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Palaxius floridanus n. isp., a new structured callianassid crustacean microcoprolite from the Pleistocene of south Florida

Eberhard Gischler,[1] Joachim Blau,[1] and Jörn Peckmann[2]

[1]Institut für Geowissenschaften, J.W. Goethe-Universität, Altenhöferallee 1, 60438 Frankfurt am Main, Germany ⟨gischler@em.uni-frankfurt.de⟩
[2]Institut für Geologie, Universität Hamburg, Bundesstraße 55, 20146 Hamburg, Germany ⟨joern.peckmann@uni-hamburg.de⟩

Abstract.—The crustacean microcoprolite *Palaxius floridanus* n. isp. is described from shallow-water carbonate platform deposits of Pleistocene limestones of south Florida. *Palaxius floridanus* n. isp. occurs in moderate-energy packstones and grainstones of the oolite facies of the Miami Limestone, and in skeletal packstones of the Key Largo Limestone, ranging in age from marine isotope stage (MIS) 11 to MIS 5a (ca. 400–80 kyr BP). The new ichnospecies resembles *P. decemlunulatus*, which has been described previously from Oligocene deposits. Late Jurassic and Late Cretaceous forms described as *P. decemlunulatus* belong to a new ichnogenus and new ichnospecies, respectively, yet to be described.

Introduction

Lithified fecal pellets of invertebrates may be very common locally and regionally in warm, shallow-water carbonate environments that form large sediment bodies, such as on the Bahamas and adjacent carbonate banks where peloidal facies cover several thousand square kilometers (Purdy, 1963; Enos, 1974). In addition to mollusks, callianassid and thalassinidean crustaceans are important producers of fecal pellets, and play a crucial role with respect to sedimentology, paleontology, and biology. They may bioturbate the sediment, modify sediment texture extensively down to one meter below the sea floor, and produce characteristic burrows and ichnofossils (Shinn, 1968; Pryor, 1975; Frey et al., 1978). These crustaceans may also redistribute organic matter and nutrients, increase the rate of organic decomposition, and increase the ventilation of the sediment column (Pinn et al., 1999, and references therein). Fleshy projections in the hindgut of thalassinidean and callianassid crustaceans may form complex systems of canals within fecal pellets that are taxonomically characteristic and have been encountered in thin-sections in sediment and microfacies studies (Moore, 1932; Brönnimann, 1972; Senowbari-Daryan, 1979; Blau and Grün, 2000, and references therein). The large majority of such studies have detailed crustacean microcoprolites from the Mesozoic. In this work, we describe a new, characteristic post-Paleogene microcoprolite that occurs in Pleistocene neritic carbonate deposits of south Florida.

Geological setting

Large parts of south Florida, including the island chain of the Florida Keys, are composed of late Pleistocene shallow-water limestone (Stanley, 1966; Hoffmeister et al., 1967; Hoffmeister and Multer, 1968; Perkins, 1977; Harrison and Coniglio, 1985). The reefal Key Largo Limestone crops out along the upper and central parts of the Florida Keys; the oolitic facies of the Miami Limestone covers the southeastern part of the peninsula and the lower part of the Florida Keys (Fig. 1). These deposits were part of a large, shallow-water carbonate platform that formed during marine isotope stage (MIS) 5e, ca. 130–115 kyr BP (Multer et al., 2002; Muhs et al., 2011, and references therein). Outcrop and subsurface data have shown that the carbonate platform consists of six stacked platforms that were formed during Pleistocene sea-level highstands overlain by the Holocene Florida Reef Tract, and separated by subaerial exposure horizons that developed during Pleistocene sea-level lowstands (Perkins, 1977; Multer et al., 2002). During most of the Pleistocene platform stages, the margin was presumably characterized by a ramp-like morphology with predominantly massive corals. The shallow bank-barrier reef margin with abundant acroporid corals and deeper water outlier reefs only developed in the latest Pleistocene MIS 5c (Lidz et al., 1991; Multer et al., 2002). Ooid shoals were abundant along the southeastern and southern parts of the platform margin during MIS 5e (Hoffmeister et al., 1967; Halley et al., 1977; Halley and Evans, 1983).

