in microns*). 25 specimens measured.

	Total length	*Chamber length*	*Maximum diameter*	*Apertural diameter*
Range:	50–75	43–68	52–92	48–62
Mean:	61	56	73	56
Holotype (Wilson and Hedlund 1964):	60	—	79	41

Remarks. The stratigraphical ranges of *D. scabiosa* (Wilson and Hedlund 1964) and *D. lecaniella* Eisenack 1965 both lie within the Upper Ordovician, and the two species are so closely similar that it would seem impractical to continue distinguishing them. Populations from the Sylvan Shale consist largely of single tests, but clusters (*sensu* Kozlowski 1963) are common at several horizons.

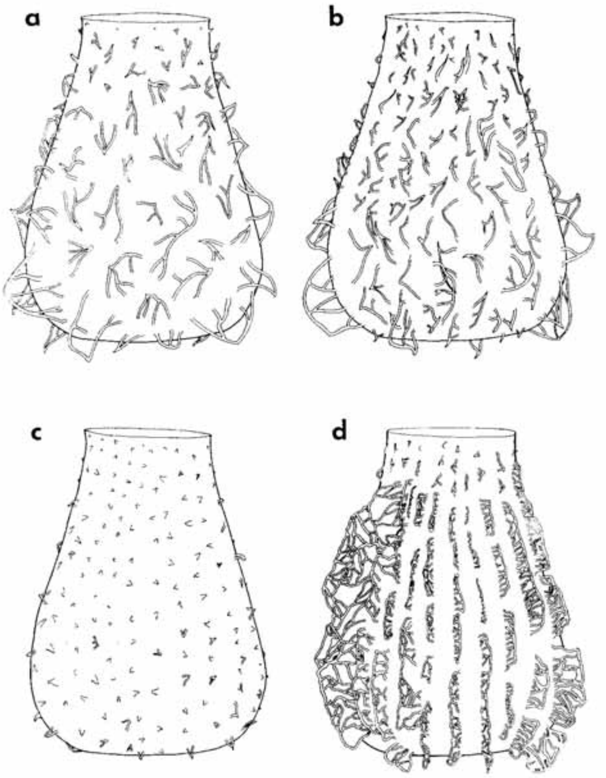
Material. Several thousand single tests, and numerous clusters of up to 11 tests each.

Occurrence. Sy40-Sy305. Wilson and Hedlund (1964) illustrate several single tests particularly well, and record the species approximately 50 ft. (15·24 m.) above the base of the formation, at an outcrop on U.S. Highway 77 about 4 miles (6·4 km.) south of Davis, Oklahoma (text-fig. 1) and 20 miles (32 km.) north-west of the Sycamore Creek section. Taugourdeau records *C. scabiosa* (illustrated as *C.* cf. *scabiosa*) in the Maquoketa Formation, Richmond, of Iowa. *Desmochitina lecaniella* has been recorded in the Caradocian Kegel Beds, D_2, of Estonia (Eisenack 1962*a*, 1965); in the Ostseekalk of north Germany, Gotland, and south Finland (Eisenack 1965); and in the Dalby Formation, Caradoc, of central Sweden (Laufeld 1967).

Genus KALOCHITINA Jansonius 1964

Type species. Kalochitina multispinata Jansonius 1964 (by original designation), Upper Ordovician, Ontario.

Remarks. The chief diagnostic features of this genus are its pyriform test, reduced neck, and ornament of numerous, generally small spines which frequently are aligned in longitudinal rows.



TEXT-FIG. 6. *Kalochitina multispinata* Jansonius 1964. Lateral views illustrating variation in the style of the ornament, ×400. *a*, Typical example with evenly spaced spines. *b*, Typical example with spines showing tendency to align themselves in longitudinal rows. *c*, Example with reduced ornament of short thorn-like spines. *d*, Example furnished with ridges which appear to have formed, figuratively, as if by fusion of closely spaced λ-spines.

Kalochitina multispinata Jansonius 1964

Plate 51, figs. 1–10, 15; text-fig. 6

1958 Genus B, Wilson, pl. 1, figs. 10, 11.
1964 *Kalochitina multispinata* Jansonius, p. 909, pl. 2, figs. 21 (holotype), 22.

Dimensions (*in microns*). 30 specimens measured.

	Total length	*Maximum diameter*	*Apertural diameter*	*Spine length*
Range:	102–156	82–103	42–60	< 12
Mean:	121	90	51	—
Holotype (Jansonius 1964):	140	—	—	—

Description. The test is pyriform to conical, with a maximum diameter about four-fifths of the total length. The neck is short, tapering, and rather weakly differentiated from the chamber; in most individuals it has been lost or was never developed. The apertural diameter equals or slightly exceeds half the maximum diameter.

In all populations of *K. multispinata* the ornament varies considerably, but, for the most part, its range of variation is much the same throughout the formation. The lower and upper beds (up to horizon Sy60 and above horizon Sy200) contain pure populations of *K. multispinata*, but throughout approximately the middle 140 ft. (43 m.) of the formation (horizons Sy80 to Sy200) the species makes up continuously intergrading populations with *A. rashidi*. The two species are distinguished from each other arbitrarily and solely on the basis of their ornaments (compare text-figs. 2 and 6). Typical examples of *K. multispinata* are covered with closely and evenly spaced λ-spines, up to 12 μ in length and possessing 2–6 proximal limbs (text-fig. 6*a*). In many, but by no means all, of the more typical examples, the proximal limbs of each λ-spine, and the spines as a whole, show some tendency to loosely align themselves in approximately 30 more or less clearly defined longitudinal rows (text-fig. 6*b*). In addition, each population contains individuals whose ornament is reduced to short ($< 2{\cdot}5\ \mu$ in length) thorn-like spines (text-fig. 6*c*). A rare form, seemingly of sporadic vertical distribution, is furnished with perforate or imperforate ridges up to 8μ in height (text-fig. 6*d*), which appear to have formed, figuratively, as if by fusion of very closely spaced λ-spines. Variants transitional to *A. rashidi* (text-fig. 2) occur from horizon Sy80 to Sy260.

