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ORIGINAL ARTICLE

Broennimannia persica n. ichnogen., n. ichnosp., a new crustacean microcoprolite from the Paleocene of eastern Iran

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Abstract

The new crustacean microcoprolite *Broennimannia persica* n. ichnogen., n. ichnosp., is described from the Paleocene (Danian-Selandian) of eastern Iran. The new microcoprolite is characterized by a bilateral symmetrical system of longitudinal "canals" that in transverse sections display an irregular (labyrinthine) outline with concave infoldings and rounded protuberances. The crescentic outline of parts of the canal system recalls the long-ranging ichnogenus *Palaxius* Brönnimann & Norton (Carboniferous to Pleistocene). In the latter ichnogenus, however, the canals are isolated. A general determination key for microcoprolites in transverse section is provided. The new microcoprolite occurs in poorly sorted foram-algal grainstones/packstones with a fine-grained siliciclastic content. The associated microfauna and –flora includes common miliolids, among the agglutinating *Haymanella*, *Stomatorbina* sp., serpulids, and dasycladalean algae (*Cymopolia* sp., *Trinocladus atacis* Segonzac). From Iran, fossil microcoprolites have been described so far only from the Upper Jurassic, Lower Cretaceous, and Miocene. *Broennimannia persica* represents the first Paleocene record from this area.

Keywords Crustaceans · New ichnotaxon · Microcoprolites · Paleocene · Iran

Introduction

Internally structured crustacean microcoprolites are common in the geological record and have been described ichnotaxonomically from the Palaeozoic (Devonian; Herbig 1993) to Recent (see overview in Knaust 2020). For example, they are widely reported from Cretaceous shallow-water carbonates (e.g., Brönnimann and Masse 1969; Vialov 1978; Senowbari-Daryan and Grötsch 1992; Senowbari-Daryan and Kuss 1992; Fenninger and Hubmann 1994; Blau and Grün 1997; Senowbari-Daryan et al. 2009; Kietzmann and Palma 2014). However, there are few reports from the Paleocene (e.g., Senowbari-Daryan and Kube 2003: *Palaxius*; Buchs et al. 2009), Eocene (Brönnimann and Norton 1960; Gavrilov and Shchepetova 2000; Peckmann et al. 2007: *Palaxius*), Oligocene (Altini 1942; Paréjas 1948: *Palaxius*), Miocene (Brönnimann and Norton 1960: *Palaxius*; Ellliott 1962: *Favreina*; Schweigert et al. 1997: *Helicerina*), or the Pleistocene (Gischler et al. 2017: *Palaxius*). The classification of these ichnogenera and ichnospecies is based on the arrangement (pattern) and number of the longitudinal canals in transverse sections (e.g., Brönnimann 1972; Knaust 2020). As known from modern crabs, these result from a complex system of folds in the wall of the digestive tract where the ingested food is circulating (e.g., Powell 1974; Dall and Moriarty 1983). These folds may be irregular, longitudinal, with and without spines (Moon and Kim 1999), thereby accounting for the variety of different canal patterns reported in the fossil record of microcoprolites.

From Iran, there are some records of crustacean microcoprolites in the literature. Brönnimann (1977) described *Favreina tabasensis* from the Upper Jurassic of the Tabas area of central Iran. From oil–wells drilled in the Persian Gulf, crustacean microcoprolites were recently reported from the Valanginian-Hauterivian Gadvan Formation (*Favreina iranensis*), the Aptian Dariyan Formation (*Palaxius minaensis*), and the Miocene Asmari Formation (*Palaxius asmariensis*) (Dalvand et al. 2015). Other Middle Jurassic to Lower Cretaceous records are from the Zagros

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Zone, SW Iran (Rostami and Ahmadi 2013; Motaharian et al. 2014).

The detailed micropalaeontological investigation of a section of Paleocene shallow-marine carbonates in eastern Iran yielded a new microcoprolite described here as *Broennimannia persica* n. ichnogen., n. ichnosp.

Geological setting

Overview

The structural geology of central Iran is characterized by a complex array of blocks and microplates (e.g., Stöcklin 1968) (Fig. 1a). The so-called Central-East Iranian

