

# *Pachycolumella* nov. gen., a new shallow-water benthic imperforate foraminifera and its species from the Maastrichtian and Paleocene of Iran

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**ABSTRACT:** A new pfenderinid taxon is described as *Pachycolumella* nov. gen. with the two species *P. elongata* n. sp. (type-species), and *P. acuta* n. sp. The type material comes from the upper Maastrichtian Tarbur Formation of the Zagros Zone, SW Iran. A reconstruction of *Pachycolumella* nov. gen. is presented including all morpho-structural elements such as a conspicuous central columella. The wall of the elongate and triserially coiled test is microgranular-agglutinated displaying a pseudokeriothecal texture. *Pachycolumella* species are also reported from the Paleocene (Danian–early Thanetian) of Turkey, Oman, Iran (this paper), India, and Pakistan, thus representing a K–Pg survivor taxon. In Iran *Pachycolumella* is reported from various localities belonging to both the former northern and the southern Neo-Tethyan margin. In the western Neo-Tethyan realm (e.g., Adriatic Carbonate Platform), *Pachycolumella* seems to be absent.

**Keywords:** Foraminiferida; Pfenderinidae; taxonomy; biostratigraphy; Upper Cretaceous; Early Paleogene

## INTRODUCTION

The Maastrichtian Tarbur Formation, named after the village of Tarbur (Fars Province), represents a shallow-water predominantly carbonate succession of SW Iran (Zagros Zone) rich in larger benthic foraminifera and calcareous algae (James and Wynd 1965). Towards the southwest, the Tarbur Formation interfingers with the Gurpi Formation that usually underlies the former. In the stratigraphic chart of Iran provided in 1995 by the Geological Society of Iran, the Tarbur Formation is assigned to the Campanian-Maastrichtian interval. Some taxa of calcareous algae and benthic foraminifera from the Tarbur Formation, often improperly illustrated, are indicated and illustrated in various recently published papers (Vaziri-Moghaddam et al. 2005; Afghah 2009, 2016; Maghfouri-Moghaddam et al. 2009; Rajabi et al. 2011; Abyat et al. 2012, 2015; Afghah and Farhoudi 2012; Pirbaluti and Abyat 2013; Pirbaluti et al. 2013; Afghah and Yaghmour 2014). New taxa including several newcomer genera, have been described in recent times (Schlagintweit and Rashidi 2016, 2017a-c, 2018; Schlagintweit et al. 2016; Consorti and Rashidi 2018, 2019; Consorti et al. 2018).

In the present paper a new genus and two new species of benthic foraminifera are described as *Pachycolumella elongata* n. gen., n. sp., and *Pachycolumella acuta* n. sp. from three sections from the Tarbur Formation (text-fig. 1). Additional finds are from the Paleocene of the Zagros Zone, Central and Eastern Iran.

## STUDIED SECTIONS

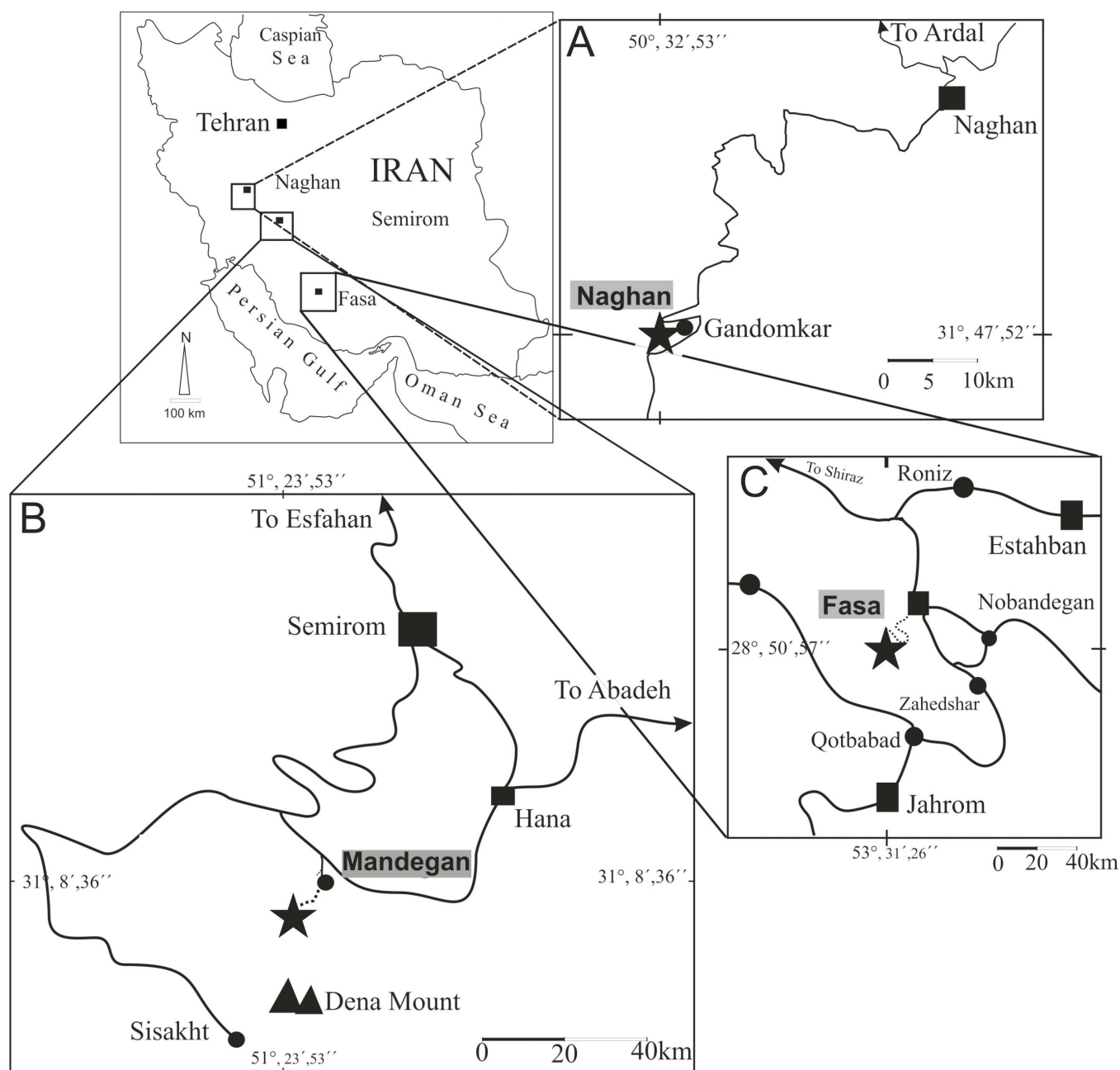
The samples containing the new taxa described herein come from all together seven localities: three from the Late Creta-

ceous (including the type-localities) and four from the Paleocene. The Paleocene samples are less rich in specimens compared to the Late Cretaceous ones. Due to this and the circumstance that the Paleocene localities have so far been only randomly sampled and crudely analyzed, only short information is provided in contrast to the Late Cretaceous type-localities. It is worth mentioning that the Tarbur Formation of the Zagros Zone belongs to the former Southern Neotethyan margin (e.g., Barrier and Vrielynck 2008). The Paleocene localities are all from different palaeotectonic positions and belong to both former Southern and Northern Neotethyan margin.

