

Catinaster virginianus sp. nov.: A new species of *Catinaster* from the middle Miocene Mid-Atlantic Coastal Plain

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Abstract: High-resolution analysis of sediments from four coreholes associated with the Chesapeake Bay impact crater has resulted in the identification of a new species, *Catinaster virginianus*. This species is similar to *Catinaster coalitus coalitus*, but differs by having a proximal stem. The first occurrence of *C. virginianus* is in Zone NN5, and is older than any previously identified *Catinaster*. This species has been identified previously as *Catinaster* sp. from the Gulf of Mexico and the Carpathian Foredeep and suggests both a global distribution and synchronous stratigraphic range. Morphologic similarities with *Discoaster variabilis* may suggest a taxonomic relationship to the *D. variabilis* lineage.

Keywords: Calcareous nannofossils, biostratigraphy, Miocene, taxonomy, *Catinaster*

1. Introduction

A new species of calcareous nannofossil, *Catinaster virginianus*, was identified during studies of multiple coreholes from the Chesapeake Bay impact structure (Edwards *et al.*, 2005, 2010) (Figure 1). *Catinaster virginianus* is an easily identifiable robust form that has a distinctly older range than any other known species of *Catinaster*. Although never very abundant, it is often recognizable even in heavily overgrown samples. The occurrence of this species has been tied to the East Coast and Atlantic Miocene dinoflagellate zones of de Verteuil and Norris (1996) and de Verteuil (1997) in several cores, and thus its early stratigraphic range is well documented, making it a potentially useful biozone marker for the middle Miocene (Figure 2).

Catinaster coalitus has long been used as a zonal marker for sediments deposited in low latitude and temperate settings of upper Miocene age (Martini and Bramlette, 1963; Bramlette and Wilcoxon, 1967; Martini, 1971; Bukry, 1973; Okada and Bukry, 1980). Early (older) catinaster-like forms variously attributed to the genera *Catinaster* or *Discoaster* have been recorded from a variety of localities. Aubry (1993) attributed occurrences of *Catinaster coalitus* and *Catinaster* sp. in sediments older than 10.9 Ma in the Eureka core (E68-136) in the Gulf of Mexico to slumping. Denne (2008) recorded the presence of a middle Miocene nannofossil restricted to Zone NN5 that he called “a variety of *D. sanmiguelensis*” as *Catinaster* sp. “A”, also from the Gulf of Mexico. Although he suggested that this form is a variety of discoaster, he also noted that it has the basket shape typical of *Catinaster* when seen in side view. Sediments from the Carpathian Foredeep (Czech Republic) assigned to Zone NN5 contain enigmatic specimens of *Catinaster* sp., similar to *Catinaster?* sp. of Perch-Nielsen (1985), that are hypothesized by Svabenicka (2002) to be possibly the central portion of a broken *D. musicus*, even though that species was not recorded at that locality. Edwards *et al.*, (2005, 2010) recorded the presence of *Catinaster* cf. *C. coalitus* from middle Miocene (Zone NN5-NN6) sediments of the Chesapeake Bay impact structure and suggested that the *Catinaster* genus evolved approximately 14 Ma.