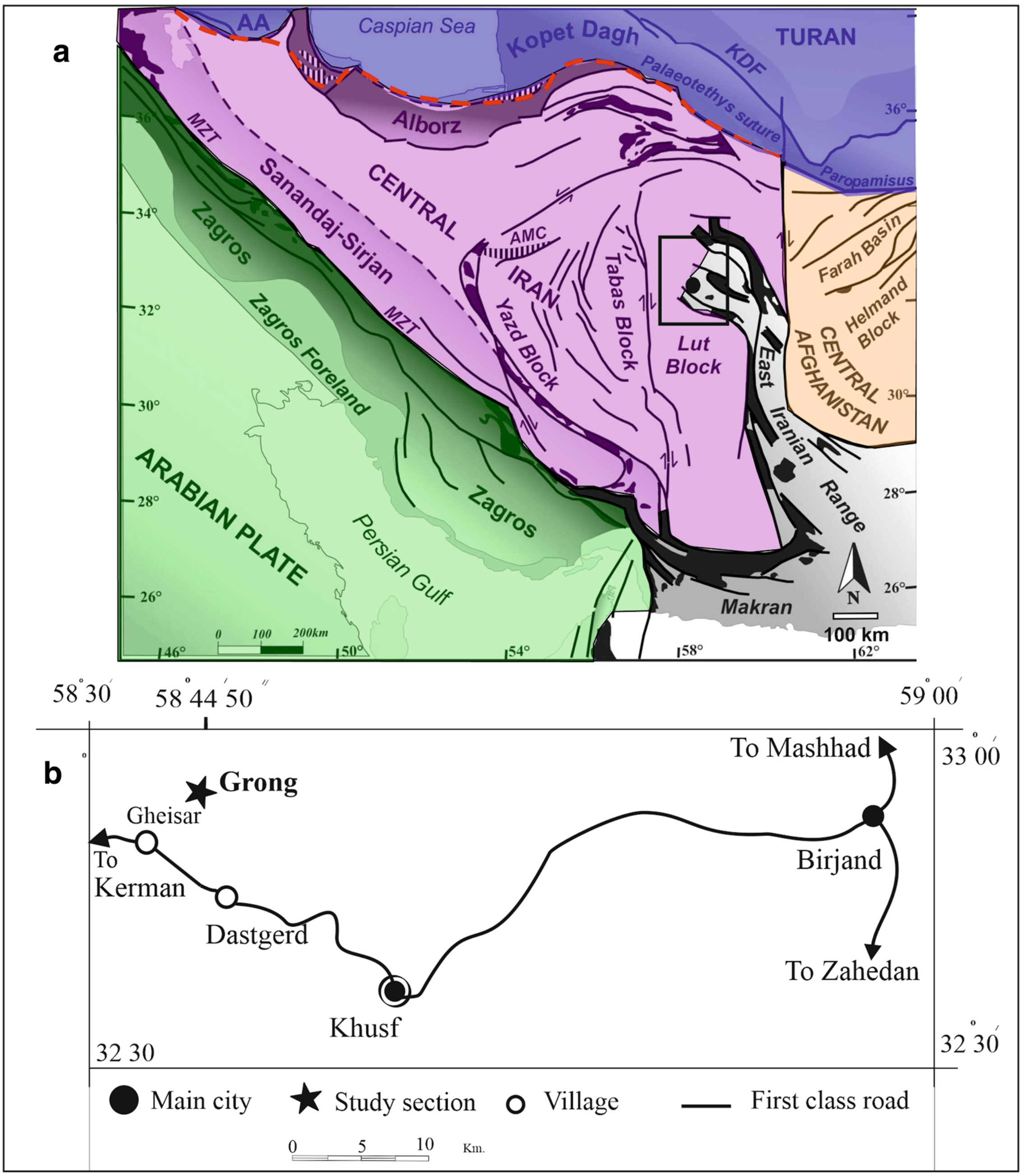


Fig. 1 Geological and geographic location of the Grong section in eastern Iran. **a** Approximate location plotted on the tectonic map of Iran (modified from Zanchi et al. 2009). AA, Anatolian–Armenian Block; AMC, Anarak Metamorphic Complex; KDF, Kopeh Dagh Foredeep, MZT, Main Zagros Trust). **b** Geographic location of the Grong section, the type–locality of *Broennimannia persica* ichngen. et ichnosp. nov

Microcontinent (CEIM; Takin 1972), consists of the Yazd, Tabas, and Lut blocks (Berberian and King 1981; Camp and Griffis 1982; Tirrul et al. 1983). The Lut Block is separated from the East Iranian Range (or Sistan Suture Zone; Tirrul et al. 1983; Aghanabati 2004) in its middle and upper parts by the Nehbandan Fault. However, there is no sharp boundary in the upper part between these two geological zones (e.g., Zanchi et al. 2009; Fig. 1). The studied section is situated in this area and consists of Upper Cretaceous sediments, ophiolitic series, flysch-type sediments, and Paleogene rocks. The thickness of the Paleogene sediments varies considerably, even within short distances.

Studied section

The studied section, here named the Grong section (after the eponymous mountain and village nearby), is located ~ 60 km west of Birjand town and 5 km north-west of Gheisar village in the Ching-dar syncline (Fig. 1b). The Greenwich coordinates of the section base are N 32° 52′ 27.3″ and E 58° 42′ 7.6″. It can be found on the geological map of the Kusf quadrangle 1:100,000 (Eftekhar-Nezad 1986). Lithologically it consists of lithostratigraphically undefined Upper Cretaceous and Paleogene sediments: conglomerates, sandstones, marls, sandy limestones and limestones (Fig. 2). The analyzed thin sandy limestone beds of samples M1-3, -5, and -12, yielded no microfossils. The assumed Upper Cretaceous age is based only on the geological map of Eftekhar-Nezad (1986), and its superposition by Paleogene sediments of the Palang Formation. The conglomerates separating this unit from a package of sandy, grey, massive limestones might correspond to the Cretaceous-Paleogene boundary. The new microcoprolite was observed in the basal part of this unit (samples M2-1, -2), together with indeterminant small rotaliids, and dasycladalean algae indicating a Paleocene age, *Clypeina elliotti* Beckmann & Beckmann and *Trinocladus atacis* Segonzac (see Barattolo 2002) (Fig. 3a, b). A lithologically similar facies, also containing *Broennimannia persica* ichnogen. et ichnosp. nov. at its base reappears higher up in the section. Here the new ichnotaxon is associated with the agglutinating miliolid *Haymanella* gr. *paleocenica* Sirel (Fig. 3f), dasycladalean and halimedacean algae. This microfacies can be compared with the *Haymanella*-algal limestone reported by Sirel (1998, 1999) from Turkey, or Danian carbonates of the Yazd Block, central Iran (Schlagintweit and Rashidi 2019). As at its base, the Paleogene sediments are overlain by conglomerates at the top containing clasts of volcanic rocks and upper Maastrichtian carbonates containing fragments of the large benthic foraminifera *Siderolites, Orbitoides,* and *Omphalocyclus*.