## Late Cretaceous

### Mandegan section

The study area, located in the High Zagros Belt, is situated north of Mount Dena, about 65 km south of the town of Semirum. The section of the Tarbur Formation is exposed about 10 km south of the village of Mandegan. Here the Tarbur Formation with a thickness of ~272 m overlies conformably the Gurpi Formation (text-fig. 2). The top of the section is unconformably overlain by conglomerates of the Pliocene Bakhtiari Formation (see Bahrami, 2009, for details). Based on the lithostratigraphy, the section has been divided into three units (from base to top): unit 1 is dominated by thick-bedded limestones, unit 2 mostly contains medium-bedded limestones with intercalated marly limestone layers, and unit 3 consists of marly limestones. Specimens of *Pachycolumella* n. gen. were not observed in lower part of the Mandegan section, the limestones containing *Orbitoides-Siderolites*, appearing in the upper part of unit 1. The Mandegan section represents the type-locality of other larger benthic



TEXT-FIGURE 1

Location of the section of the late Maastrichtian Tarbur Formation containing *Pachycolumella elongata* n. gen., n. sp., and *Pachycolumella acuta* n. sp. A: Naghan section (type-locality), B: Mandegan section, C: Fasa section. For the Paleocene localities see Table 1.

foraminifera: *Accordiella? tarburensis* Schlagintweit and Rashidi, and *Spirolina? farsiana* Schlagintweit and Rashidi. The Greenwich coordinates of the section base are N 31°, 2', 58.13" and E 51°, 24', 34.58".

#### Naghan section

The studied area in the folded Zagros belt is located approximately 50 km south west of Naghan town near the Gandomkar village and is here named Naghan section. At this locality, the Tarbur Formation is underlain by the Gurpi Formation and overlying by the Paleocene Sachun Formation. Lithologically,

the Gurpi Formation consists of dark, grey carbonatic shale with planktonic foraminifera. The Sachun Formation consists of gypsum, red shales, anhydrite and some layers of carbonates.

The thickness of the Tarbur Formation at the Naghan section is about ~ 273 m. It is composed of medium to thick-bedded grey limestone, shales and marls and can be subdivided into 5 units

- unit 1 (99 m), red to yellow shales
- unit 2 (61 m), medium- to thick-bedded grey limestones with *Loftusia* and rudist debris (calcarenes to calcirudites)

TABLE 1

Comparison table of the four localities with Paleocene carbonates from Iran containing *Pachycolumella* nov. gen.

Locality (section base)	East Iran ~215 km N of Zahedan (31°22'59.10"N, 60°49'36.58"E)	Central Iran ~70 km S of Yazd (31°14'37.28"N 54°33'43.27"E)	North-eastern Iran	Southwestern Iran ~60 km SE of Shiraz (29°11'31.59"N; 52°52'33"E)
Section name	Kuh-e-Patorgi (or Zahedan)	Kuh-e Chahtorsh	Chehel-Kaman	Qorban
Section thickness	~315 m	> 150 m	~120 m	~210 m
Formation	Palang Formation	Lithostratigraphically not defined	Chehel-Kaman Formation	Sachun Formation, Qorban Member
Geotectonic setting	Sistan Suture Zone (or East Iran Flysch Zone)	Yazd Block, Central Iran Microcontinent	Kopet-Dagh Basin	Zagros Zone, Arabian Plate
Palaeogeographic setting	Northern Neotethyan margin			Southern Neotethyan margin
Reference	Tirrul et al. (1983) Habibimood et al., 2016.	Deloffre et al. (1977)	Rivandi et al. (2013, 2015)	Bavi Oweydi et al. (2016), Heibati et al. (2014)

- unit 3 (33 m), intercalation of grey shales and cream to grey, medium- to thick-bedded limestones (calcilutites and calcarenite)

- unit 4 (38 m), thick-bedded to massive, grey to cream-colored limestones containing broken rudist shells and tests of *Loftusia* (calcarenite, calcilutite, calcirudite)

- unit 5 (~ 41.6 m), shales interbedded with medium- to thick-bedded yellow limestones containing *Loftusia* fragments.

*Pachycolumella* species were observed within a wide interval, starting at the base of the carbonatic unit 1 and reaching almost the top of the Tarbur Formation (unit 5). The Naghan section represents the type-locality of other larger benthic foraminifera: *Dictyoconus bakhtiari* Schlagintweit, Rashidi and Babadipour, *Persiacyclammina maastrichtiana* Schlagintweit and Rashidi, *Flabelloperforata tarburensis* Schlagintweit and Rashidi, *Persiella pseudolituus* Schlagintweit and Rashidi, *Pseudonummuloculina kalantarii* Schlagintweit and Rashidi, *Zagrosella rigaudii* Schlagintweit and Rashidi. With the designation of the two holotypes, the Naghan section is also the type-locality of *Pachycolumella elongata* nov. gen., n. sp., and *P. acuta* n. sp.

The Greenwich coordinates of the section base are N 31°47' 52" and E 50° 32' 53".

#### Paleogene

Kuh-e-Patorgi section, East Iran, Sistan Suture Zone

Kuh-e Chahtorsh section, Central Iran

Chehel-Kaman section, North-eastern Iran, Kopet-Dagh Basin

Qorban section, South-western Iran, Zagros Zone

For short information see Table 1.

#### MATERIAL AND METHODS

The specimens of the new taxon described illustrated in the present contribution in Plates 1–3 are from numerous thin-sections from the upper Maastrichtian Naghan section (pre-fix NG, 2NG), the Mandegan section (prefix Rt). One specimen illustrated comes from the Fasa section (labelled A 6). The Paleocene material shown in Plate 4 are from the Chelkaman section (labelled Nf 3, and Nf 5), the Qorban section (prefixes Q and Qs), the Zahedan section (labelled 1pz 25, and 2pz 27), and the Chahtorsh section (labelled Ah 162). These thin sections are stored at the Ardakan Payame Noor University, Iran, in the Rashidi collection.

#### SYSTEMATIC PALEONTOLOGY

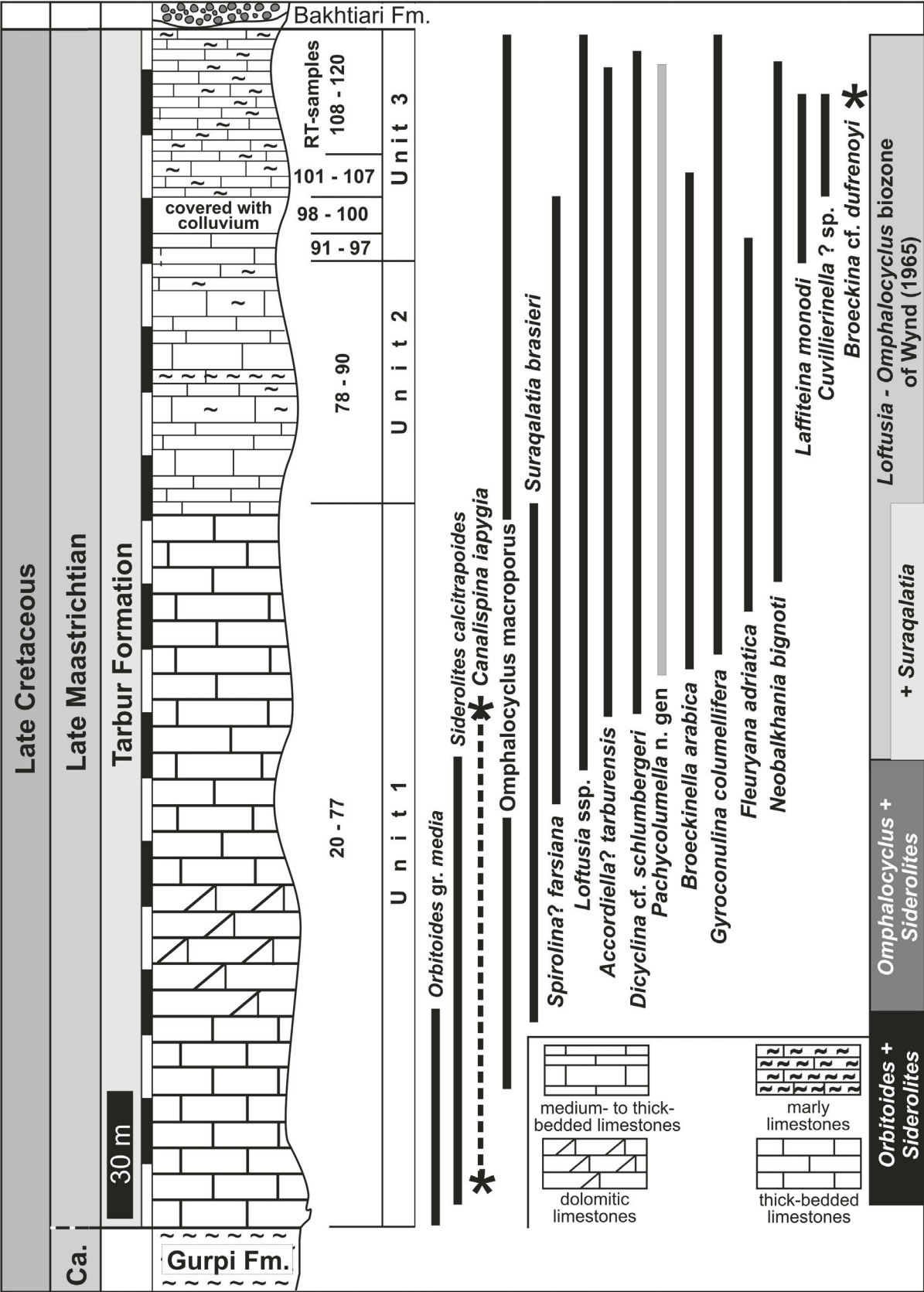
The high-rank classification follows Pawlowski et al. (2013). For the low-rank classification see Kaminski (2014).