Material. Several thousand single tests, and 20 chains of up to 4 tests each.

Occurrence. Sy16-Sy260. The type material is from the subsurface Upper Ordovician of Ontario (Jansonius 1964).

Genus RHABDOCHITINA Eisenack 1931

Type species. *Rhabdochitina magna* Eisenack 1931 (by original designation), Ordovician, Baltic.

Rhabdochitina sp.

Plate 51, fig. 14

Remarks. A species of very large chitinozoan is present in the Sylvan Shale, but only 2 incomplete examples are recorded here, one from horizon Sy80, the other from Sy120.

EXPLANATION OF PLATE 51

Figs. 1–10, 15. *Kalochitina multispinata* Jansonius 1964, all but 10 $\times 250$. 1–5, Sy40/3/1/C, Sy100/3/1/A, E, G and Sy60/3/1/D, respectively. 6, Sy40/3/1/A, showing ornament through translucent test. 7, 8, Sy100/3/1/B and Sy40/3/1/D, respectively. 9, Da2/3/1/D, cluster of four tests showing a roughly parallel alignment of their longitudinal axes, a particularly common phenomenon in this species. 10, Sy40/3/1/M, λ-spines, in phase-contrast illumination $\times 1000$. 15, Sy100/3/1/D, chain of two tests.

Figs. 11–13, 16–20. *Sphaerochitina lepta* sp. nov., a series of tests illustrating *inter alia* the variable length of the neck, $\times 250$. 11, Sy60/11/1/F, compressed so the longitudinal axis of the neck has folded into the same plane as the transverse axis of the chamber (cf. text-fig. 7*a*). 12, 13, 16–18, Sy60/11/1/K (holotype), E, M, R, and B, respectively. These specimens are not carinate, as might be erroneously assumed from the photographs. The sharp prominences on the chambers are not original features but occur in tests where accommodation during compression has involved an inward collapse of the base (cf. text-fig. 7*b*). 19, 20, Sy100/11/1/C and D, with relatively long necks.

Fig. 14. *Rhabdochitina* sp., Sy80/5/1/A, $\times 100$.

The tests are for the most part cylindrical, swollen at their aboral ends, and quite smooth. The larger specimen is 180 μ in width, and its original length exceeded 850 μ.

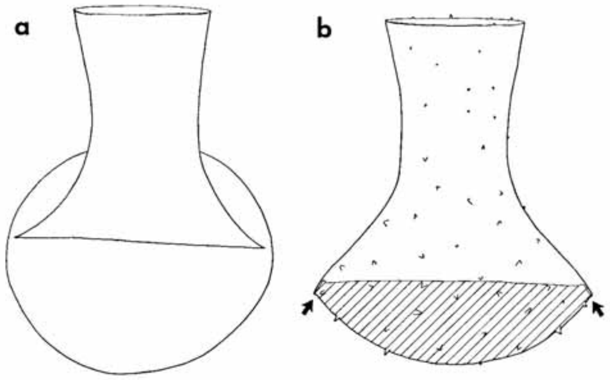
Genus SPHAEROCHITINA Eisenack 1955*a*

Type species. Lagenochitina sphaerocephala Eisenack 1932 (by original designation), Silurian, Baltic.

Sphaerochitina lepta sp. nov.

Plate 51, figs. 11–13, 16–20; text-fig. 7

Holotype. Plate 51, fig. 12. Specimen Sy60/11/1/K; Sylvan Shale, 60 ft. (18·28 m.) stratigraphically above base, Sycamore Creek.



TEXT-FIG. 7. *Sphaerochitina lepta* sp. nov., × 550. *a*, Smooth form which is found in the middle and upper Sylvan Shale, compressed so the longitudinal axis of the neck has folded into the same plane as the transverse axis of the chamber. *b*, example of the ornamented form which occurs in the upper Sylvan Shale, compressed laterally. The small sharp prominences (indicated by arrows) simulate the carinae of other species. They are not original features, however, but are common in tests where accommodation during compression has involved an inward collapse of the base (shaded).

Diagnosis. Small, cylindroconical or fungiform test. Chamber and neck of approximately equal length. Maximum diameter about 150% chamber length; base flat or convex. Neck one-third to half maximum diameter in width. Aperture straight or fimbriate. Wall smooth, or bearing small, generally simple processes, thinly and uniformly distributed over entire test.

Dimensions (in microns). 25 specimens measured.

	Total length	*Chamber length*	*Maximum diameter*	*Neck diameter*	*Apertural diameter*	*Process length*
Holotype:	89	55	85	32	38	—
Range:	83–120	45–60	72–88	29–33	35–43	< 3·5
Mean:	97	52	79	31	39	—

Description. In size and shape, this species remains virtually the same wherever it has been found. The test wall is relatively thin and translucent, and large secondary folds are generally present. The ornament consists of cones, simple spines, and a few λ-spines with blunt or pointed tips. The species first occurs in the middle of the formation (Sy120–Sy180) where it is represented exclusively by smooth forms. Thereafter (Sy200–Sy305) smooth and ornamented forms occur together.

Comparison. Several species are closely similar to *S. lepta*, including *S. schwalbi* Collinson and Scott 1958, *S. nodulosa* Collinson and Scott 1958, and *S. actonica* Jenkins 1967. All may be distinguished, however, by the style and distribution of their ornamental processes.