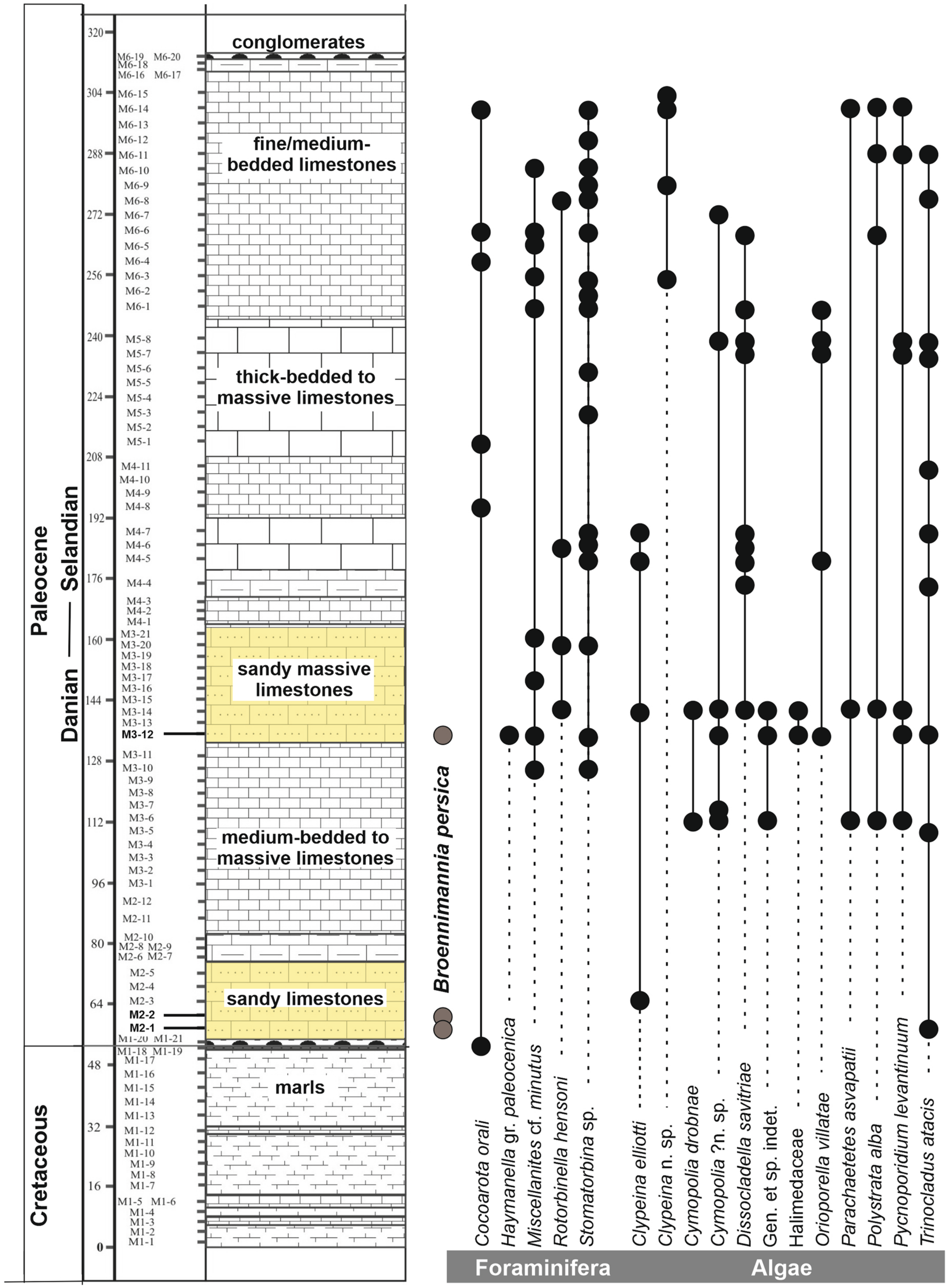
Biostratigraphy

Contrasting with other sections of Paleocene carbonates in Central Iran or the Zagros Zone of southwestern Iran (e.g., Rahaghi 1983; Schlagintweit and Rashidi 2019), the studied section is devoid of biostratigraphically important benthic foraminifera. The lack of typical large benthic foraminifera (see Serra-Kiel et al. 1998) is particularly striking. *Cocoarota orali* İnan has been observed in the first samples overlying the conglomerates at the base of the Paleogene sediments (Fig. 3c). This species ranges from the Maastrichtian to middle Eocene (İnan 2003). The rotaliid taxon *Rotorbinella hensoni* (Smout) (including the morphotype *R. detrecta* Hottinger) higher up in the section (Fig. 3d) indicates the shallow benthic zones (SBZ) 1 to 3 of Serra-Kiel et al. (1998), that is, late Danian to Thanetian (e.g., Hottinger 2014). The range of *Miscellanites minutus* (Rahaghi) (Fig. 3e) was originally restricted to SBZ 3 by Hottinger (2009) and extended to the SBZ 2 recently by Consorti and Köroğlu (2019). No benthic foraminifera typical for (or restricted to) the Thanetian (SBZ 3 *pro parte*) have been observed. This leads us to conclude that the Paleocene sediments of the Grong section can be assigned to the Danian-Selandian interval. The observed dasycladalean algae such as *Dissocladella savitriae* Pia (Fig. 3h, j) or *Cymopolia drobnae* Radoičić support this age (Barattolo 2002). The known range of *Trinocladus atacis* (Fig. 3i), Thanetian fide Barattolo (2002), must be extended.

Palaeoenvironment

Microcoprolites have been reported from diverse palaeoenvironments such as (i) the basal parts of transgressive series representing near-shore environments (e.g., Fenninger and Hubmann 1994), (ii) peritidal carbonates (tidal flats) and hostile hypersaline ponds with thrombolites (e.g., Rindsberg and Kopaska-Merkel 2013), (iii) reefal (here commonly in cavities; Senowbari-Daryan 1979) and near-reefal carbonates (e.g., Senowbari-Daryan et al. 1979), or (iv) hydrothermal vent sites in shallow (Bujtor 2011, 2012; Senowbari-Daryan et al. 2007) and deep marine settings (Buchs et al. 2009). Rather commonly, the palaeoenvironments where microcoprolites occur in great abundance are described as “hostile to most forms of life” (Rindsberg and Kopaska-Merkel 2013). Crustacean microcoprolites may also be reworked into storm deposits (Kietzmann and Palma 2014).

Concerning the occurrence of the *Broennimannia persica*, we note its presence in two distinct levels both displaying similar microfacies (Figs. 2, 3a, b). In these poorly sorted grainstones (with a fine–grained siliciclastic content), the microcoprolites are associated with dasycladalean algae, more frequent in the upper level and here together with the agglutinating miliolid *Haymanella* gr. *paleocenica* Sirel.