Catinaster virginianus has only been found in middle

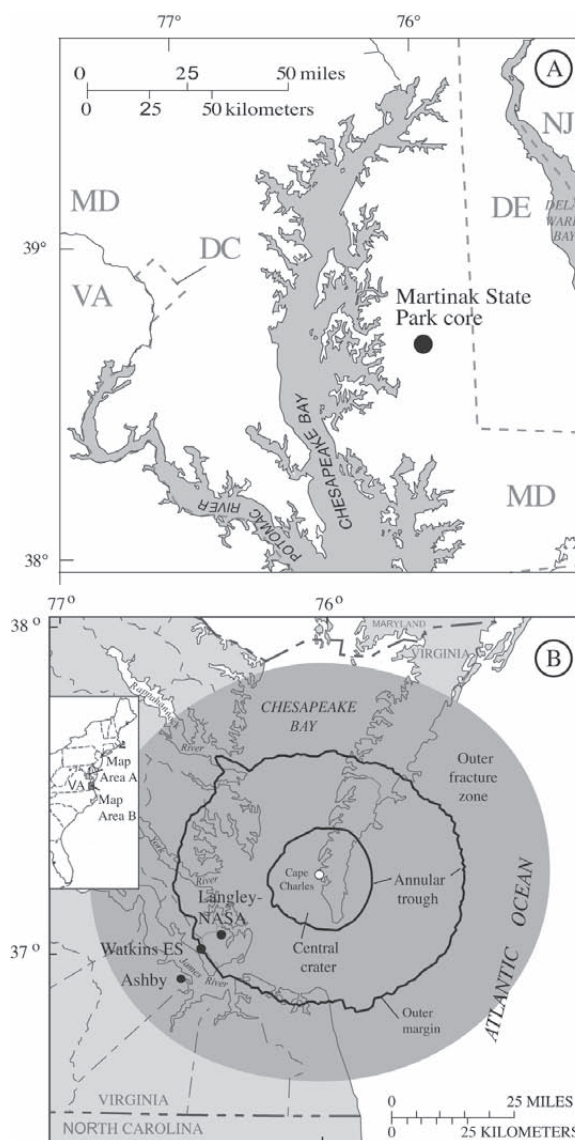


Figure 1. A) map showing the location of the Martinak State Park corehole in Maryland; B) map showing the location of the Chesapeake Bay impact structure and the USGS-NASA Langley corehole, the Watkins Elementary School corehole, and the Ashby corehole in Virginia. Small insert in map B shows the location of both of these maps to each other and to the Eastern seaboard of the United States.

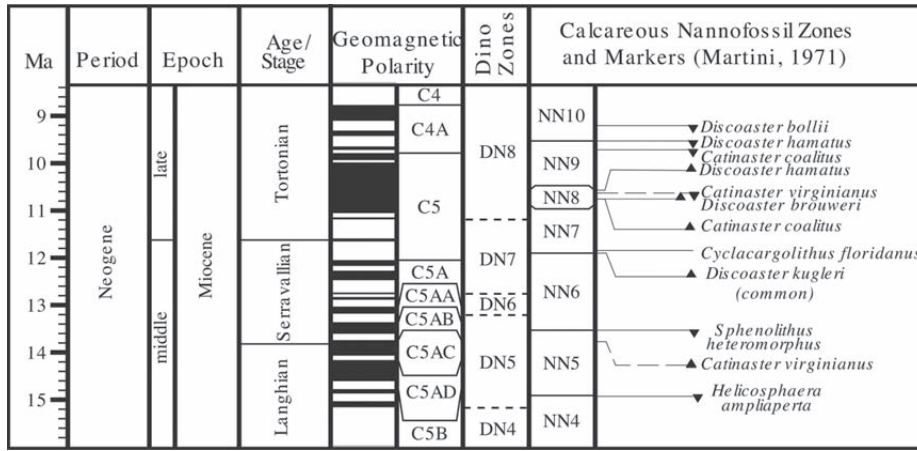


Figure 2. Geochronologic chart showing the relative position of the calcareous nannofossil Martini (1971) zones to the East Coast dinoflagellate zones of de Verteuil and Norris (1996) and de Verteuil (1997) and to the geologic time scale of Gradstein *et al.* (2012). Correlation of nannofossil events to the timescale is based on Hilgen *et al.* (2012). Upward pointing triangles indicate a first occurrence datum; downward pointing triangles indicate a last occurrence datum.