Phylum FORAMINIFERIDA d'Orbigny 1826  
Class GLOBOTHALAMEA Pawlowski et al. 2013  
Order LOFTUSIIDA Kaminski and Mikhalevich 2004  
Suborder ORBITOLININA Kaminski 2004  
Superfamily PFENDERINOIDEA Smout and Sugden 1962  
Family SIPHOVALVULINIDAE Gale, Barattolo and Rettori 2018

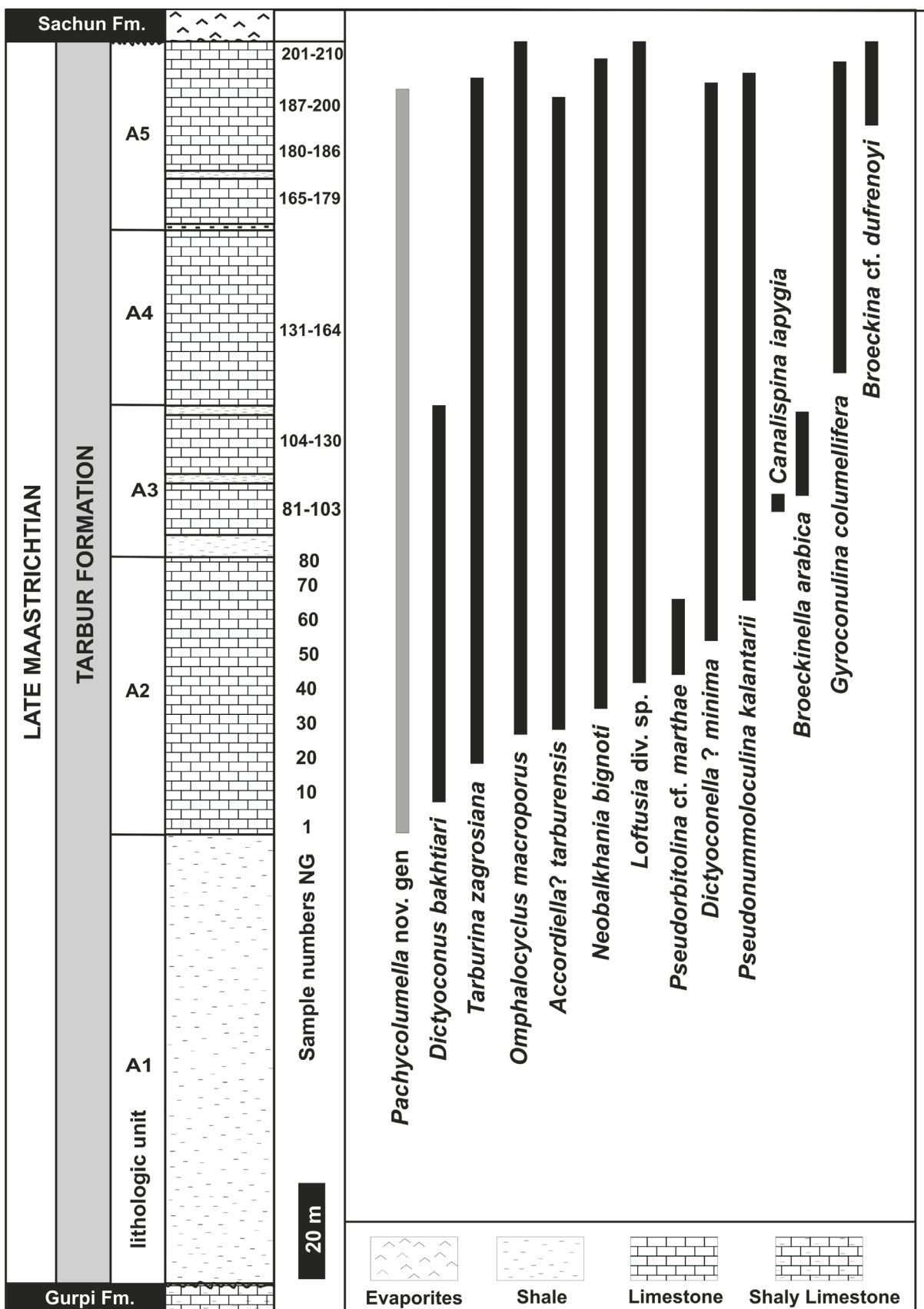
Genus *Pachycolumella* Septfontaine, Schlagintweit and Rashidi **n. gen.**

*Composition of the genus: Pachycolumella elongata* Septfontaine, Schlagintweit and Rashidi nov. sp. (type-species) and *Pachycolumella acuta* Septfontaine, Schlagintweit and Rashidi nov. sp.

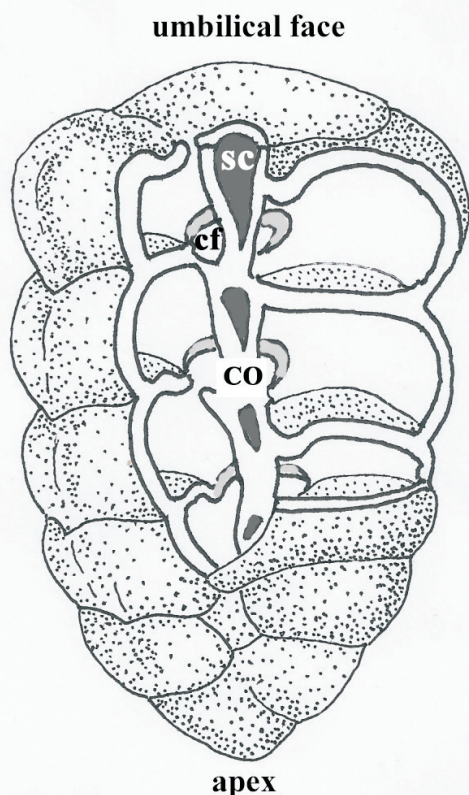
*Diagnosis:* Test elongate, cylindrical to conical. Wall microgranular-agglutinated, with pseudokeriotheca rarely visible. Chambers simple (undivided), trochospirally coiled, triserial throughout. Conspicuous central columella appearing as an



TEXT-FIGURE 2  
Distribution (total vertical range) of *Pachycolumella* nov. gen. and some other larger benthic foraminifera in the Tarbur Formation of the Mandegan section.