Cretaceous
Paleocene
Danian —— Selandian
0
16
32
48
64
80
96
112
128
144
160
176
192
208
224
240
256
272
288
304
320
M1-1
M1-2
M1-3
M1-4
M1-5 M1-6
M1-7
M1-8
M1-9
M1-10
M1-11
M1-12
M1-13
M1-14
M1-15
M1-16
M1-17
M1-18 M1-19
M1-20 M1-21
M2-1
M2-2
M2-3
M2-4
M2-5
M2-6 M2-7
M2-8 M2-9
M2-10
M2-11
M2-12
M3-1
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M6-16 M6-17
M6-18
M6-19 M6-20
conglomerates
fine/medium-bedded limestones
thick-bedded to massive limestones
sandy massive limestones
medium-bedded to massive limestones
sandy limestones
marls
Broennimannia persica
Cocoarota orali
Haymanella gr. paleocenica
Miscellanites cf. minutus
Rotorbinella hensoni
Stomatorbina sp.
Clypeina elliotti
Clypeina n. sp.
Cymopolia drobnae
Cymopolia ?n. sp.
Dissocladella savitriae
Gen. et sp. indet.
Halimedaceae
Orioporella villatae
Parachaetetes asvapatii
Polystrata alba
Pycnoporidium levantinuum
Trinocladus atacis
Foraminifera
Algae

◀**Fig. 2** Stratigraphic log of the Grong section, showing lithostratigraphic units, position of samples and distribution of benthic foraminifera, calcareous algae and the microcoprolite *Broennimannia persica* ichnogen. et ichnosp. nov

The lower level is underlain by terrestrial conglomerates and corresponds to the basal part of a transgressive unit, thus reflecting a near-shore depositional setting. In addition, the second level corresponds to the base of a lithologic change marked by the siliciclastic influx and is interpreted as deposits of a very shallow, siliciclastic–influenced inner lagoon, evidenced also by the common occurrence of dasycladalean algae. The overall high-energy environment is documented by the grainstone texture.

Material and depository

The images of the new microcoprolite refer to five thin–sections deposited in the Geosciences Museum of Mashhad (in the Geological Survey of North-Iran East territory) (Table 1).

Systematic description

Ichnofamily: Favreinidae Vialov 1978

Broennimannia n. ichnogen

Type species. ***Broennimannia persica*** n. ichnosp.

Derivatio nominis. Dedicated to Paul Brönnimann for his numerous fundamental ichnotaxonomic works on crustacean microcoprolites.

Diagnosis. Rod-shaped coprolite, rounded to slightly oval in transverse section (in some cases with a small concave "dorsal" depression), displaying a bilaterally symmetric pattern of longitudinal canals with irregular constrictions and swellings of labyrinthine aspect. The upper ("dorsal") canals are larger than the lower ("ventral") ones. The concave infoldings of the canals face the surface of the microcoprolite. The microcoprolite is composed of homogenous micrite without a "ventral" cap.