Material. Several thousand single tests, and a dozen clusters of up to 20 tests each.

Occurrence. Sy120–Sy305.

GENERAL CONCLUSIONS

The chitinozoan fauna of the Sylvan Shale has been examined at widely scattered localities throughout the Arbuckle Mountains, and at stratigraphical intervals of 20 ft. (6·10 m.) throughout the 305 ft. (93 m.) thick sequence exposed in the bed and banks of Sycamore Creek (text-fig. 1), Johnston County, Oklahoma. Preservation is generally excellent except for the reworked material in the uppermost part of the formation (p. 282), and rich assemblages occur throughout the area and at all stratigraphical levels. The fauna has been referred to the following nine genera, and twelve species of which five are new:

Acanthochitina rashidi sp. nov.
Ancyrochitina merga sp. nov.
Clathrochitina sylvanica sp. nov.
Conochitina cactacea Eisenack 1937
Conochitina elegans Eisenack 1931
Cyathochitina agrestis sp. nov.
Cyathochitina ontariensis (*Jansonius* 1964) comb. nov.
Desmochitina minor Eisenack 1931
Desmochitina scabiosa (Wilson and Hedlund 1964)
Kalochitina multispinata Jansonius 1964
Rhabdochitina sp.
Sphaerochitina lepta sp. nov.

THE FAUNAL SUCCESSION

No *abrupt* changes interrupt the general continuity of the chitinozoan succession in the Sylvan Shale sequence at Sycamore Creek, and deposition would appear to have continued without significant interruption. *Conochitina elegans* and *C. cactacea* occur throughout the formation, while several other species (*Ancyrochitina merga*, *Cyathochitina ontariensis*, *Desmochitina minor*, *D. scabiosa* and *Kalochitina multispinata*) are present at nearly all stratigraphical levels and may be considered, for most practical purposes, characteristic of the formation as a whole (Table 1).

On the basis of *gradual* changes in the composition of its chitinozoan fauna, however, the Sylvan Shale at Sycamore Creek may be divided into three biostratigraphical units. These are not formally proposed in this paper as zones but, since they can be recognized seemingly unchanged 20 miles (32 km.) north-west of the Sycamore Creek outcrop in

	HORIZON \ CHITINOZOAN	*Cyathochitina agrestis*	*Conochitina elegans*	*Conochitina cactacea*	*Clathrochitina sylvanica*	*Kalochitina multispinata*	*Desmochitina minor*	*Ancyrochitina merga*	*Desmochitina scabiosa*	*Acanthochitina rashidi*	*Cyathochitina ontariensis*	*Sphaerochitina lepta*
SYLVAN SHALE	Sy305		●	●				●	●		●	●
	Sy300		●	●				●	●		●	●
	Sy280		●	●				●	●		●	●
	Sy260		●	●		●	●	●	●		●	●
	Sy240		●	●		●	●	●	●		●	●
	Sy220		●	●		●	●	●	●		●	●
	Sy200		●	●		●	●	●	●	●	●	●
	Sy180		●	●	●	●	●	●	●	●	●	●
	Sy160		●	●	●	●	●	●	●	●	●	●
	Sy140		●	●	●	●	●	●	●	●	●	●
	Sy120		●	●	●	●	●	●	●	●	●	●
	Sy100		●	●	●	●	●	●	●	●	●	
	Sy80		●	●	●	●	●	●	●	●	●	
	Sy60		●	●	●	●	●	●	●			
	Sy40		●	●	●	●	●	●	●			
	Sy16		●	●	●	●	●					
	Sy1	●	●	●	?							

TABLE 1. Summary of the stratigraphical distribution of chitinozoan species in one section through the Sylvan Shale of Oklahoma. The two occurrences (Sy80, Sy120) of *Rhabdochitina* sp. are not shown.

exposures along U.S. Highway 77, it is not unlikely that after further study they will form the basis of a more formal, and widely applicable stratigraphical subdivision. In the lower unit, about 110 ft. (33·5 m.) thick at Sycamore Creek, the fauna diversifies steadily from 3 to 10 species, and is strikingly characterized by large numbers of *Desmochitina minor*, which are often preserved in very long chains. Only one species, *Cyathochitina agrestis*, disappears within this interval, at the top of which the fauna attains its maximum diversity.

No new forms appear above horizon Sy120, and the fauna in approximately the middle 160 ft. (48 m.) of the formation, from horizon Sy120 to Sy260, is remarkably stable. It consists initially of 10 species and changes qualitatively only in that about midway up it loses *Acanthochitina rashidi* and *Clathrochitina sylvanica*. In addition, the numbers of *Desmochitina minor* above horizon Sy160 are drastically reduced and only rarely is the species preserved in chains.

The upper biostratigraphical unit of the Sylvan Shale lies above horizon Sy260 and is between 25 and 45 ft. (7·6–13·7 m.) thick at Sycamore Creek. It contains throughout a reduced fauna of only 6 species, and its base is marked by the disappearance of *in situ* specimens of *Desmochitina minor* and *Kalochitina multispinata*. In addition, numerous chitinozoans are present which, judging from their condition and identity, are almost certainly reworked from older Sylvan sediments. Their state of preservation contrasts strikingly with that of the forms considered to be *in situ*. They are bleached, corroded, perforated by the holes of 'boring organisms', and lack all but the stumps of their ornamental processes.

The occurrence of reworked Sylvan chitinozoans in upper Sylvan strata indicates that during late Sylvan time uplift took place, at least locally, in the southern mid-continent. The area of uplifted strata is not known, however (Ham, personal communication, 1969), and will need to be determined by future work demonstrating the absence of uppermost Sylvan beds beneath the lower Llandovery Keel Formation, which is the basal unit of the Silurian–Devonian Hunton Group. Although the pre-Keel unconformity is well-known and widely distributed (though very poorly exposed) in the Arbuckle Mountains, associated uplift beginning in late Sylvan time has thus far been unsuspected.