TEXT-FIGURE 3  
Distribution (total vertical range) of *Pachycolumella* nov. gen. and some other larger benthic foraminifera in the Tarbur Formation of the Naghan section.



TEXT-FIGURE 4

Three-dimensional test reconstruction (drawing) of *Pachycolumella elongata* n. gen., n. sp., type-species of the genus (vertical size of the model: ~1 mm). The white parts of the wall are cutted at an angle of 90° on the right side, and 225° on the left side. Dark grey surfaces = spiral canal, a half tube open on one side into the columella (see sc on Plate 1); light grey surfaces = crescentic foramina (in horizontal plane), interiomarginal (see cf on Plate 1). For other details and microstructure see Plates 1-4.

helicoïdal succession of inverted half-cones fitted together and connected laterally to the septal flaps, with primary hollow central spiral canal connecting earlier chambers (from the apex) to the aperture. Foramina interiomarginal, crescentic, a basal hemi-annular horizontal slit against the columella, successively and irregularly aligned vertically from one whorl to the next (up to six whorls) defining a characteristic vertical extracolumellar open passage.

**Generic description:** Test free elongated, cylindrical to conical, early ontogenetic contour (apex) characteristically slightly (species *P. elongata*) to strongly acute (species *P. acuta*). Later adult stage subcylindrical with moderately incised sutures. The shape of test and chambers appear as very polymorphic with many transitional morphotypes. Wall thick, microgranular to agglutinated with some isolated calcitic grains. Pseudokeriotheca present (or only visible) in specimen with a thick wall. High conical forms (species *elongata*) may display thinner walls. Chambers subglobular to rhomboedric, sometimes with longitudinal constrictions (pseudokeel, pk) becoming characteristic and constantly present in *P. acuta*. Chambers wider than high, trochospirally coiled in a triserial series

throughout ontogeny. The main axis runs perpendicular to the columella. Septa wavy, with a terminal “hook” directed distally at the margin of the peri-columellar crescentic foramina, facing the columella. The septa can partly coalesce aside with a part of the columella, supporting and defining it; the distal parts of the septa appear as a horizontal flap covering partly the umbilicus above the crescentic interiomarginal foramen and the spiral canal opened to the exterior in umbilical position.

The central columella is made of the juxtaposition of successive vertical inner part (adaxial side) of the chambers wall (side by side) arranged in a trochospire around the umbilical axis, after addition of each chamber. The columella (inner wall of chambers) appears in vertical sections as a succession of black sub-triangular calcitic surfaces corresponding to the sections of inverted half-cones fitted together by their extremities (apex against base). They represent a classical helicoidal arrangement (“endless screw”) in volume. Each inverted cone projects sharply displaying short annular (abaxial) extensions in the chambers, sometimes bifid.

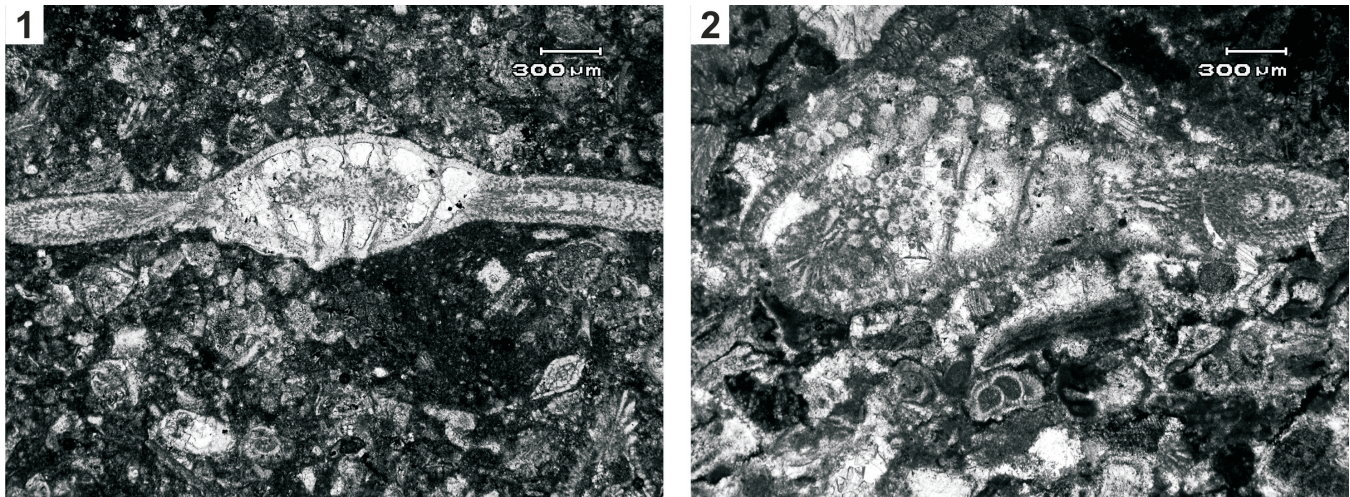
The columella defines an elongated half-spiral canal in its center. It is rarely visible in vertical axial sections cutting episodically the canal, thereby appearing clearly separated and as elongated vertical/oblique dots in the dark central mass. The open distal end of this primary half-spiral canal emerges in the center of the apertural face as an open umbilic, connected laterally to the septal flaps.

The main foramen/aperture is a hemi-annular interiomarginal crescentic horizontal slit open into the septa around and against the columella. It corresponds to a normal basal opening vertically. The successive crescentic openings appear aligned on vertical axial sections, up to a maximum of six whorls.

**Morphological considerations:** The problem of the umbilical siphonal microstructure and its morphological interpretation as well as the biological meaning during the ontogenetic development of the foraminifera is still debatable, and of important taxonomic significance. Regarding the microgranular imperforate “siphonvulinids” with or without visible pseudokeriotheca (see also Gale et al. 2018), classically described in shallow water carbonates of the Mesozoic (often the Liassic), we partly share the interpretation of Gale et al. (2018). For these authors the siphonal canal represents “a narrow umbilical cavity extending from the umbilical side of the test towards the proloculus” which implicate the inner chambers wall, without any other microstructure (or modification?). This definition implies that the “siphon” is an open hollow columella running all along the umbilical axis, primarily formed by the arrangement of the chambers without any transformation. This interpretation is retained here and fits well with the description of the new genus *Pachycolumella*.

Different morphological strategies are applied by the pfenderinid cell (sometimes concomitantly) to manage the connection between chambers, in the central zone (from the earliest chambers to the umbilical face), when new chambers are built or during reproduction (ejection of gamontes to the exterior) (Hottinger 2006a, p. 81):

a. classically through the main interiomarginal or central aperture in morphotypes without columella



TEXT-FIGURE 5

Siderolitid foraminifera *Canalispina iapygia* Robles-Salcedo, Vicedo, Parente and Caus from the late Maastrichtian Tarbur Formation of the Mandegan (1) and Naghan (2) sections. Thin-sections Rt 24 and 2NG101-1. Note its occurrence near the base of the Mandegan section (see text-figure 2).

b. through the primary hollow columella (*Pseudochablaisia* Schlagintweit, Septfontaine and Rashidi, in press, *Pachycolumella* nov. gen., *Radoicicina* Gale, Barattolo and Rettori 2018.

c. the main interiomarginal aperture in trochospirally coiled, microgranular-agglutinated forms, and

d. through the tunnel or groove formed by resorption of a columellar mass of calcitic material by the mature cell, then a cavity of secondary origin (the classical tunnel of the pfenderinids. The spiral canal of *Chablaisia*, and *Pseudochablaisia*, however, may be of diverse origin, primary or secondary (b and c) during ontogenesis.