Remarks. Fossil microcoprolites have different cross-sections of their canals arranged bilaterally symmetrically (Fig. 4). They may be of a different shape such as in *Fundalutum* (Fig. 4a) or they may display a homogeneous morphology: rounded (*Favreina,* Fig. 4e), Y-shaped within the plane of symmetry (*Helicerina, Lercarina,* Fig. 5c, d), sickle-shaped (*Palaxius,* Fig. 4g), or triangular (*Parafavreina,* Fig. 4f). *Sulcusina* displays a median canal (or furrow) and rounded canals like *Favreina* (Fig. 4b). Others display a light–grey micritic "ventral" cap (*Payandea, Thoronetia,* Fig. 4i, j). *Broennimannia* differs from all these morphotypes by its relatively large canals displaying irregular constrictions and swellings, giving it a labyrinthine aspect (Fig. 4h). It is noteworthy that Kietzmann and Palma (2014, p. 216) discussed the possibility that *Fundalutum* is not a new taxon, but might be "a poorly preserved specimen of *Palaxius caucaensis* in which narrower parts of the canals are not preserved". The presence of concave depressions of the canals facing the microcoprolite surface in *Broennimannia* recalls the ichnogenus *Palaxius*. This aspect may especially be relevant in cases where the degree of preservation is low. In *Palaxius*, the crescentic- to hook-shaped canals are isolated (e.g., like a crescent moon), whereas in *Broennimannia* the canals display a complex laterally connected system with numerous concave infoldings or depressions. A general determination key for microcoprolites is presented in Fig. 5.

Broennimannia persica n. ichnosp

Figures 3a, b, 6

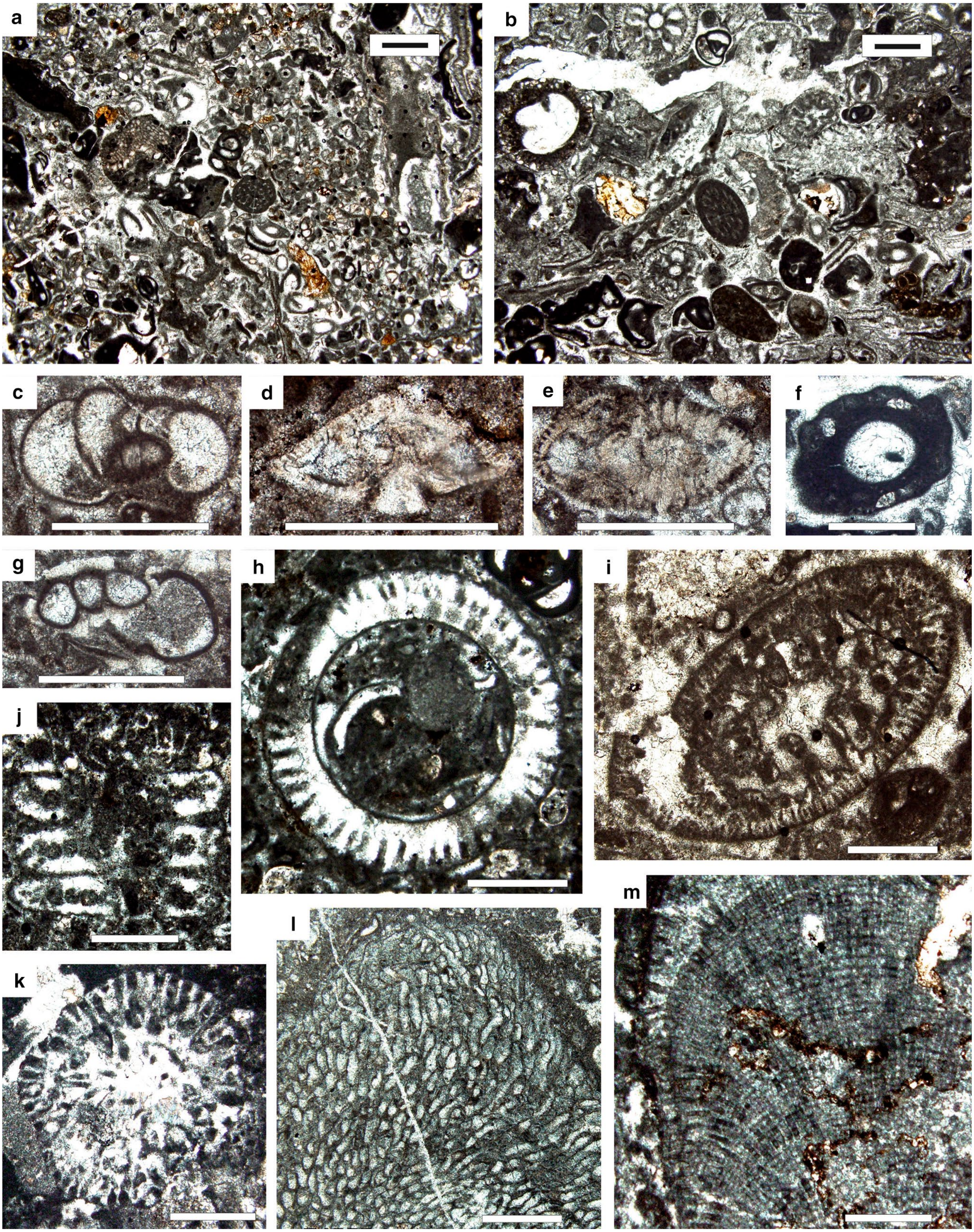
Derivation nominis. For Persia, the historically common name for Iran.