At Sycamore Creek, the three biostratigraphical subdivisions distinguished above correspond approximately to the three units of a tripartite lithostratigraphical subdivision (q.v., p. 263) that is recognizable widely within Oklahoma and clearly apparent in the Arbuckle Mountains. These are successively, a sequence of hard, very fissile, brown to dark grey shales up to 130 ft. (40 m.) or so thick in the lower part of the formation; a succession of soft, weakly fissile, greenish-grey shales up to 200 ft. (61 m.) thick in the upper part; and a thin sequence, about 30 ft. (9 m.) thick, of soft, massive, light green claystone at the top.

LATERAL DISTRIBUTION OF THE SYLVAN CHITINOZOAN FAUNA

In order to determine how much the character of the Sylvan chitinozoan fauna varies regionally, several samples were collected at widely scattered localities throughout the Arbuckle Mountains. In addition to those from Sycamore Creek, which lies at the extreme southern end of the mountains, samples were obtained from outcrops along

U.S. Highway 77 about 4 miles (6·4 km.) south of Davis (text-fig. 1), map reference sec. 30, T. 1 S., R. 2 E., Murray County, in the western 'thumb' of the mountains; at Lawrence (Ideal Portland Cement Company) Quarry (text-fig. 1), map reference sec. 36, T. 3 N., R. 5 E., Pontotoc County, in the area's most northerly exposure of Sylvan Shale; and at several localities in between. Assemblages of chitinozoans from these samples indicate clearly that the Sylvan fauna extends throughout the Arbuckle Mountains and remains essentially unchanged 20 miles (32 km.) to the north-west, and 30 miles (48 km.) to the north, of the Sylvan outcrops on Sycamore Creek. Furthermore, the fauna is not restricted to the immediate environs of the Arbuckle Mountains. Core samples from borings in north-western Texas prove its very extensive lateral distribution, and demonstrate that its composition remains essentially unchanged up to 180 miles (288 km.) west of the Arbuckle Mountains.

Several species of Sylvan chitinozoans are present 650 miles (1050 km.) north-north-east of the Arbuckle Mountains in outcrops of the Maquoketa Formation in eastern Iowa. These include *Conochitina elegans*, *Cyathochitina ontariensis*, *Desmochitina minor*, *D. scabiosa*, and *Kalochitina multispinata*, and provide substantial fossil evidence that the Sylvan Shale of Oklahoma and the Maquoketa Formation of Iowa are, for the most part, of the same general age. In so far as they correlate the two formations, they would support Decker's (1935, p. 698) view that in the subsurface the Sylvan Shale grades north-eastward into the Maquoketa Formation. At the same time these fossils provide some palaeontological evidence to substantiate Lee's (1943, p. 40) assertion that 'The Maquoketa shale . . . in the Mississippi Valley . . . is equivalent to the Sylvan shale of Oklahoma', and (op. cit., p. 42) his view that 'The Maquoketa shale was originally deposited . . . probably across the Chautauqua arch in continuation with the Sylvan shale of Oklahoma.'

Several species not mentioned above have been identified by Taugourdeau (1965) in poorly preserved material from two samples of the Maquoketa Formation from Iowa. These are: *Ancyrochitina ancyrea* (Eisenack 1931), but Taugourdeau's doubts (op. cit., p. 465) about this identification are clearly implied, and his specimens may well be broken examples of *A. merga* sp. nov.; *Cyathochitina campanulaeformis* (Eisenack 1931); *C. kuckersiana* (Eisenack 1934); *Desmochitina minor* forma *ovulum* Eisenack 1962*a*, here considered specifically distinct from *D. minor* Eisenack 1931; and *Hoegisphaera utricula* Taugourdeau 1965. In addition, Taugourdeau (op. cit.) records *Desmochitina scabiosa* (designated *Calpichitina scabiosa* in text, but *C.* cf. *scabiosa* in plate explanations) and *Rhabdochitina hedlundi* Taugourdeau 1965 (here [p. 271] considered a junior synonym of *Conochitina elegans* Eisenack 1931).

CHITINOZOAN FAUNAS FROM ABOVE AND BELOW THE SYLVAN SHALE

The chitinozoan fauna of the Sylvan Shale differs strikingly from that which precedes it in the underlying Viola and Fernvale Limestones (Jenkins 1969), the two faunas containing only one species, *Desmochitina minor*, in common. Numerous samples of both units, collected at points throughout the Arbuckle Mountains, indicate that the differences between the two faunas persist laterally over a wide area and are everywhere essentially the same. As noted earlier (op. cit., p. 34): 'The striking difference between the Viola–Fernvale and Sylvan faunas suggests that the unconformity between the two stratigraphical units probably represents a substantial period of time (although no reliable indication of its duration can presently be given) or that the character of chitinozoan faunas may be very much more subject to control by the environment of deposition than has hitherto been suspected.'

Chitinozoans have been cursorily examined from the several carbonate formations of the Silurian–Devonian Hunton Group, which overlie the Sylvan Shale in Kansas, Oklahoma, and Texas. It would appear from this preliminary examination that the younger faunas are entirely different from those of the Ordovician Viola, Fernvale, and Sylvan formations, and that their affinities lie with faunas which existed contemporaneously in Europe (Eisenack 1955*a*, 1955*b*, 1959, 1962*a*, 1964) and North Africa (Taugourdeau and Jekhowsky 1960, Taugourdeau 1962).