Methods

Descriptions of the microcoprolites were made based on thin-section observations using a Leica DM 2500 M petrographic microscope with attached digital camera. Microcoprolites were compared to existing descriptions in the literature, taking into account the general comments by Brönnimann (1972). After the specimens analyzed here had been found, >200 existing thin-sections of the study by Multer et al. (2002) were searched for structured crustacean microcoprolites, along with 20 thin-sections from outcrops in Coral Gables and the Everglades, south Florida. In addition, 120 thin-sections from the Pleistocene shallow-water limestones of Belize (Gischler, 2007; Gischler, et al., 2010) were searched for structured crustacean microcoprolites, albeit, without success.
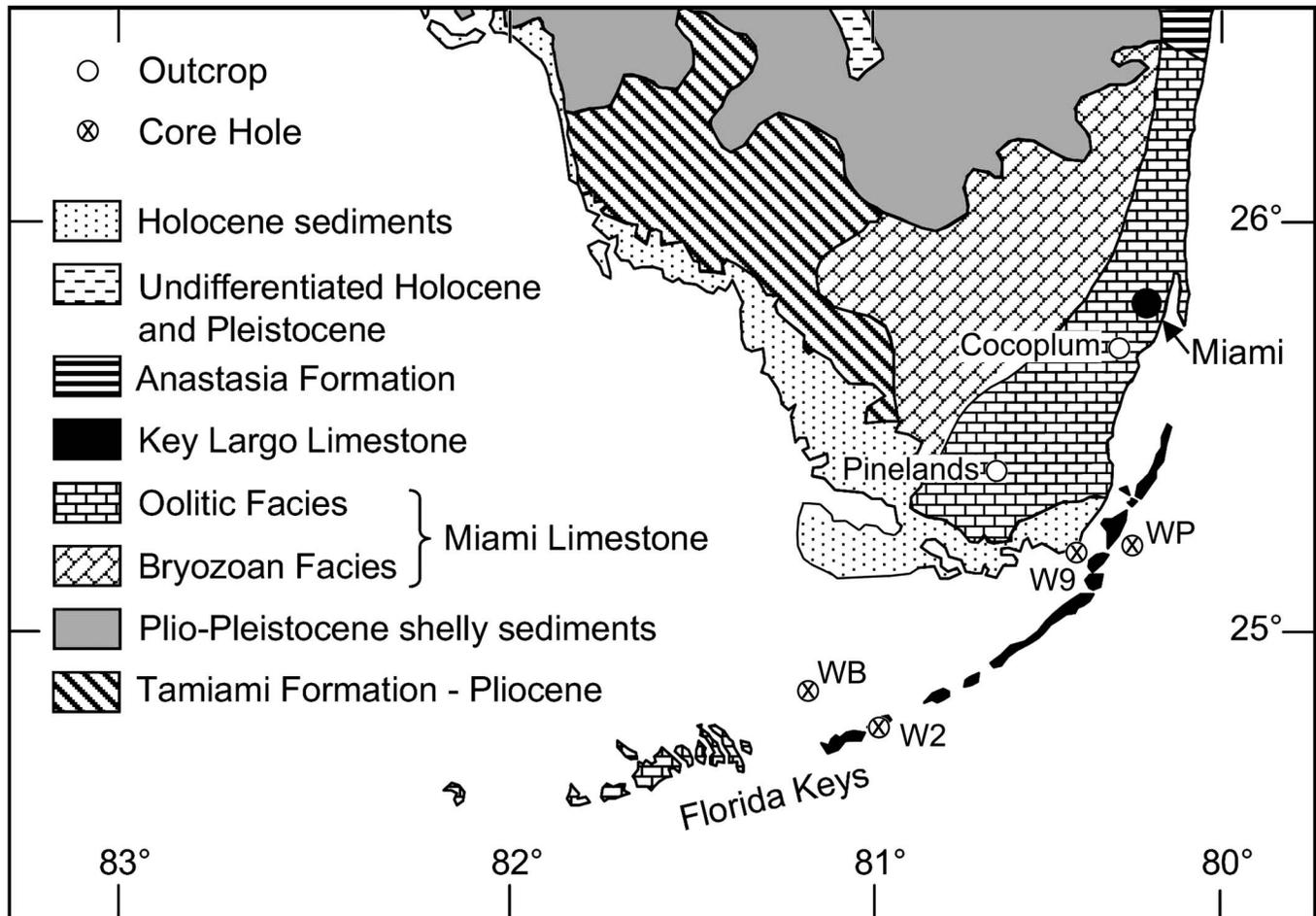
Figure 1. Map of occurrences of *P. floridanus* n. isp. in two outcrops and four subcrops (rotary cores) in south Florida. Map redrawn after Hoffmeister et al. (1967) and Neal et al. (2008). Core locations from Multer et al. (2002).

