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FORAMINIFERAL SHELL STRUCTURES: EXOSKELETON AND ENDOSKELETON

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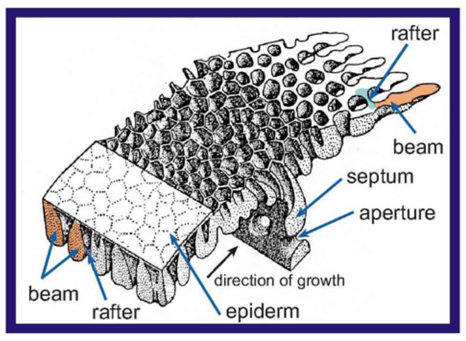
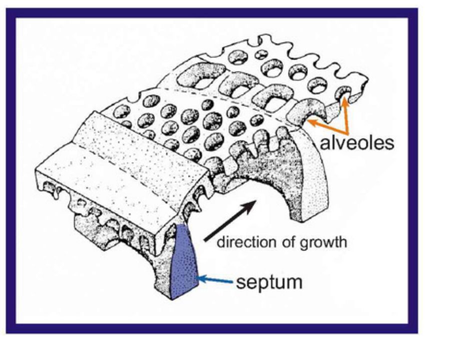
STRUCTURE
Three-dimensional design shaping chamber covities as patterns repeated in successive chamber or chamberlet cycles. It is recommended to use the term "structure" in a very precise and somewhat restricted way, i.e. In opposition to wall texture, patterns unrelated to shape of chamber lumina, as well as shell architecture.

TEXTURE
Pattern of arrangement of crystallites, agglutinated grains, organic matter, pores, lamination or layering. Not related to shape of the chamber cavity, i.e. of the protoplast.

ARCHITECTURE
Term combining structural design, chamber shape and chamber arrangement to a complex, highly diagnostic set of patterns.

Shell elements subdividing chamber lumen produce by their repetition regular geometrical patterns in space called structures. Most of them can be recognised in randomly oriented sections of a shell. Many are diagnostic on the generic level.
The functionality indicated by striking analogies in structural evolution through geological time and the biostratigraphical significance of the structural patterns observed oblige to distinguish two sets of patterns subdividing the chamber lumen and occurring in various combinations. One type is produced by different kinds of alveolar layers usually coating the internal surface of lateral chamber walls; the other is due to mineralised shell elements linked to the protoplasm circulating between neighbouring chambers. The former is called *exoskeleton*, the latter *endoskeleton*.





EXOSKELETON

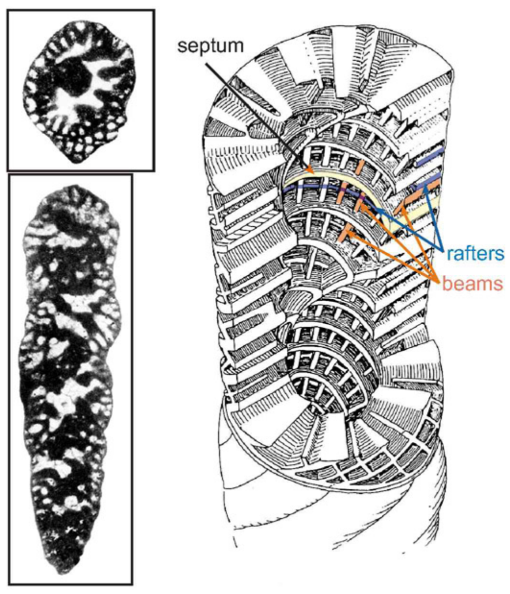
Localised thickenings of the chamber's outer walls on its internal surface subdividing the chamber lumen into blindly ending compartments and forming geometric patterns which are independent in number and direction from those determined by protoplasmic foraminal systems. Three basic type are distinguished. In many Recent, larger foraminifera the exoskeletal cavities harbour symbionts.

Orbitopsella Munier-Chalmas

Lituosepta Cati

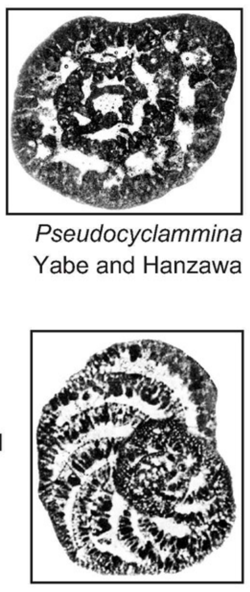
A) Subdivision of the chamber lumen below lateral walls by a series of simple partitions perpendicular in respect to the septum. Such partitions are called **beams**. Their position, direction and number is not related to position, direction and number of the neighbouring foramina. Example: *Orbitopsella, Lituosepta.*

Kurnubia Henson.
Columellar endoskeleton with subepidermal reticular network as exoskeleton.