AGE AND CORRELATION OF THE SYLVAN SHALE

The Sylvan Shale has been dated uppermost Ordovician on the basis of its graptolite fauna (Decker 1935, pp. 698–700; 1936*a*, pp. 308–9; 1936*b*, pp. 1256–7; Berry 1960*a*, p. 31, table 2). Generally it has been correlated (Decker 1935, Twenhofel *et al.* 1954, Berry 1960*a*) with part of the Richmond Stage, which is typically developed in the upper valley of the Ohio River and considered approximately correlative with the Ashgill Series of Britain. It is also correlated by graptolites with the Maquoketa Formation of the upper Mississippi Valley (Decker 1935, p. 698; 1936*a*, p. 308; 1936*b*, p. 1257; Twenhofel *et al.* 1954); the upper Maravillas Chert in the Marathon Basin of western Texas (Twenhofel *et al.* 1954; Berry 1960*a*, p. 38, table 2); and the Polk Creek Shale in the Ouachita Mountains of south-eastern Oklahoma and south-western Arkansas (Decker 1936*a*, p. 308; 1936*b*, pp. 1256–7, table 1; Harlton 1953, p. 787, fig. 2; Twenhofel *et al.* 1954; Berry 1960*a*, p. 38, table 2). The fauna contains, in particular, *Dicellograptus complanatus*, which gives its name to the lower graptolite zone of the British Ashgill. Lee (1943, p. 40) asserts, but without supporting evidence, that the Maquoketa Formation and the Sylvan Shale are equivalent, and (op. cit., pp. 43, 108) uses the terms 'Maquoketa' and 'Sylvan' interchangeably.

For many years prior to the mid 1930s the age of the Sylvan Shale was in dispute, the formation being assigned alternately to the Ordovician and Silurian Systems. Although most authors expressed their opinions about the Sylvan's age cautiously, sometimes acknowledging them to be provisional, a few asserted their views with unwarranted confidence. Indeed, in 1930 (p. 306) Levorsen, making no attempt to substantiate his claim, went so far as to state categorically that 'Eventually the Sylvan shale and the underlying upper Viola limestone will undoubtedly be generally regarded as Silurian in age.' A few years later Decker (1935) recorded graptolites of unquestionable Ordovician age in the lower beds of the formation, and the debate virtually ceased.

It is important to realize, however, that Decker's discovery of graptolites did not completely solve the problem of the Sylvan Shale's age, and that for 35 years the *whole* formation has been dated and correlated on the basis of graptolites which generally are confined to the basal beds and only exceptionally extend up through the lower 100 ft. (30 m). The upper part of the Sylvan Shale, 200 ft. (60 m.) or more thick over much of southern Oklahoma, apparently lacks not only graptolites but all macrofossils, and has been placed in the Ordovician on the basis of its association with the lower Sylvan.

The present study demonstrates for the first time that the formation is Ordovician *in its entirety*, and at the same time confirms with additional fossil evidence the Upper Ordovician age of the lower beds. It is hoped, and considered likely, that when the vertical ranges of chitinozoans in the North American type sections (or other standards of stratigraphical reference) are better documented this study will provide a means of correlating and more precisely dating all parts of the formation.

TABLE 2. List of previously described species (column A) found in the Sylvan Shale and their occurrences in reliably dated sediments outside Oklahoma.

Previously described species in the Sylvan Shale \ Occurrence outside Oklahoma	Upper Ordovician			Lower Ordovician of Estonia and Britain
	Northern Europe	Southern Ontario	Anticosti Island, Quebec	
Conochitina cactacea	X			
Conochitina elegans	X			
Cyathochitina ontariensis		X		
Desmochitina minor	X		X	X
Desmochitina scabiosa	X (designated *D. lecaniella*)		X	
Kalochitina multispinata		X		
Column A	B	C	D	E

The six previously described species in the Sylvan Shale occur in Upper Ordovician sediments over a very wide area. To my knowledge only one of them, *Desmochitina minor*, has been recorded in reliably dated sediments below the Upper Ordovician (Eisenack 1958, 1962*a*, *b*; Jenkins 1967), and none is known from sediments reliably dated as Silurian. Four (Table 2, column B) are present in northern Europe (Eisenack 1962*b*, 1965; Laufeld 1967; Jenkins 1967) and two (column C) occur in the subsurface of southern Ontario (Jansonius 1964). In addition, I have encountered typical examples of *D. minor* and *D. scabiosa* in photographs of Upper Ordovician chitinozoans from the subsurface of Anticosti Island, Quebec; this record, based upon material kindly provided by Dr. Jansonius, raises to four the number of species common to the Sylvan Shale and the Upper Ordovician of eastern Canada (Table 2, columns C and D).

A new species found in the Sylvan Shale, *Acanthochitina rashidi*, is furnished with a well-developed 'raised reticulum' (q.v., text-fig. 2; and Jenkins 1967, text-fig. 3), a rare style of ornament which elsewhere, perhaps significantly, is known only from young Ordovician deposits. These are, namely, the Ostseekalk of north Germany (Eisenack 1965), the Lyckholm Beds, F_1, of Estonia (Eisenack 1962*b*), the Caradoc of Anticosti Island, Quebec (Jansonius 1967, pl. 1, fig. U), the upper Caradocian Onnia Beds in the Caradoc type section, Shropshire, England (Jenkins 1967), and the uppermost Caradoc of central Sweden (Laufeld 1967, pp. 295–6, 298).

The presence in the Sylvan Shale of cylindroconical chitinozoans with strongly developed, anastomosing appendices (*Clathrochitina sylvanica*) would appear to herald the approach of Silurian time and emphasizes the very young Ordovician age of the formation. Chitinozoans of this general type are elsewhere known only from sediments of Silurian and, perhaps, earliest Devonian age (Eisenack 1959; Taugourdeau and Jekhowsky 1960, pl. 2, fig. 32; Cramer 1964, 1967*a*; Taugourdeau 1967).