Repository and institutional abbreviation.—The thin-sections, on which this study is based, are deposited at the Institut für Geowissenschaften at Goethe-University, Frankfurt am Main, Germany (http://www.uni-frankfurt.de/49537872.home). The thin-section with the *Palaxius floridanus* n. isp. holotype has the number: "GU-IfG-EG-Cocoplum Circle #10."

Systematic paleontology

<div align="center">

Class Crustacea
Order Decapoda
Infraorder Callianassidea
Superfamily Callianassoidea
Ichnofamily Favreinidae Vialov, 1978
Ichnogenus *Palaxius* Brönnimann and Norton, 1960
Palaxius floridanus new ichnospecies
Figures 2.4, 3.1

</div>

Holotype.—A well-preserved microcoprolite in thin-section "GU-IfG-EG-Cocoplum Circle #10" (Figs. 2.4, 3.1). Late Pleistocene (marine isotope stage 5e).

Additional material.—Ten thin-sections other than the one with the holotype specimen contain *Palaxius floridanus* n. isp.: Cocoplum Circle #7, Cocoplum Circle #8, Cocoplum Circle #9, Pinelands #9, Pinelands #10, core W9-10, core WB-32, core WB-41, core WP-46/49, and core W2-132/139.

Diagnosis.—Crustacean microcoprolite with round to oval cross section and ten internal, crescentic canals. In cross-section, openings of marginal crescents are oriented inward; openings of central crescents oriented outward to ventral groove.

Etymology.—Named after the geographic occurrence of this ichnospecies.