B) Subdivision of the chamber lumen below lateral walls by series of partitions perpendicular to the septum (**beams**) and parallel to the septum (**rafters**), producing layers of alveolar cavities with a blind ending of polygonal outline below a thin epiderm. **Polygonal subepidermal network** of this type are a wide-spread differentiation in foraminifera with agglutinated walls and may be combined with parapores (*Dicyclina*) or keriothecal (*Neoschwagerina*) wall textures. They also occur in perforate-lamellar, conical foraminifera (*Fabiania*).

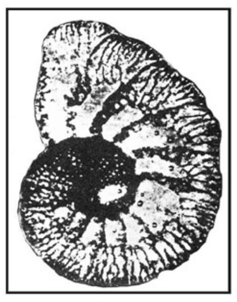
Anchispirocyclina Jordan and Applin.
Septa strongly bent in axial direction and intercalation of new radial elements during shell growth produces some apparent irregularities of the foramenal patterns.



Pseudocyclammina Yabe and Hanzawa

C) True alveolar layers have no endoskeletal differentiation with thicker beams perpendicular to the septum reaching further into the main chamber lumen, and thinner, shorter rafters. The blind endings of the alveole below the lateral wall surface is rounded in outline. There may be layers of short alveoles coating the inner surface of lateral walls or deep layers of several generations of alveoles. In the agglutinated genus *Cyclammina* and in the porcelaneous genus *Austrotrillina,* the evolution of simple to composite alveolar layers can be demonstrated with their respective subsequent stratigraphical ranges.

Everticyclammina Redmond

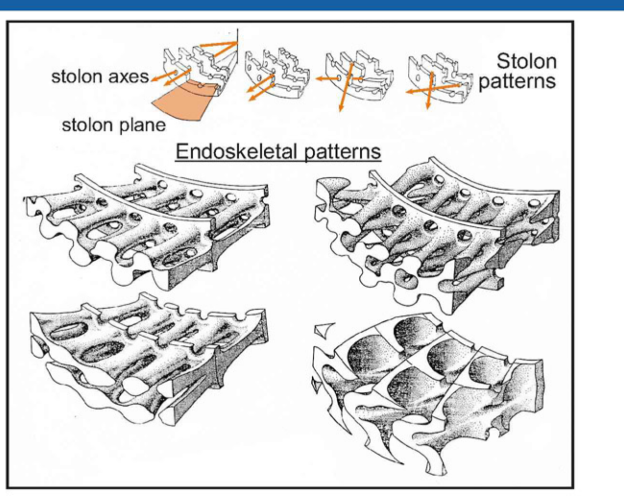


Cyclammina Brady

Alveosepta Hottinger.
Exoskeletal structures are incorporated in the septum.

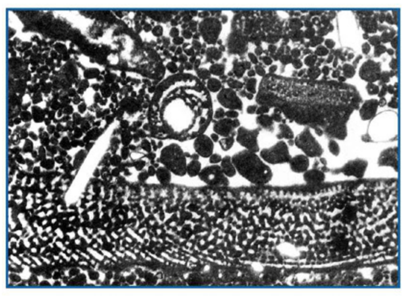
ENDOSKELETON

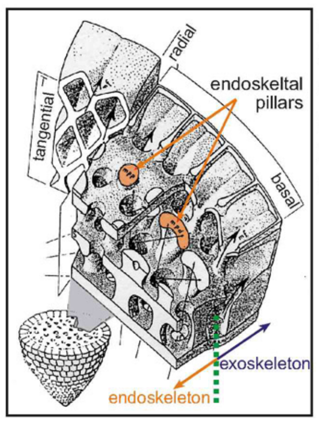
Localised thickenings of the chamber's outer walls on its internal surfacace partly or totally subdividing the main chamber lumen in the lee of protoplasmic streams according to a pattern produced by the arrangement of inter-cameral foramina in the sequence of successive septa (i.e. septula, pillars or interseptal pillars, basal layers of miliolids, chomata and parachomata of fusulinids).
The endoskeletal shell elements may consist of walls subdividing the chamber into chamberlets (septula) or linear elements (pillars) following the flux of the protoplasm along the foramenal axes without subdividing the chamber lumen into definite compartments. The endoskeleton must allow the migration of the symbionts from their position below one lateral shell wall to the other, a device for regulation of the light irradiance of the symbionts in the daily cycle.



A) *Orbitopsella*: radial pillars alternating in radial direction from one apertural layer to the next one. This kind of endoskeletal pattern is by far the most widespread in agglutinated discoidal or peneropliform-planispiral shells and characterises also the porcelaneous archaiasinids.