APPENDIX: DESCRIPTION OF SAMPLES

The samples used in this study are listed below in ascending stratigraphical order. They are numbered according to their original positions (measured in feet) above the Fernvale Limestone–Sylvan Shale contact. Thus sample Sy280, for example, is from a horizon 280 ft. above this datum.

The total thickness of the Sylvan Shale in Sycamore Creek was measured as 305 ft. (93 m.).

Syl	Calcareous, dark brown, hard platy shale with conchoidal fracture, containing black graptolite compressions.
Sy16	Slightly calcareous, buff- to orange-weathering brown shale.
Sy40	Slightly calcareous, dark grey shale containing abundant graptolites.
Sy60	Slightly calcareous, dark greyish-brown shale.
Sy80	Slightly calcareous, dark greenish-grey, hard splintery shale with conchoida fracture.
Sy100, Sy120	Slightly calcareous, dark brown silty shale with thin yellow and grey laminae.
Sy140	Slightly calcareous, green to greenish-brown, soft shale.
Sy160	Slightly calcareous, green, soft shale with purple-hearted concretions.
Sy180, Sy200	Slightly calcareous, dark greenish-grey, soft shale.
Sy220, Sy240, Sy260	Calcareous, greenish-grey, soft concretionary shale.
Sy280, Sy300, Sy305	Calcareous, light green, soft claystone, which disaggregates readily in water.

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W. A. M. JENKINS
Humble Oil and Refining Company
P.O. Box 2189
Houston, Texas 77001, U.S.A.

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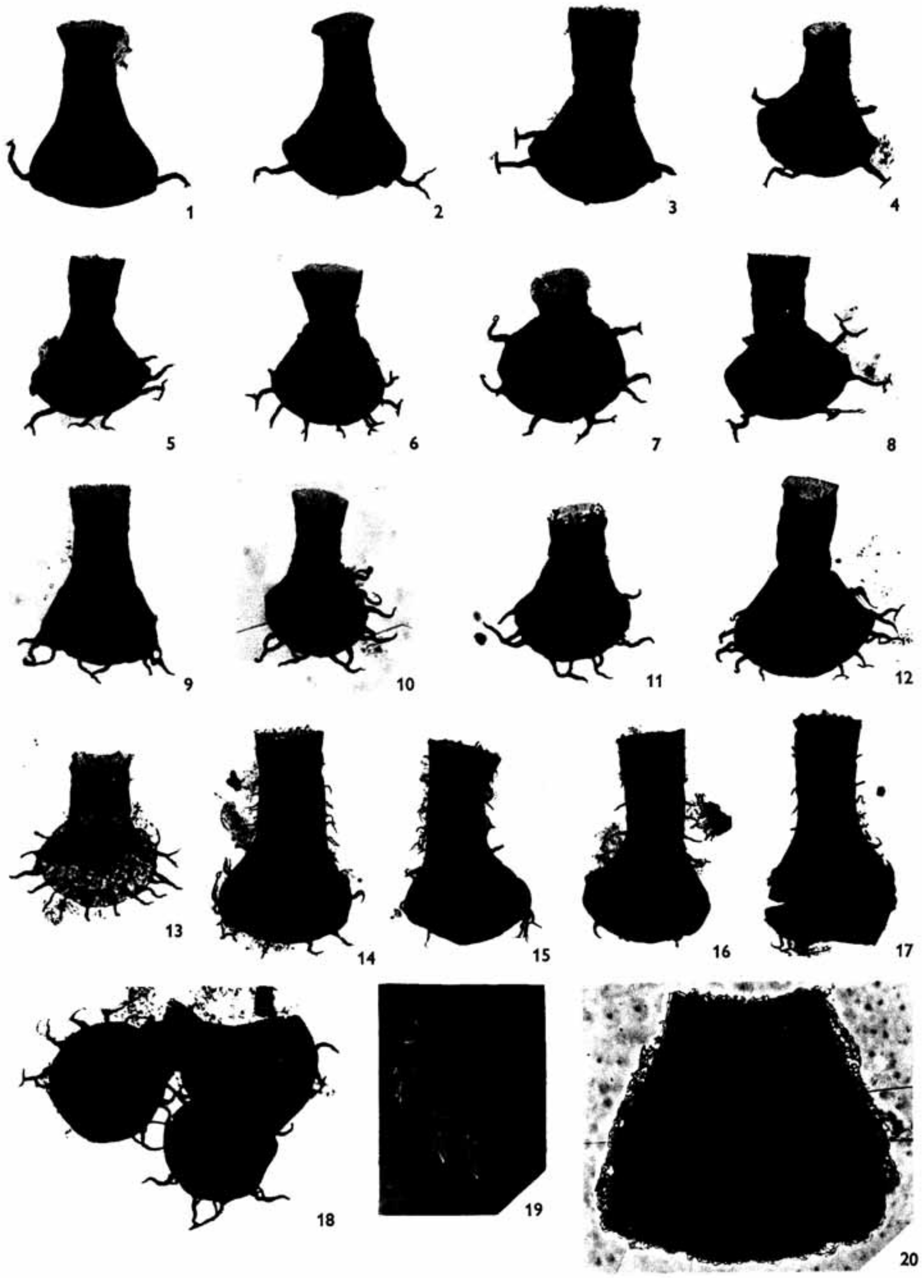
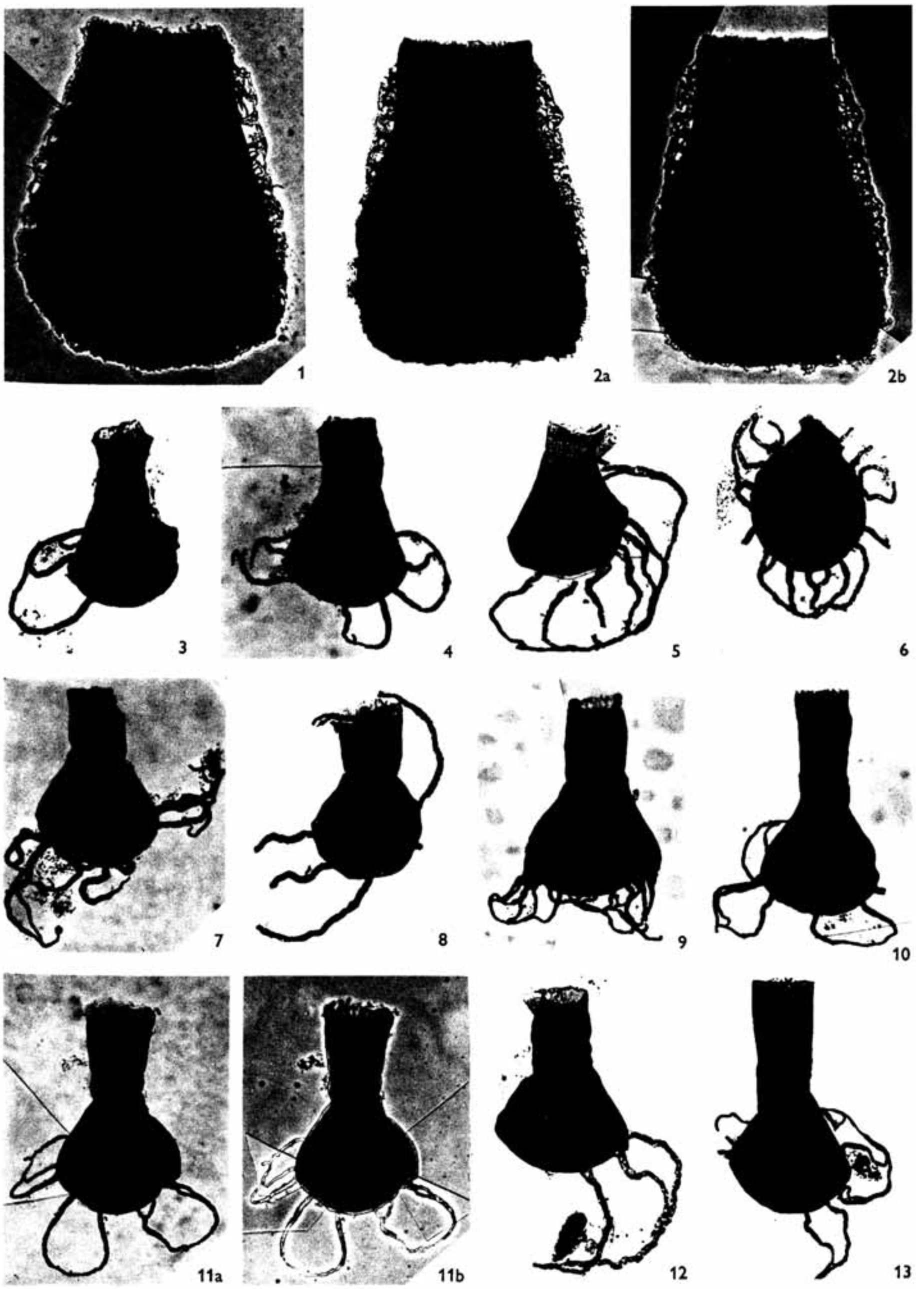