Other communication between the earliest chambers and the umbilical face in the central zone of the test may be organized by the presence of a siphonal tube or a “tooth plate” (Hofker 1963 in Hottinger 1967). Here the tooth plate or dental plate (modified in a central vertical half-tube) is associated with the central aperture as in *Siphogenerinoides* Cushman. In contrast to the pfenderinids, it is independent of the coiling (columella) and of the mode of arrangement of the chambers (uniserial, biserial to triserial) in hyaline perforate Foraminifera (*Rotalina*, *Bulimina* etc.). The “entosolenian tube” is an equivalent (if not synonym) of the “tooth plate” sensu Hofker, associated with the central aperture and extending from it back into the chambers. According to Hottinger (1967, p. 25) this structure serves to canalize the protoplasmic flux (the dynamic protoplasm) during the building of a new chamber, independently of the marginal zones of the chambers.

**Remarks on pseudokeriothecal wall texture:** Recent larger discoidal shallow-water porcelaneous miliolids (*Sorites*, *Amphisorus* and *Marginopora*) are known to host photosynthetic symbionts such as dinoflagellates, microalgae etc., (e.g., Richardson 2006). They are located in the chamberlets of the marginal zone, divided by radial partitions. It can be reasonably deduced that the isomorphic radial partitions and other analogous microstructures dividing the marginal zone of the chambers like the hypodermic network (defining irregular chamberlets) of

shallow-water Mesozoic microgranular-agglutinated litiolids contained photosynthetic symbionts as well. Pseudokeriotheca (or pseudokeriothecal wall texture) is defined as “uniform parallel, radial elements covered by some kind of tectum” (Hottinger 2006b). This microstructure is morphologically very close to the keriotheca of fusulinids (see discussion in Septfontaine 1980). According to Vachard et al. (2004) this microstructure with tiny alveolae (with flower-like structures) served to house symbiotic algae or cyanobacteria. The pseudokeriotheca is sometimes well discernible in the wall of *Pachycolumella elongata* (Plate 1, figs. 9–10) and common in many litiolid genera but incompatible with radial partitions or a hypodermic network.

**Comparisons:** The latest Cretaceous–early Paleogene *Pachycolumella* n. gen. can be considered as a younger homeomorph of the Liassic *Radoicicina* Gale, Barattolo and Rettori, 2018 in the siphovalvulinids clade. Therefore we propose the placement of *Pachycolumella* n. gen. into the family Siphovalvulinidae Gale, Barattolo and Rettori 2018. It differs from the *Radoicicina* only by secondary characters, as the shape of the chambers (wider and subrectangular in section, perpendicular to the axis of coiling, more rarely subglobular, instead of being always inclined on the axis of coiling by *Radoicicina*) and by the biserial arrangement of adult chambers in the later. In both cases the relationship with the siphovalvulinids with a spiral canal (or siphon) in the columella is apparent. The comparisons at the species level (*P. acuta*) are discussed below. Species of the genus *Pachycolumella*, mainly *P. acuta* n. sp. have already been figured several times in the literature from the late Cretaceous–Paleocene interval under different names (see synonymy above). The most common (erroneous) attribution is to the genus *Valvulina* respectively to the type-species *V. triangularis* d’Orbigny from the Eocene (Lutetian) of France, which does not hold columellar or siphonal microstructures.

We postulate that small valvulinids with horizontal septal flaps may be early ancestral populations of siphovalvulinids (including the latest Cretaceous–Paleocene *Pachycolumella* n. gen.) in the Liassic, after backward deformation of the septa forming a

central siphon. But the true advanced valvulinids genera lack a central columella with spiral canal or siphon and are characterized by a simple horizontal septal flap successively covering the umbilicus, as their ancestors. This is the case of *Redmondoides lugeoni* (Septfontaine), with an interiomarginal aperture (Septfontaine 1977; Banner et al. 1991). The flap can be transformed in a trematophore-like plate and pillars in advanced forms (*Paravalvulina-Chrysalidina*), a character absent in the siphovalvulinids and *Pachycolumella* n. gen. The central half columella spiral canal and the crescentic pericolumellar (interiomarginal) foramina (cf, see model fig. 4) permit a sufficient communication with the exterior for the dynamic protoplasm.

**Etymology:** The genus name refers to the thick columella (pachy, greek = thick, dense, large).

***Pachycolumella elongata*** Septfontaine, Schlagintweit and Rashidi n. sp.

Text-figure 4; Plate 1, figures 1–11; Plate 2, figures 1–14; Plate 4, figures 8–9

not indicated – WEISS 1993, pl. 4, fig. 4, Middle Paleocene of Northern Pakistan.

*Valvulina* aff. *V. triangularis* – SOLAK et al. 2017, fig. 13r, Late Maastrichtian of Turkey.

**Diagnosis:** An elongate (10 to 12 whorls) cylindrical-conical morphotype of *Pachycolumella*, with subglobular chambers and slightly acute contour of the first nepionic chambers. Columella regular, well defined.

**Description:** Test shape an elongate cylindrical to conical shell with a high number of whorls (10 to 12), wall thick; chambers regular sub-globular, larger (2/3) than high, arranged in a triserial coiling throughout. The distal part of the septa in axial section show a conspicuous “hook” directed to the adult part of the test. This structure is the section of an annular furrow sometimes deeply incised which is however common in siphovalvulinids, but less characteristic. Columella regular throughout

the test, with annular lateral extensions into the chambers from the base of each cone of the successive whorls of the columellar “screw”.

**Remarks:** transitional forms to *Pachycolumella acuta* n.sp. are frequent with less whorls (6 to 7) and more acute test contour of earlier chambers, and an irregular (deformed or oblique) columella. Some sections may also belong to immature, not yet adult individual tests.

**Holotype:** Axial section shown in Plate 1, Figure 3, thin-section 2NG 178, Naghan section.

**Dimensions:** The test length in axial section is always millimetric, 1 to 2 mm.

**Etymology:** The species name refers to the elongate test morphology.

**Stratigraphy:** The samples from the Tarbur Formation are of late Maastrichtian age based on larger benthic foraminifera such as *Siderolites calcitrapoides* Lamarck, *Gyrogonulina columellifera* Schroeder and Darmonoian, *Neobalkhania bignoti* Cherchi, *Omphalocyclus macroporus* (Lamarck), and *Loftusia* div. sp. The newly described siderolite *Canalispina iapygia*, a late Maastrichtian marker taxon (Robles-Salcedo et al. 2019), is also reported from the Mandegan and Naghan sections section (text-fig. 5). At the Mandegan section *C. iapygia* has been observed in two samples, one near the base of the Tarbur Formation (text-fig. 2). This excludes early Maastrichtian or even Campanian parts in contrast to observations of Wynd (1965).

From the Pontides of Turkey *Pachycolumella* species have been reported from the late Maastrichtian–earliest Danian (e.g., Solak et al. 2017, fig. 9, “assemblage IIIb”). For the Paleocene from the Turkey detailed data have been provided by Sirel (1998, 2015). For *Valvulina* ? sp. 1 (= *Valvulina triangularis* in Sirel, 2015), Sirel (1998) indicated a Danian to Thanetian age. In a recent contribution specimens of *P. acuta* were illustrated by Solak et al. (2019) from carbonates containing the

## PLATE 1

*Pachycolumella elongata* nov. gen., n. sp., late Maastrichtian Tarbur Formation of the Naghan (1, 5, 6–8) and Mandegan sections (2–4, 9).