Materials.—The microcoprolites are not abundant, based on the fact that only seven out of >200 samples contained *P. floridanus* n. isp. The eleven thin-sections come from two outcrops and four rotary cores in the Miami area and the Florida Keys in south Florida (Fig. 1). The outcrops include the oolitic facies of the Miami Limestone exposed on the southern shore of the Coral Gables Waterway, right below Cocoplum Circle, Coral Gables, Florida (25°42'21.1"N, 80°15'38.2"W), and at the parking lot at the "Pinelands" trail along State Highway 9336 in Everglades
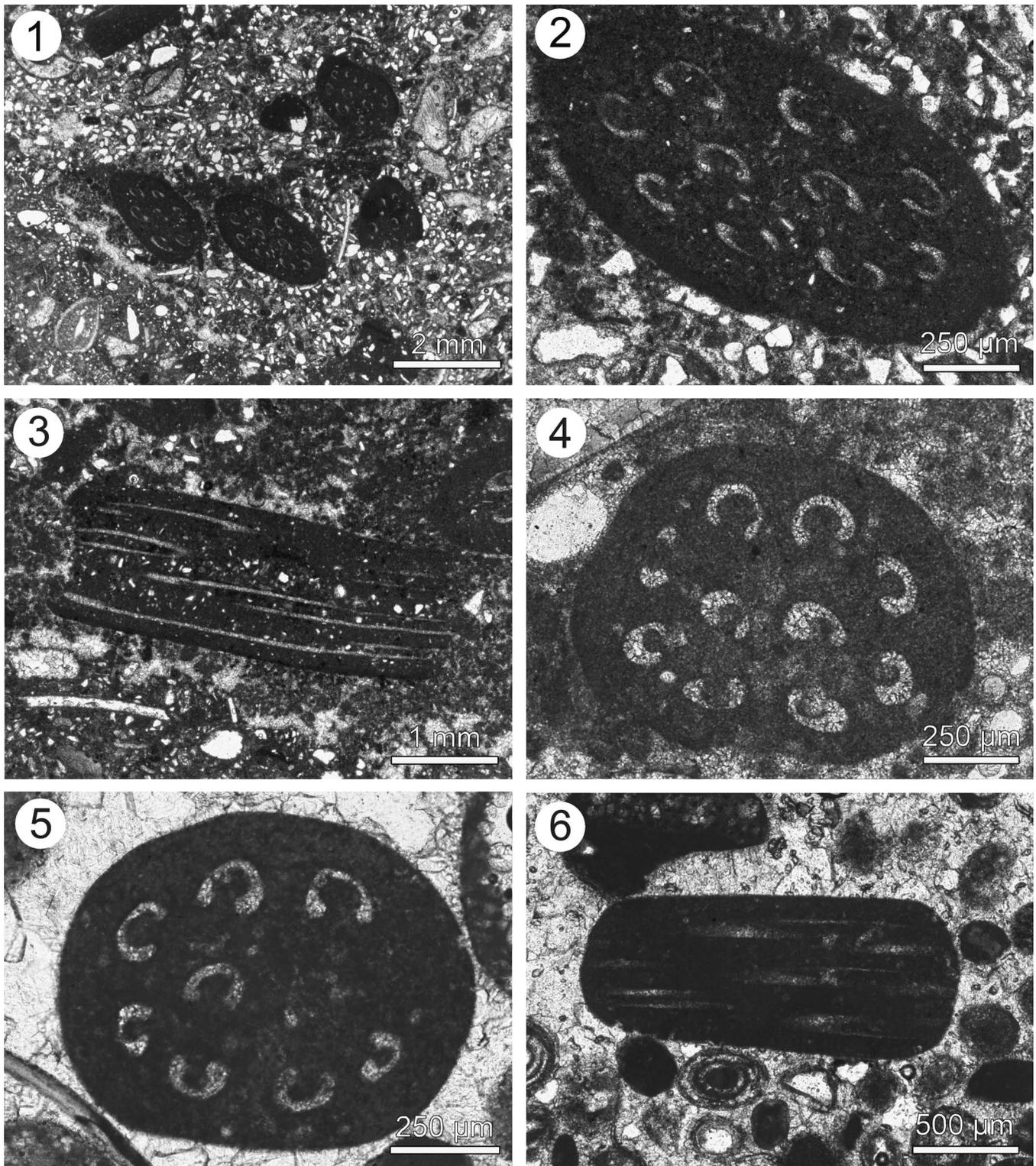
Figure 2. Thin-section micrographs of *P. floridanus* n. isp. in Pleistocene deposits of south Florida. (**1**) Slightly oblique sections through several microcoprolites; skeletal packstone with quartz; core W2, depth 45.2 m; (**2**) close-up of same sample; (**3**) longitudinal section through microcoprolite, skeletal packstone, core W2, depth 45.2 m. (**4**) Cross-section through microcoprolite (ichnoholotype); skeletal packstone; note recrystallization of mollusk shell; Cocoplum Circle. (**5**) Cross-section through microcoprolite; oolitic grainstone; Cocoplum Circle. (**6**) Longitudinal section through microcoprolite; oolitic grainstone; Cocoplum Circle.

National Park (25°25'23.3"N, 80°40'43.6"W). The Cocoplum Circle outcrop has been described by Halley et al. (1977), Halley and Evans (1983), and Neal et al. (2008). The rotary

cores include W9 (Key Largo, Jewfish Creek), WP (Basin Hill Shoals), WB (Florida Bay), and W2 (Grassy Key), which have penetrated the Key Largo Limestone (Multer et al., 2002).
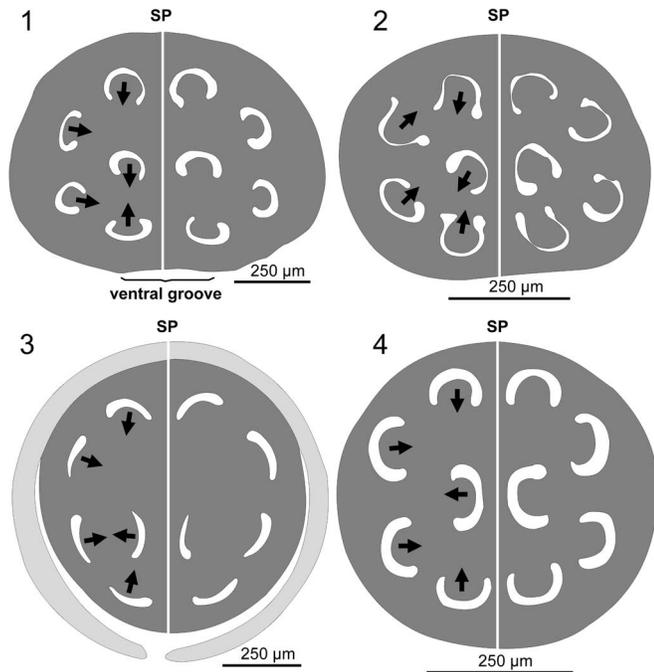
Figure 3. Schematic cross-section through *P. floridanus* n. isp. and other microcoprolites that resemble the new ichnospecies. (**1**) *P. floridanus* n. isp. from the Miami Limestone showing the details of internal structuring by ten crescentic canals. Note the slight ventral depression of the pellet. Drawn based on pellet shown in figure 2.4 (ichnoholotype). (**2**) Cross-section through *P. decemlunulatus* from Paréjas (1948). (**3**) Cross-section through coprolite identified by Kennedy et al. (1969) as *Favreina decemlunulatus*. (**4**) Schematic cross-section through microcoprolite assigned to *P. decemlunulatus* by Kuss and Senowbari-Daryan (1992) and Senowbari-Daryan and Kuss (1992). The bilateral symmetry plane (SP) runs vertically through the center of all examples.