JENKINS, Ordovician chitinozoa from Oklahoma



JENKINS, Ordovician chitinozoa from Oklahoma

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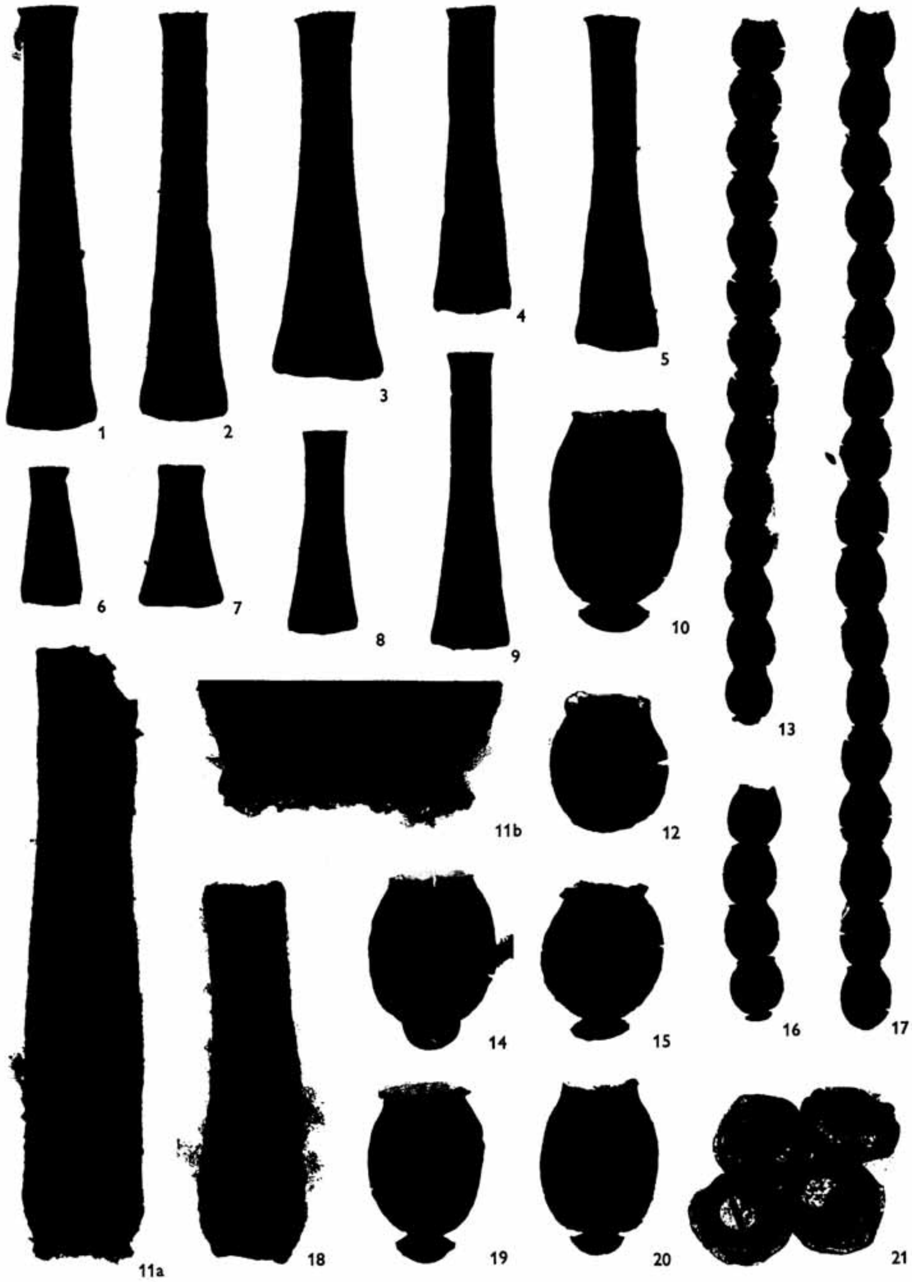
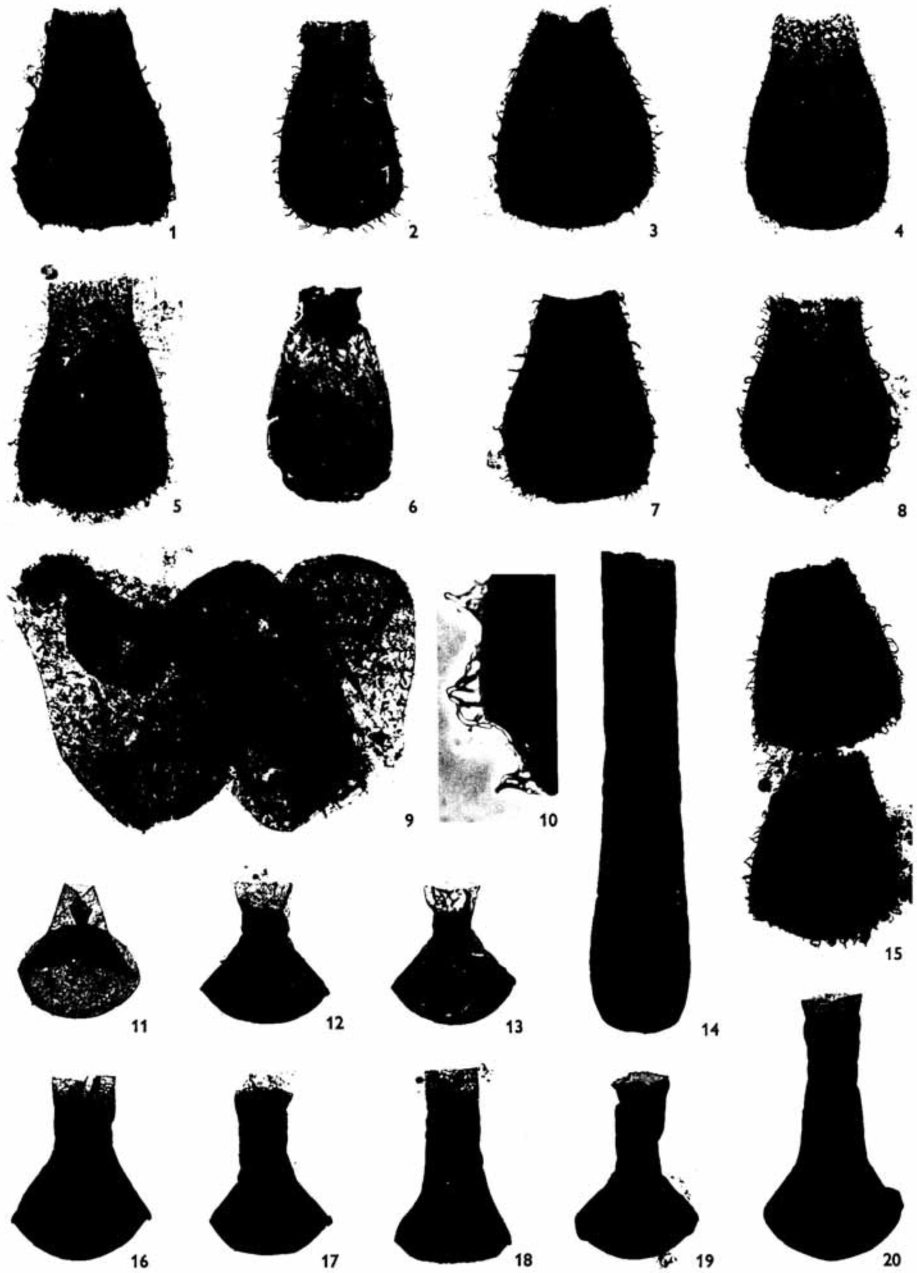


JENKINS, Ordovician chitinozoa from Oklahoma



JENKINS, Ordovician chitinozoa from Oklahoma