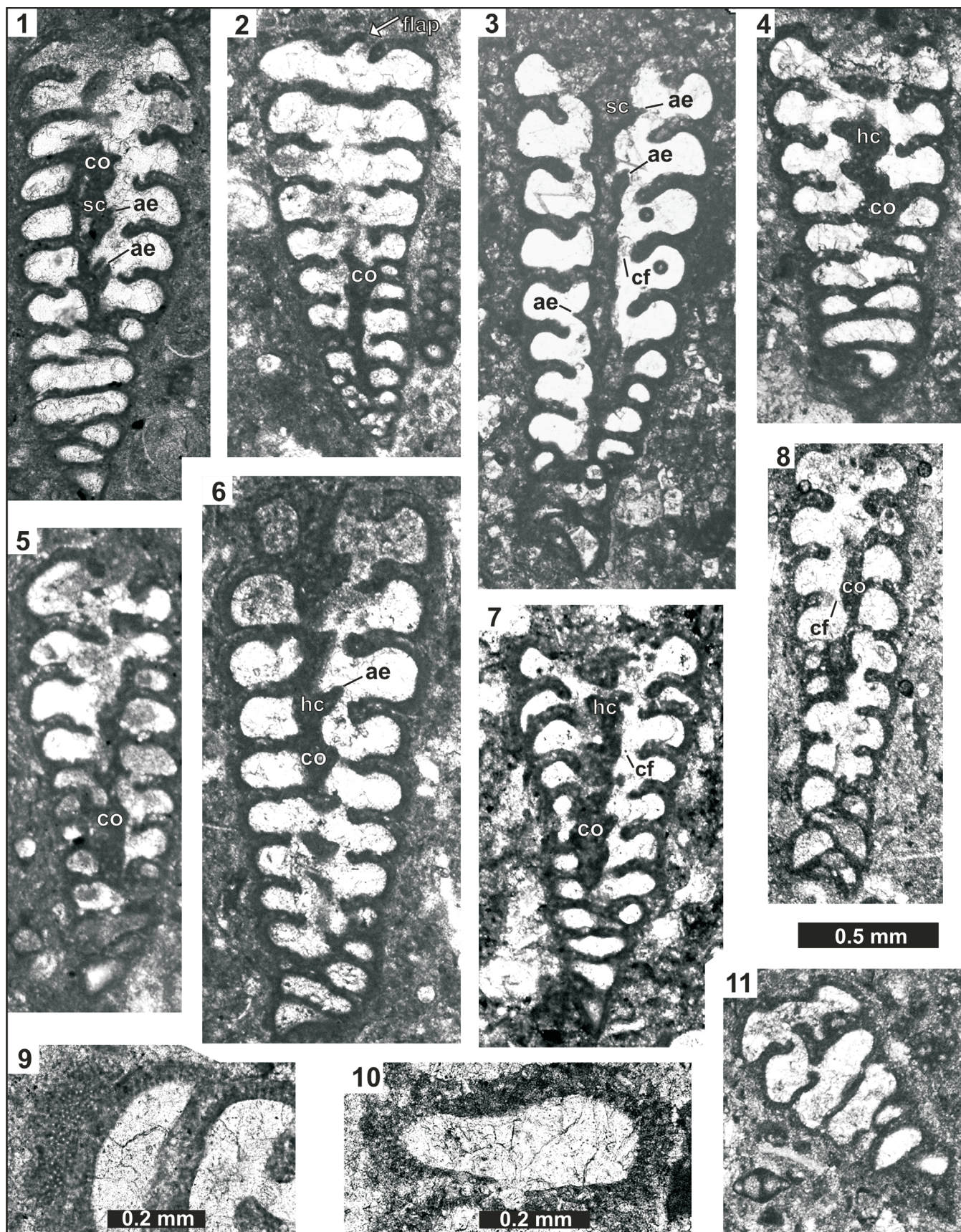
Abbreviations: co = columella, ae = annular extension (from the base of inverted half-cone), cf = crescentic (in the septal horizontal plane) peri-columellar interiomarginal foramen, aligned (black arrow), hc = inverted half-cone of the central “screw”, sc = spiral canal, only sporadically visible as clear dots in axial sections (see model Figure 3).

Thin-sections: 2NG 1 (1, 6, 8), Rt 85 (2), Rt 89-3 (3), Rt 113-1 (4, 9), 2NG 85-3 (5, 7).

1–8, 4–5 (sub)axial sections along the columella.

11 tangential-oblique section.

9–10 detail of the wall showing pseudokeriothecal texture.



dasycladale *Clypeina bucuri* Barattolo described from the uppermost Paleocene?–lower Eocene of Italy (Barattolo and Romano 2002) and later also from the lower Eocene (Ypresian) of Croatia (Sokač et al. 2012). Summarizing, *Pachycolumella* with its two species *elongata* and *acuta* are so far reported from the late Maastrichtian–Thanetian interval, and might possibly also range into the early Eocene.

***Pachycolumella acuta*** Septfontaine, Schlagintweit and Rashidi n. sp.

Plate 3, figures 1–20; plate 4, figures 1–6, 10–11.

*Valvulina*? sp. 1. – SIREL 1998, p. 38, pl. 4, figs 1–17, Danian of Turkey  
*Valvulina*? sp. – SCHLÜTER et al. 2008, fig. 5c-d, Danian–Selandian of Oman.

*Valvulina triangularis*. – SIREL 2015, fig. 21 (table; Paleocene of Turkey; not illustrated)

*Valvulina*? sp. 1 Sirel. – SCHLAGINTWEIT et al. 2016, fig. 7M–N, late Maastrichtian of Iran.

*Pseudochrysalidina* sp. – MATSUMARU and SARMA 2010, pl. 4, fig. 12, Paleocene of India. – MATSUMARU, 2016, pl. 9, fig. 7, Paleocene of Turkey

*Valvulina* aff. *V. triangularis* – SOLAK et al. 2017, fig. 13p-q, 15a-c, f, late Maastrichtian to ?Early Danian of Turkey. – SOLAK et al. 2019, fig. 12d-g, ?early Eocene of Turkey.

*Valvulina* ssp. – SOLAK et al. 2017, fig. 15g-h, m, ?early Danian of Turkey.

**Diagnosis:** Test trochospiral with 6 whorls, triserial; general shape low conical with large umbilical face. Contour of the test in earlier whorls very acute (apex). Most chambers with an angular contour in sections perpendicular to the axis, with a conspicuous constriction (pseudokeel). Central columella irregular (most often a half-circle in basal section) with a large open spiral canal covered by a diversely deformed septal flap on the umbilical face. Extra peri-columellar crescentic openings (in horizontal plane) in an interiomarginal position.

**Description:** Test low conical with variable axial external contour, straight or curved; contour of earlier part very acute to the apex. Triserial arrangement of the chambers, sutures not visible or slightly incised. Chambers rhomboidal in axial section or with very variable shapes, depending of the highly (abnormally) deformed septal flap linked to the central columella. Last chambers occasionally globular in axial sections. Chamber contour sub-triangular in basal section with constricted wall at the exterior end (pseudokeel or ridge, pk). Central columella appearing as a half circle in basal section (defining an irregular

central spiral canal) formed by fusion of successive septal flaps often deformed backward and sutured to the chamber wall of the previous whorl. Aperture an interiomarginal crescentic slit around the columella in horizontal plane. The spiral canal opens to the umbilical face, covered by the wavy septal flap of the last chamber.