Because these cores were taken in the early 1960s, no GPS-coordinates of the exact drill locations exist.

Occurrence.—The samples from Coral Gables and Everglades National Park come from surface outcrops and belong to MIS 5e (thin-sections Cocoplum #7, 8, 9, 10; Pinelands # 9, 10). The sample in core W9 is from a core depth of 3.0 m (thin-section W9-10) and belongs to MIS 7. The sample in core WP comes from a core depth of 14.4 m (thin-section WP-46/49) and can be assigned to MIS 5a or 5c. Two samples from core WB derive from 9.7 m and 12.4 m core depth, thin-sections WB-32 and WB-41, respectively, in MIS 7. The sample from core W2 is from a core depth of 41.0 m (thin-section W2-132/139) and belongs most likely in MIS 11.

Description.—The microcoprolites consist of fine-grained detrital material. They are cylindrical with round to slightly oval cross-sections (Fig. 2). They are as long as 3.5 mm and have diameters of 0.7–1.2 mm. In some specimens, a shallow indentation or ventral groove may be seen on one side (Figs. 2.4, 3.1). The microcoprolites have ten crescentic or U-shaped internal canals 20–30 μm across, which are widest at the ends. The canals are filled with small crystals of blocky calcite. The total diameter of the canals ranges from 100–150 μm. In cross-section, the microcoprolites are bilaterally symmetrical. Eight of the ten crescents are oriented with their openings towards the center; the two central crescents have their openings directed in the same direction towards the outside, usually towards the shallow indentation (Figs. 2.4, 2.5, 3.1).

Discussion

Taxonomy.—The new ichnospecies belongs to the genus *Palaxius* because of the crescentic, internal canals. To our knowledge, seven *Palaxius* ichnospecies with ten internal canals have been described (Elliot, 1962; Palik, 1965; Kennedy et al., 1969; Senowbari-Daryan, 1979; Kuss and Senowbari-Daryan, 1992; Senowbari-Daryan and Kuss, 1992; Blau et al., 1993; Blau and Grün, 2000; Becker and Chamberlain, 2006; Peckmann et al., 2007; Kietzmann and Palma, 2010, 2014; Kietzmann et al., 2010). From the size and arrangement of crescentic canals, the south Florida specimens resemble the Oligocene *P. decemlunulatus* (Paréjas, 1948), however, there are some marked differences. In *P. decemlunulatus*, the openings of the two central crescents are inclined away from each other in cross-section; they are facing in the same direction in the Florida specimens (Fig. 3.1, 3.2). Also, the opening of the two upper, lateral crescents in *P. floridanus* n. isp. are pointed inward, towards each other (Fig. 3.1), and oriented outward in *P. decemlunulatus* (Fig. 3.2). Two Mesozoic microcoprolites, assigned to the latter ichnospecies resemble *P. floridanus* n. isp. as well at first glance. However, the Jurassic form, reported as *Favreina decemlunulatus* (Kennedy et al., 1969), and the Late Cretaceous (Cenomanian) form, described as *Palaxius decemlunulatus* (Kuss and Senowbari-Daryan, 1992; Senowbari-Daryan and Kuss, 1992), are different from *P. floridanus* n. isp. based on the orientation of the cross-sections of the two central crescents, the openings of which are oriented outward, in opposing directions (Fig. 3.3, 3.4). The openings point in the same direction in *P. floridanus* n. isp. and slightly away from each other in *P. decemlunulatus* (Fig. 3.1, 3.2). For these reasons, the Cretaceous form belongs to neither *P. decemlunulatus* nor *P. floridanus* n. isp., but to a new Cretaceous ichnospecies of *Palaxius* yet to be described. The stratigraphic occurrence of *P. decemlunulatus*, previously described as reaching from Cenomanian to Oligocene (Senowbari-Daryan and Kube, 2003), should be restricted to the Oligocene. The internal canals in the Jurassic *F. decemlunulatus* are relatively thin and more "comma-shaped" as compared to the wider and U-shaped canals in the Cenomanian, Oligocene, and Pleistocene specimens. Furthermore, the Jurassic form has an external sediment envelope that is lacking in the three younger forms, and in *Palaxius* in general. Therefore, for the Jurassic *F. decemlunulatus* (Kennedy et al., 1969) a new ichnogenus should be erected, as suggested already by Senowbari-Daryan and Kuss (1992).