Depth (m)	Depth (ft)	Number of <i>Catinasters</i>	Number of Other Nannofossils	Percent <i>Catinasters</i>
Ashby Core				
79.5	261	0	0	0
82.6	271.0	0	400	0
85.6	280.8	14	386	3.5
88.2	289.6	0	0	0
90.8	298.0	5	395	1.25
93.9	308.3	0	400	0
USGS-NASA Langley Core				
121.8	399.8	0	400	0.00
131.4	431.2	0	0	0.00
134.4	440.9	7	393	1.75
136.5	448.0	4	396	1.00
139.3	457.0	1	399	0.25
142.1	466.3	0	400	0.00
Martinak State Park				
18.9	62.1	0	400	0
22.0	72.2	0	400	0
25.1	82.4	1	399	0.25
27.5	90.4	1	399	0.25
31.8	104.3	1	399	0.25
34.2	112.2	0	400	0
Watkins ES				
104.5	343.0	0	400	0
111.4	365.7	0	0	0
115.0	377.3	7	142	4.66
118.1	387.5	13	387	3.25
123.2	404.2	0	400	0

Table 1. Number of specimens of *Catinaster virginianus* against 400 total calcareous nannofossils counted.

to upper Miocene sediments of the Plum Point and Calvert Beach Members of the Calvert Formation and the upper Miocene sediments of the basal St. Marys Formation. Sediments of the Calvert and St. Marys Formations typically consist of fossiliferous, massive to thinly bedded silty clays to clayey silts. Microfossils (calcareous nannofossils, dinoflagellates, and diatoms) are common. Paleoenvironmental interpretation based on sediment type and fossil content indicates that the Calvert Formation was deposited in a warm, nearshore to shallow shelf setting and the St. Marys was deposited in a marine inner to outer shelf setting, with possible cool water upwelling

(Powars *et al.*, 2005; Edwards *et al.*, 2010).

The purpose of this paper is to describe and name this new species of *Catinaster* and to comment on its biostratigraphic range, to discuss the evolution of the *Catinaster* genus from *Discoaster*, and to speculate on the possible modes of global dissemination for this new species.

2. Materials and Methods

The four cores utilized for this study are the Watkins Elementary School (ES) core (lat 37°04'31.921"N; long 76°27'30.650"W), the USGS-NASA Langley core (lat 37°05'44.28"N; long 76°23'08.96"W) and the Ashby core (lat 36°55'59.407"N; long 76°31'47.021"W), from Virginia, and the Martinak State Park core (lat 38°51'58.00"N; long 75°50'17.02"W) from Caroline County, Maryland. The Virginia cores are located in the Chesapeake Bay impact structure in Virginia (Figure 1b) and the Maryland core is located approximately 106 miles (170 km) north of the northern edge of the crater (Figure 1a).

Samples were taken from the center of freshly broken core segments in order to avoid contamination by drilling fluid. Smear slides were prepared using the double slurry method of Watkins and Bergen (2003) and mounted with Norland Optical Adhesive 61. Slides were scanned using a Zeiss Axioplan 2 light microscope at x1250 magnification under cross-polarized light (XPL) and plane parallel light (PL) and photographed at x2000. Scanning electron microscope photomicrographs were taken on a Jeol JSM-6400. Relative percent abundance of *C. virginianus* for each slide was calculated based on the number of *Catinasters* present per 400 specimens of calcareous nannofossils (Table 1).

3. Abundance and Biostratigraphic Range

The relative abundance of *Catinaster virginianus* sp. nov. was calculated for each core in the study area. This species typically represents less than 5% of the total assemblage in all four cores, and reached its peak abundance in the Watkins ES core (Figure 3). Some samples in each core were barren or rare, containing only dissolution resistant species, due to poor preservation of calcareous microfossils in the sandy parts of the Calvert Formation and