**Holotype:** Axial section shown on Plate 3, Figure 1, thin-section 2NG 198, Naghan section.

**Etymology:** The name refers to the acute early ontogenetic stage of the test.

**Type-locality:** Naghan section, Zagros Zone of SW Iran (see Text-figure 1).

**Stratigraphy:** See remarks for *P. elongata*.

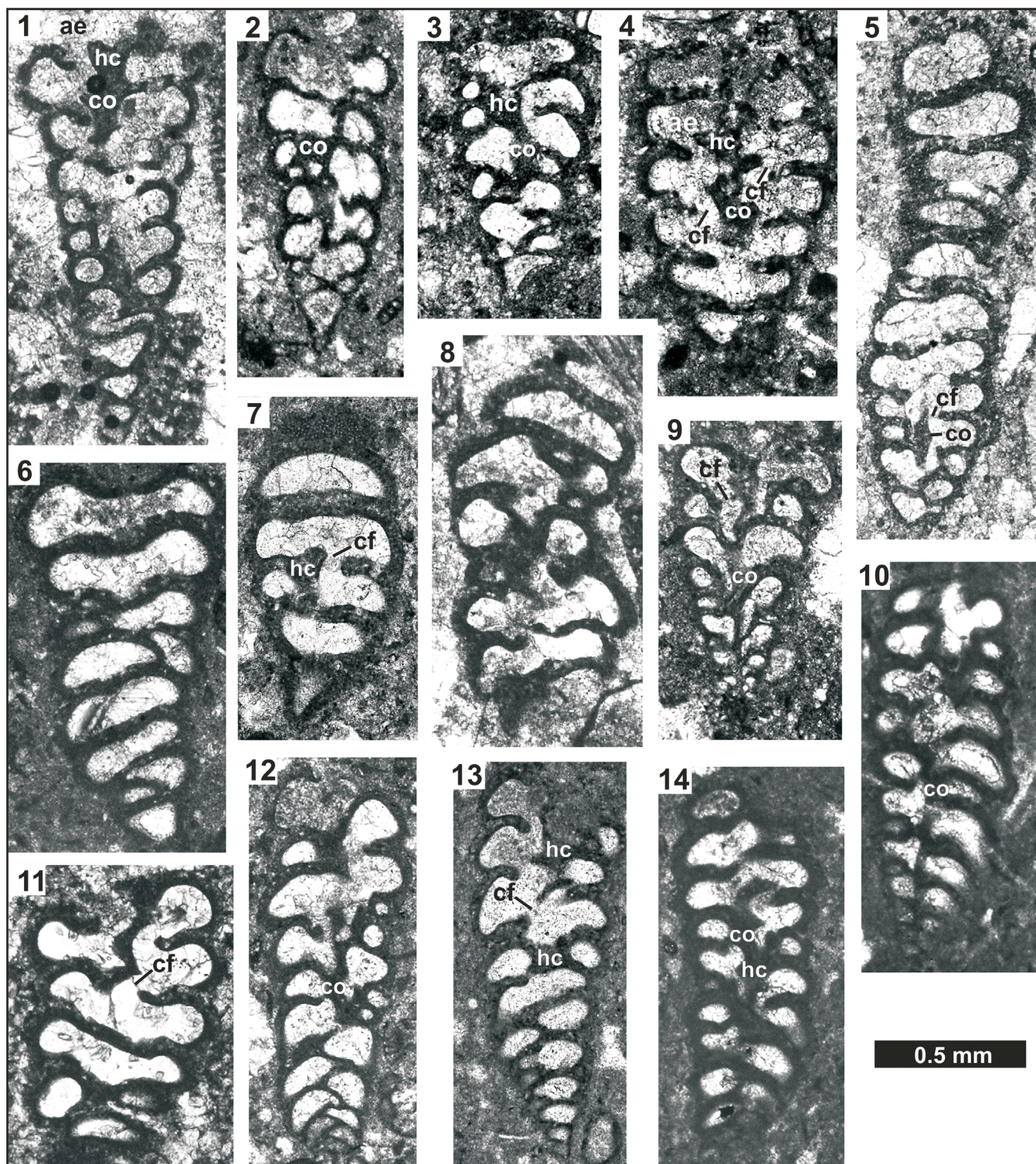
## CONCLUDING REMARKS

The new taxon *Pachycolumella* n. gen. and its two species *P. elongata* n. sp. and *P. acuta* n. sp. belongs to an outstandingly diverse microfaunal assemblage of microgranular imperforate foraminiferids with a pseudokeriotheca in the wall or an hypodermic network in the marginal part of the chambers, indicating possible symbionts bearing cells. These Maastrichtian shallow water inhabitants are phylogenetically related to an older (and roughly smaller) Jurassic stock of planispiral (mesoendothyrids) or trochospiral-columellar (pfenderinids, siphovalvulinids) clades in shallow water environments (Septfontaine 1988). Previous papers from the Tarbur Formation deal with a thorough description of several remarkable Maastrichtian newcomer genera among shallow water microgranular foraminifera at the twilight of the Mesozoic times, during a period of deep perturbations (sea level, temperature and climatic, trophic, anoxic changes etc.): *Flabelloperforata* Schlagintweit and Rashidi 2017a, *Neodubrovnikella* Schlagintweit and Rashidi, 2018, *Persiacyclammina* Schlagintweit and Rashidi 2017b, *Persiella* Schlagintweit and Rashidi 2017a, *Zagrosella* Schlagintweit and Rashidi 2017c. All these taxa evolved at the final acme of the Late Cretaceous Maturation Cycle of Larger Benthic Foraminifera (Hottinger 2001), and became extinct at the K/Pg boundary. Consorti and Rashidi (2018) were speculating that the demise of larger foraminifers could have been linked to the fluctuation of trophic levels (including cooling and a sea

## PLATE 2

*Pachycolumella elongata* nov. gen., n. sp., late Maastrichtian Tarbur Formation of the Naghan (1–12, 14) and Mandegan sections (13).

Abbreviations see Plate 1. Thin-sections: 2NG 17 (1), 2NG 32 (2), 2NG 49 (3), NG 75 (4), 2NG 147 (5, 7), NG 3 (6), 2NG 142 (8), NG 180-1 (9), NG 1 (10), NG 189 (11), NG 49 (12), Rt 67-3 (13), NG 8 (14).



level fall) being responsible for loss/reduction of photosynthetic activity and decrease of ecological niches of these K-strategists.

In spite of unfavorable environmental conditions, the new taxa described in the present paper however crossed the K/Pg boundary and persisted during the lowest Tertiary times in assumed equivalent environmental conditions of shallow carbonate platform deposits. As for some other larger discoidal foraminifera (e.g., hauraniids with hypodermic network in the marginal zone, etc.) the question still remains unsolved: how can these very sensitive and specialized larger foraminifera persist as survivors in shallow water lagoons or middle shelves near oceanic perturbations of different kinds.

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## PLATE 3

*Pachycolumella acuta* n. sp., late Maastrichtian Tarbur Formation of the Naghan (1–3, 7, 9) Mandegan sections (4–6, 8, 10–15–18, 20), and Fasa (19) sections. All microstructures are deformed compared to *P. elongata*. The polymorphism is clearly linked to the variable deformations of the septal flap, folded backward or partly covering the umbilicus, during ontogenesis.

Abbreviations: co = hollow half columella, cf = crescentic (in the septal horizontal plane) peri-columellar interiomarginal foramen, sc = spiral canal. Thin-sections: 2MG 198 (1), 2NG 174 (2), 2NG 210 (3), RT 79 (4), Rt 100 (5, 12–13, 16–17), Rt 109 (6), Rt 113-1 (8, 11), NG 138 (9), Rt 108-3 (10), Rt 89 (14), Rt 72 (15), Rt 102 (18), A6 (19), Rt 89-39 (20).