Holotype. The specimen illustrated in Fig. 6h; thin–section Gmm 13980F25 (M3 12-2, see Fig. 2 for sample location). The diameter of the holotype is 0.87 mm.

Horizon and locality. Paleogene (Danian–Selandian) carbonates (lithostratigraphically not defined) of the Grong section located ~ 60 km west of Birjand town (Fig. 1b). The Greenwich coordinates of the section base are N 32°52′27.3″, E 58°42′7.6″.

Diagnosis. As for the ichnogenus.

Description. *Broennimannia persica* is a rod-like microcoprolite represented by different random sections. Transverse sections are rounded to slightly oval. In some specimens, a shallow concave depression can be observed on the "ventral" side. Some specimens display an elliptical outline (Fig. 6i) that might be due to compression. The microcoprolite itself is homogeneously micritic with a smooth surface and no further differentiation of the material or texture (e.g., "ventral cap"). There are four canals (or canal systems) arranged in bilateral symmetry (Fig. 6a, g–i). All these canals display an irregular labyrinthine outline with constrictions, concave depressions or infoldings and rounded protuberances. There are two pairs of canals on each side with identical morphology but different in outline (1–1′ versus 2–2′, Fig. 4h). The upper two canals have a larger diameter and display a straight and closed inner side parallel to the median plane. On the periphery, i.e. following the rounded


a
b
c
d
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f
g
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m

◂**Fig. 3** Microfacies (**a**, **b**), benthic foraminifera (**c**–**g**), and calcareous algae (**h**–**m**) from the Grong section, Eastern Iran. **a**, **b** Poorly sorted grainstone/packstone with benthic foraminifera, dasycladalean algae (*Trinocladus atacis* Segonzac in **b**) and *Broennimannia persica* (center). **c** *Cocoarota orali* İnan, oblique section. **d** *Rotorbinella hensoni* (Smout), axial section. **e** *Miscellanites* cf. *minutus* Rahaghi, subaxial section. **f** *Haymanella* gr. *paleocenica* Sirel, transverse section. **g** *Stomatorbina* sp., subaxial section. **h, j** *Dissocladella annulata* Pia, transverse and longitudinal-oblique sections. **i** *Trinocladus atacis* Segonzac, oblique section. **k** *Cymopolia drobnae* Radoičić, tangential-oblique section. **l** *Pycnopridium levantinuum* Johnson. **m** *Parachaetetes asvapati* Pia. Thin-sections: M3-12-2 (**a**), M3-12-3 (**b**), M6-4 (**c**), M4-6 (**d**), M3-21 (**e**), M3-12-2 (**f**), M6-15 (**g**), M4-5 (**h**), M3-14-1 (**i**), M4-5 (**j**), M6-11-2 (**k**), M17 (**l**), M3-6-2 (**m**). Scale bars: 0.6 mm for **a**, **b**, 0.5 mm all others

Table 1 Numbers of thin-sections (original field numbers) and official depository numbers of the Geosciences Museum of Mashhad (in the Geological Survey of North-Iran East territory)

Order number	Sample thin-section number	Official depository numbers	Figures
1	M2-2	Gmm 13980f22	6a
2	M2-1-1	Gmm 13980F23	6o
3	M2-1-4	Gmm 13980F24	6 l
4	M3-12-2	Gmm 13980F25	6a; 4b-f, h (holotype), j, k, n
5	M3-12-3	Gmm 13980F26	3b; 6 g, i, m

margin of the microcoprolite, there are two (up to three?) concave depressions. One basal opening slightly shifted towards the direction of the median plane, is present (e.g., Fig. 6h). The base of the canal (perpendicular to the plane of symmetry) may be straight or obliquely arranged. The two smaller canals at the "ventral" side display one inner opening towards the median plane. In some specimens, the canal appears as displaying a continuous outline with constrictions (Fig. 6h), whereas in others it is split into several canals with an irregularly crescentic outline with short terminal swellings recalling the ichnogenus *Palaxius* (Fig. 6i).