Orbitopsella Munier-Chalmas



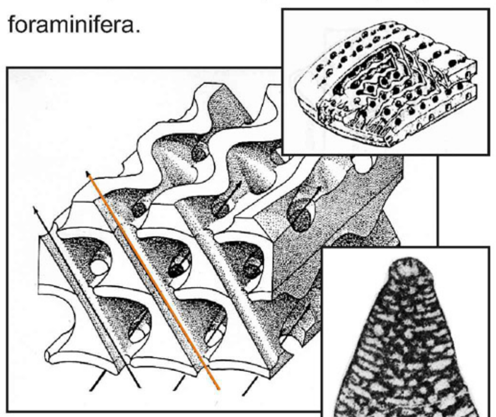


Fallotella Mangin
Endo- and exoskeleton in conical imperforated, non-lamellar shell (apertural view).

Spirocyclina Munier-Chalmas

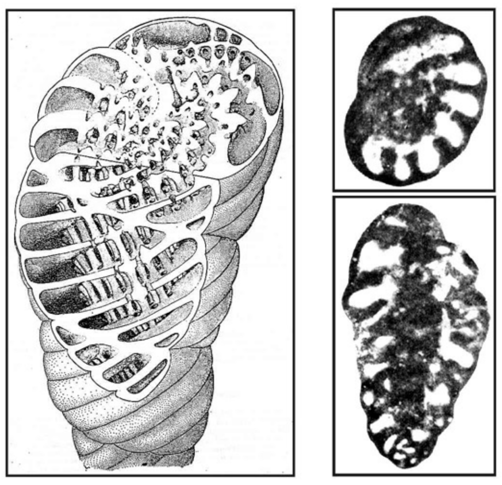
B) *Cyclopsinella*: radial pillars superimposed in radial position from one apertural layer to the next. This pattern is found in agglutinated *Spirocyclina* or *Saudia* as well as in porcelaneous endemists of the Caribbean Eocene (*Cyclorbiculinoides*).

C) "Orbitolinid structure": the endoskeletal elements are oblique in respect to the radius of the shell and changing direction in subsequent foramenal layers. This produces undulated endoskeletons if they are composed of septula. Apertures superposed in successive foramenal layers are most frequent and appear in agglutinated-conical (*Orbitolina*) as well as in discoidal-porcelaneous (*Orbitolites*) larger foraminifera.

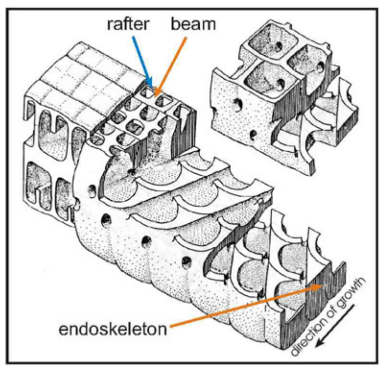


Orbitolina d'Orbigny

Pseudopfenderina Henson.
Columellar endoskeleton where the septa are closed together, apertures and endoskeletal pillars may be cemented by secondary (?) deposits producing an almost solid columella bordered by one or several, large, resorbed foramina.

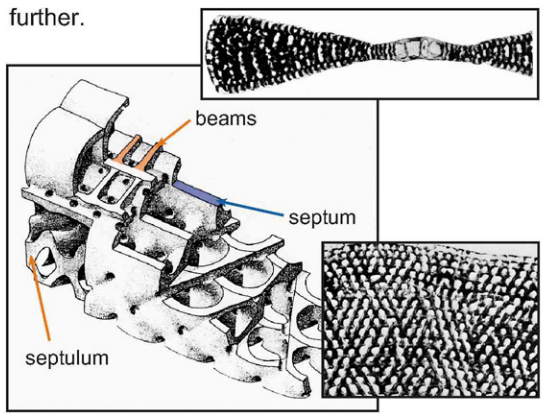


D) The endoskeletal elements are oblique in respect to the radius of the shell and changing direction in subsequent foramenal layers. However, the apertures are alternating in radial position in successive foramenal layers. This pattern is rather rare but, again, appears independently in agglutinated (*Ilerdorbis*) and porcelaneous (*Marginopora*) genera.



Ilerdorbis Hottinger and Caus

Marginopora Quoy and Gainard.
Thickening of the margins in a discoidal shell during ontogeny multiplying the number of radial apertures. The margin is folded in addition to its thickening in order to enlarge the septal face even further.



RELATIONSHIP EXOSKELETON-ENDOSKELETON

Where endoskeletal and exoskeletal elements coexist in the same chamber both contribute to the compartmentation of the chamber protoplast. In *Orbitopsella* and *Anchispirocyclina* for instance, having both pillared endoskeletons, there is a clear separation of exoskeletal from endoskeletal elements by an empty space of open chamber lumen designated some times as annular passage. In most conical foraminifera with septular endoskeletons such as *Orbitolina*, in planispiral-involute agglutinated forms, such as *Neoschwagerina*, *Reticulinella*, as well as in biserial-annular forms (*Dicyclina*, *Cuneolina*), the septula fuse with the first generation of beams. This fusion produces complete partitions reaching the primary lateral chamber wall. The occasional fusion of endo- and exoskeletal elements is no argument to abandon its distinction in favour of undifferentiated terms such as "subepidermal partitions".

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