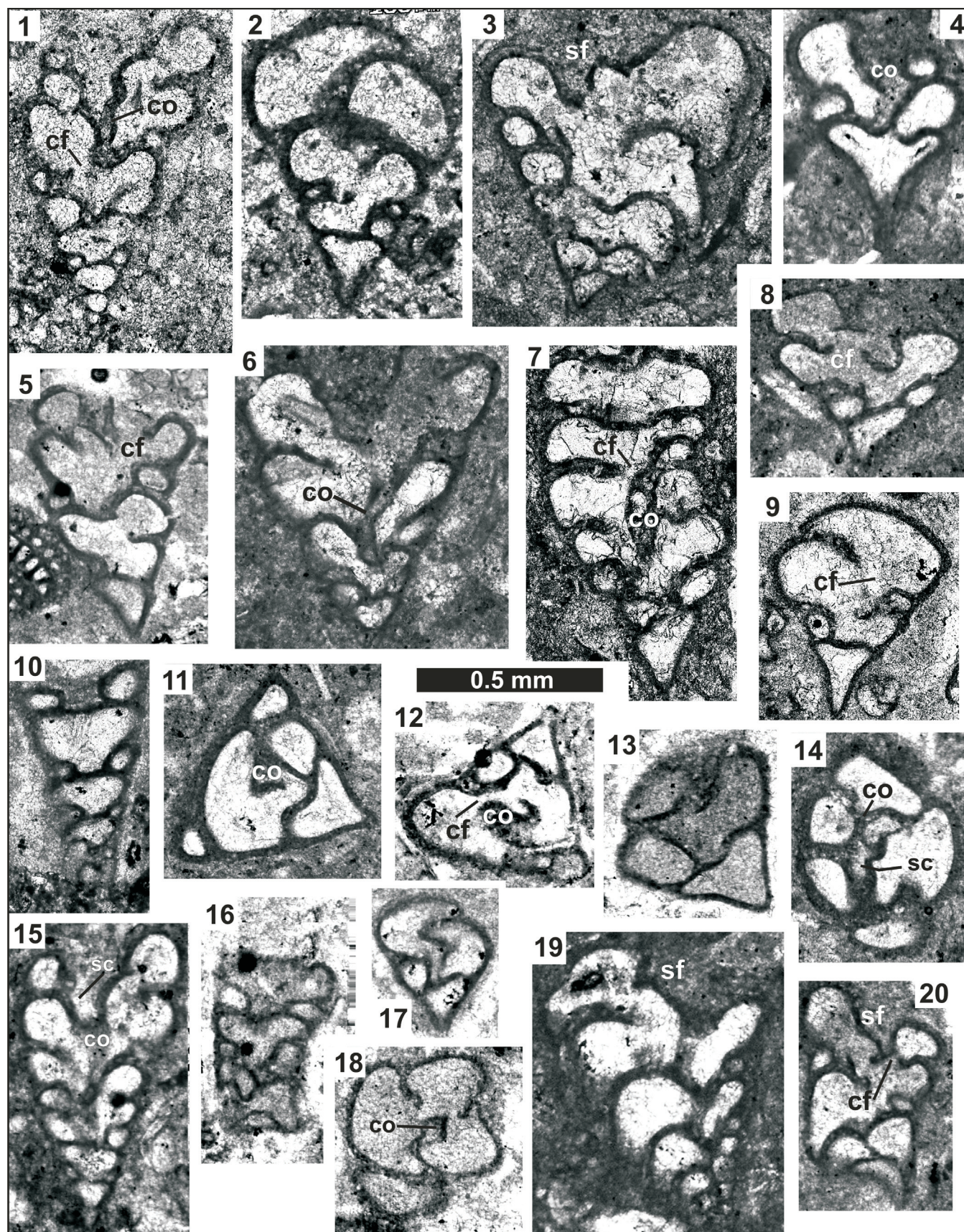
1-2,5-7, (Sub)axial sections  
15,19

4,8-9, Oblique sections through the early part of the test displaying acute apex. The spiral canal appears as a vertical siphon in fig. 4.

3,14 Oblique sections.

10,16 Tangential sections.

11-13,18 Transverse sections. The spiral canal appears as a vertical siphon in fig. 18.



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#### PLATE 4

*Pachycolumella acuta* n. gen., n. sp. (1–6, 10–11), and *Pachycolumella elongata* n. sp. from the Paleocene (Selandian–Thanetian) of Iran.

Thin-sections: Nf 5 (1), Qs 65 (2), Q 17 (3), Qs 28 (4), Ah 177 (5–6), 1pz 25 (7), Ah 162 (8), Nf 3 (9), Q 16-1 (10), 2pz27 (11). Localities: Chehel-Kaman section (1, 9), Qorban section (2–4, 10), Kuh-e-Patorgi section (7, 11), Kuh-e Chahtorsh section (5–6, 8).

1–2,7 axial sections.

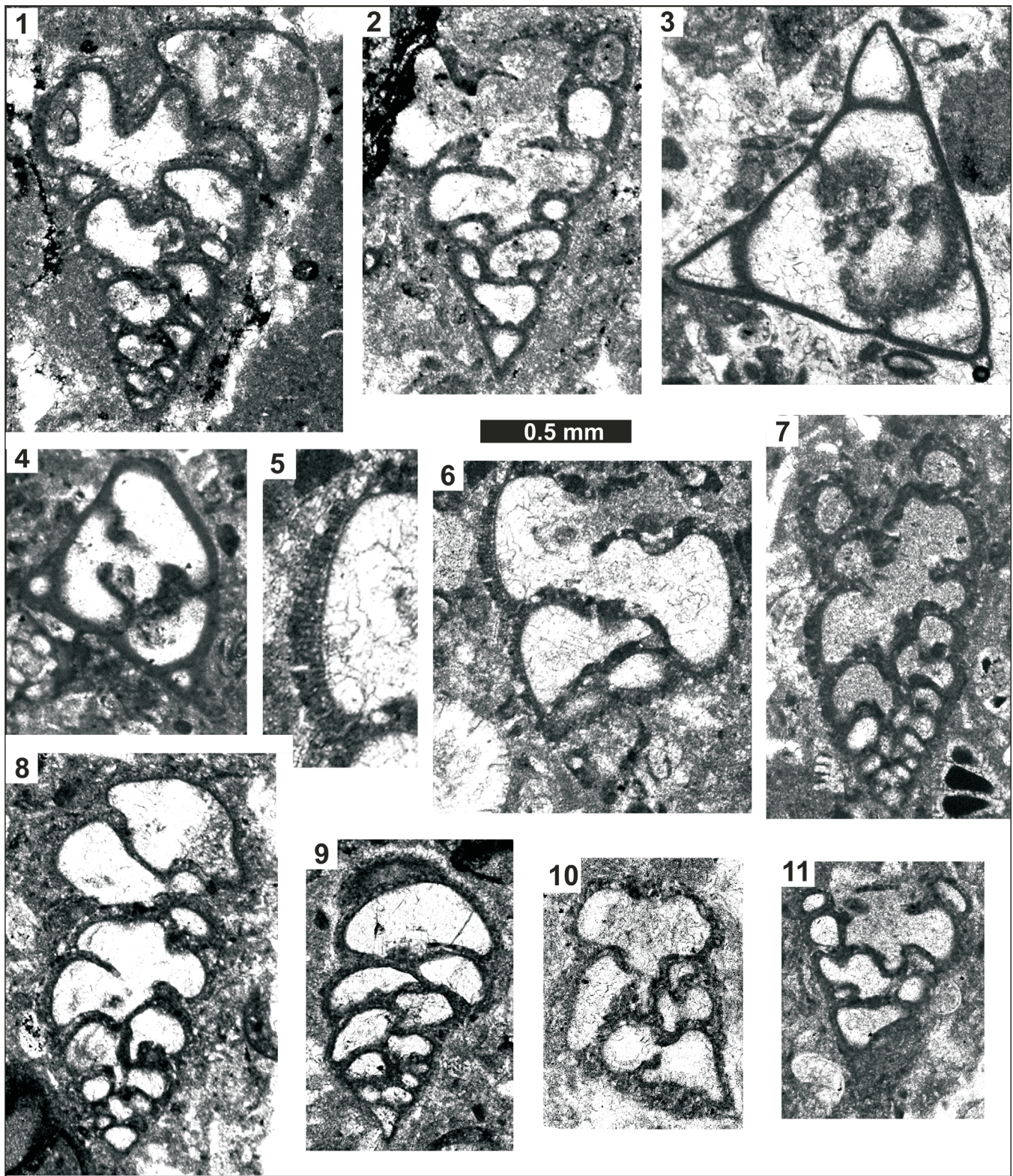
3–4 oblique transverse sections.

5–6 fragmentary axial section; detail showing pseudokeriothecal (parapores auct.) wall texture.

8–9 oblique axial sections.

10 oblique section of juvenile part.

11 tangential section.



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