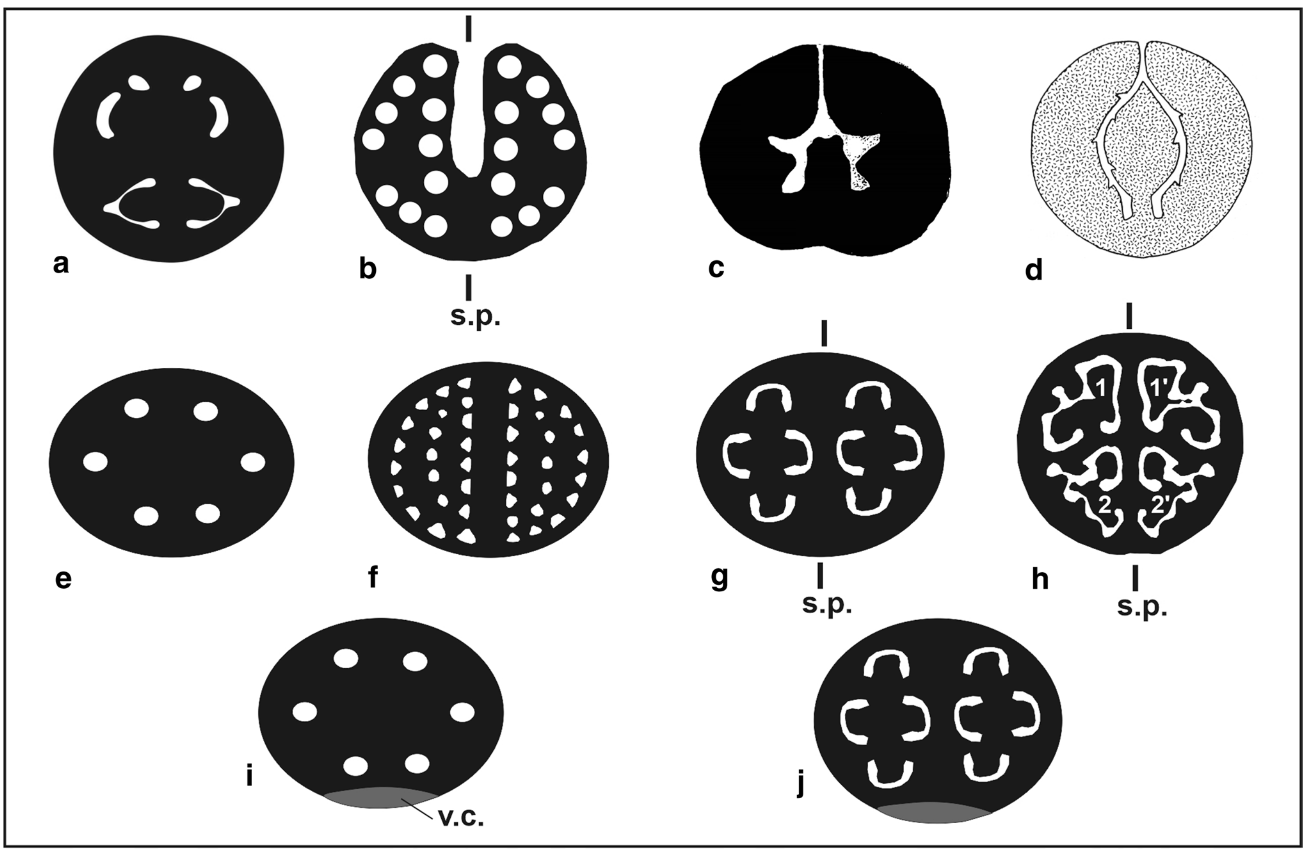

Fig. 4 Idealized cross sections (drawings) of microcoprolites (without scale). **a** *Fundalutum* Senowbari-Daryan and Kuss (1992). **b** *Sulcusina* Schlagintweit et al. (2016). **c** *Helicerina* Brönnimann and Masse (1969). **d** *Lercarina* Senowbari-Daryan (1988). **e** *Favreina* Brönnimann. **f** *Parafavreina* Brönnimann et al. (1972). **g** *Palaxius* Brönnimann and Norton (1960). **h** *Broennimannia*, this work. **i** *Payandea* Blau et al. (1993). **j** *Thoronetia* Brönnimann et al. (1972). s.p., symmetry plane; v.c., ventral cap

A: With canal(s) in the symmetry plane

I.1 With additional canals (mostly grouped bilateral symmetrically around the median plane)

I.1.1 round *Favreina*-type canals: ***Sulcusina*** Schlagintweit et al., 2016:

I.1.2 spine-like extensions/triangular or diamond-shaped canals connected by a system of fissural spaces: ***Helicerina*** Brönnimann & Masse, 1969

I.1.3 canal dividing into two side canals displaying small spine-like protrusions on both sides: ***Lercarina*** Senowbari-Daryan, 1988:

B: Without canal(s) in the symmetry plane; canals grouped bilateral symmetrical

II. 1 Without micritic „ventral" cap

II. 1.1 canals with equal morphology and size

II.1.1.1 round canals: ***Favreina*** Brönnimann, 1955

II.1.1.2 triangular canals: ***Parafavreina*** Brönnimann et al., 1972

II.1.1.3 hook-like/crescentic canals: ***Palaxius*** Brönnimann & Norton, 1960 (syn. *Agantaxia* Kristan-Tollmann, 1989)

II.1.1.4 rim of half-spherical canals: ***Petalina*** Leinfelder in Schweigert et al., 1997

II.1.2 canals of different morphology and size

II.1.2.1 ***Fundalutum*** Senowbari-Daryan & Kuss, 1992: Y-, crescentic, round or ovoid

II.5 ***Broennimannia*** Schlagintweit & Rashidi, this work: labyrinthine canals

II.2 With micritic „ventral cap"/ canals of equal morphology and size

II.2.1 ***Thoronetia*** Brönnimann et al., 1972: with *Favreina*-type canals

II.2.2 ***Payandea*** Blau et al., 1993 : with crescentic, *Palaxius*-type canals)

C: Canals arranged radially

III.1 ***Octotriangulella*** Blau et al., 1987: with eight canals

Fig. 5 General determination key for microcoprolites in transverse sections. For further details the reader is referred to the original diagnoses provided by the authors

Dimensions.