Aspects of paleoecology and preservation.—Microcoprolites of *P. floridanus* n. isp. were mostly found in packstone-facies (i.e., in moderate-energy environments) locations >20 km away from the former platform margin. The Coral Gables outcrop and the WP-core (Basin Hill Shoals) locations are closer to the platform margin, but still several kilometers inboard. The fact that *P. floridanus* n. isp. microcoprolites occur also in an oolite grainstone facies suggests that the producer also inhabited somewhat higher energy depositional environments. Today, considerable areas in the intertidal and shallow subtidal zones of the south Florida carbonate platform interior are inhabited by burrowing callianassid and thalassinidean shrimps along with the endobenthic crustacean *Alpheus* (Shinn, 1968). In the Pleistocene Miami Limestone, *Ophiomorpha* trace fossils are common (Halley

and Evans, 1983; Neal et al., 2008; Netto et al., 2017). The observations of Moore (1932) and Shinn (1968) of modern crustacean fecal pellets suggest that the producer of the Pleistocene *Palaxius* could have been a callianassid. Crescentic canals like those in *P. floridanus* n. isp. were found in modern pellets of other callianassid crustaceans, such as *Axius*, according to Moore (1932, pl. 1, fig. 7). Canals of fecal pellets of the modern *Neotrypaea* (*Callianassa*) *californiensis* exhibit ten crescentic canals in cross-section (Powell, 1974, fig. 14), although in different orientation than the Pleistocene specimens described here. The fecal pellets of the modern *Callichirus* (*Callianassa*) *major* have twenty-six crescentic internal canals (Pryor, 1975). As a consequence of these observations, Becker and Chamberlain (2006) have considered callianassids as producers of *Palaxius* ichnofossils. This hypothesis is supported by the association of *Palaxius* with callianassid body fossils in an Eocene methane-seep deposit (Peckmann et al., 2007). Because of the ubiquity of callinassids in modern environments of the Florida platform, it seems curious that *P. floridanus* n. isp. has not been encountered more frequently. An explanation could be diagenetic micritization, a common phenomenon in shallow marine carbonates (Purdy, 1968; Reid and Macintyre, 1998) that has potentially obliterated the original canal structures leaving only texturally inconspicuous fecal pellets in this environment. Another explanation could be the fact that both the Key Largo and the Miami limestones underwent additional diagenetic alteration, especially in the meteoric environment, that has caused widespread recrystallization and neomorphism (Stanley, 1966; Robinson, 1967; Evans and Ginsburg, 1987; Multer et al., 2002).

Conclusions

The new Crustacean microcoprolite *Palaxius floridanus* n. isp. is described from late Pleistocene shallow-water limestones of south Florida. The producer of the ichnofossil presumably was a callianassid crustacean, which inhabited moderately agitated environments behind the south Florida platform margin. *P. floridanus* n. isp. resembles *P. decemlunulatus* from the Oligocene. Late Jurassic and late Cretaceous forms reminiscent of *P. floridanus* n. isp. and previously assigned to *P. decemlunulatus* belong to a different ichnogenus and ichnospecies, respectively.

Acknowledgments

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