Diameter: 0.5–1.2 mm (mostly around 0.7 to 1.0 mm)

Length: up to 1.2 mm.

Concluding remarks

A new ichnotaxon of crustacean microcoprolite, *Broennimannia persica* n. ichnogen., n. ichnosp., is described from the Danian–Selandian shallow-water carbonates of eastern Iran. From Iran, fossil microcoprolites have been described so far from the Upper Jurassic, Lower Cretaceous and the Miocene, but not from the Paleocene. The new ichnogenus displays a rather complex, bilaterally symmetrical canal system. With its irregularly concave depressions, it shows similarities to *Palaxius*. *Broennimannia persica* occurs in poorly sorted grainstones with a fine-grained siliciclastic content of transgressive units. They reflect a near-shore, terrestrial influenced inner lagoonal depositional setting with common dasycladalean algae and porcelaneous benthic foraminifera.

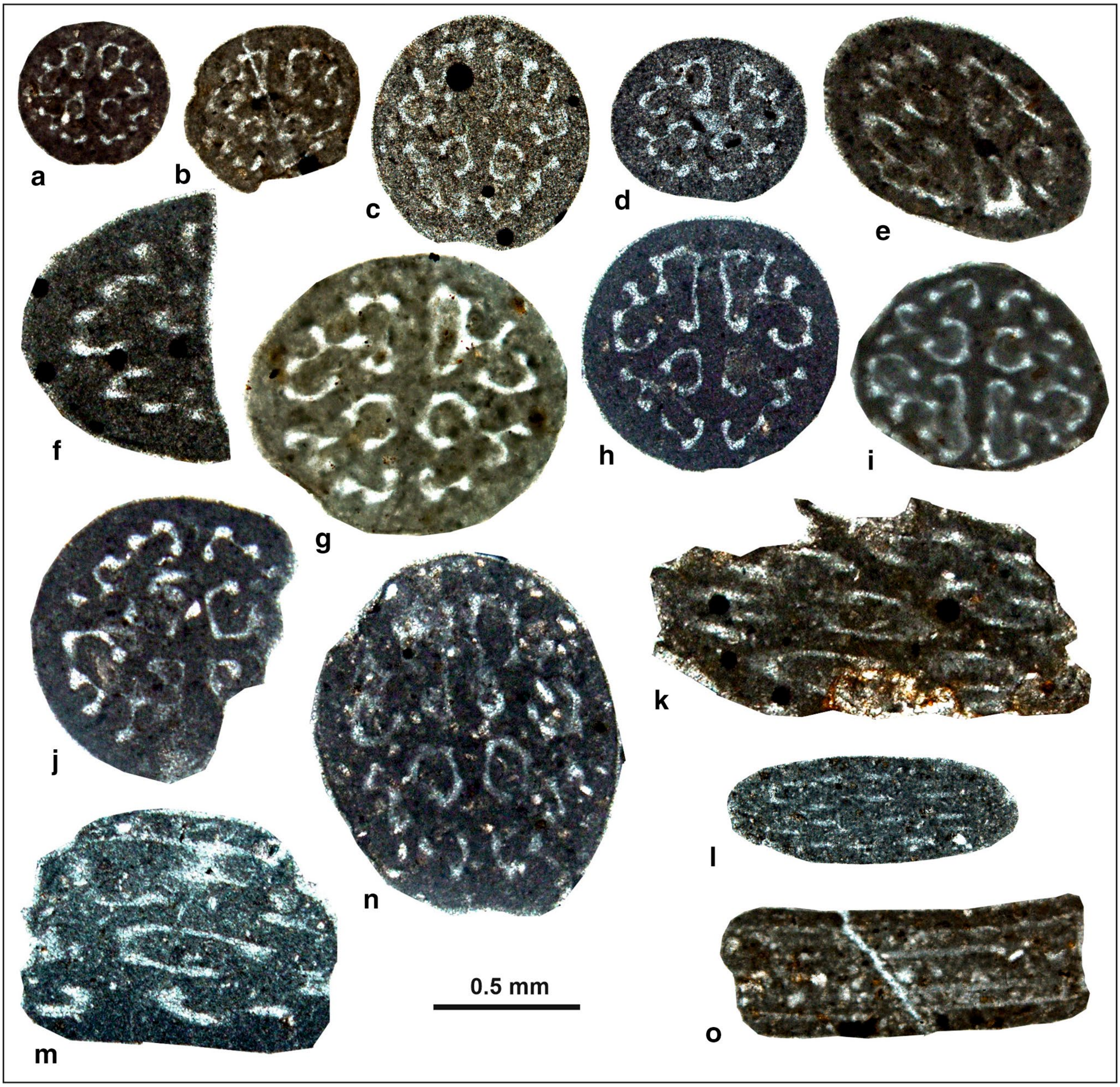

Fig. 6 *Broennimannia persica* ichngen. et ichnosp. nov. from the Paleocene Grong section of eastern Iran. **a, d, g–i** transverse sections. Holotype specimen in **h**. **b–c, e, n** slightly oblique transverse sections. **f, j** fragmentary, slightly oblique transverse sections. **k–m** oblique sections. **o** longitudinal section. Thin-sections: M2-2 (**a**), M3-12-2 (**b–f, h, j, k, n**), M3-12-3 (**g, i, m**)

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