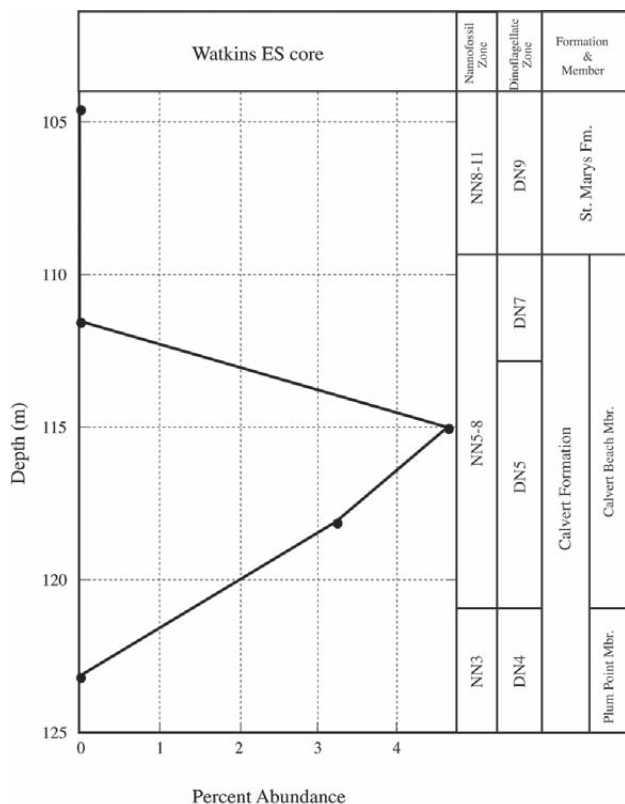


Figure 3. Graph showing percent abundance of *C. virginianus* sp. nov. to total nannofossil assemblage in the Watkins ES core. Lithostratigraphy and dinoflagellate biostratigraphy after Edwards *et al.* (2010). The sample at 111.5 m is entirely barren of calcareous nannofossils.

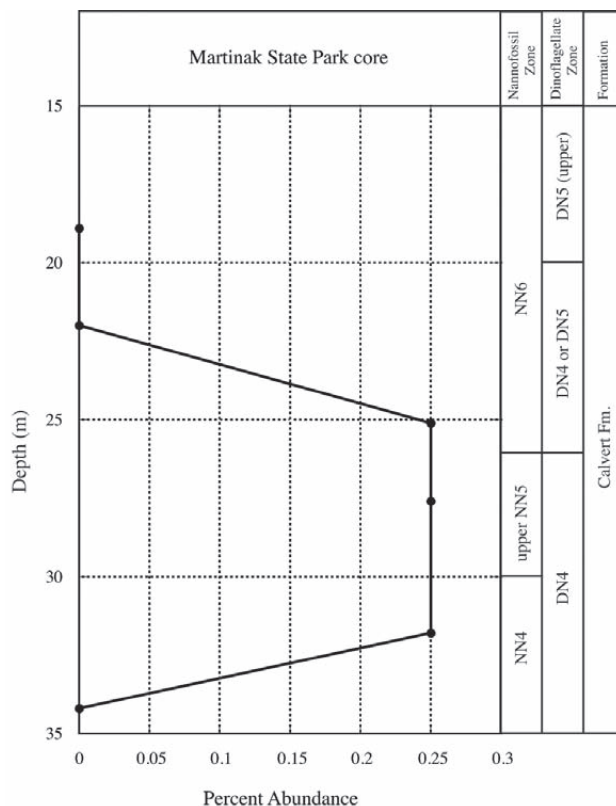


Figure 4. Graph showing percent abundance of *C. virginianus* sp. nov. to total nannofossil assemblage in the Martinak State Park core. Lithostratigraphy and dinoflagellate biostratigraphy after Edwards, Powars, and Self-Trail (unpub. data).

the silty St. Marys Formation.

The documentation of *C. virginianus* (usually as *Catinaster* sp.) from other basins has largely been attributed to slumping of sediments, downhole contamination, or as misidentification of specimens by mistaking broken discoasters for catinasters (Aubry, 1993; Svabenicka, 2002; Denne, 2008). It is interesting to note, however, that in each case, the older sediments in which the enigmatic *Catinaster* forms have been found were dated as NN5 or NN6, suggesting that early specimens of *Catinaster*, heretofore undescribed, existed and have been consistently misidentified. Often these *Catinaster* specimens are overgrown, making identification difficult but resulting in a high preservation potential.

The first occurrence (FO) of *Catinaster virginianus* in the study area occurs after the last occurrence (LO) of *Helicosphaera ampliaperata* and before the LO of *Sphenolithus heteromorphus*, which restricts the FO of this species to Zone NN5. The co-occurrence of *C. virginianus* with *Discoaster musicus*, which has its FO in mid-NN5, and with *S. heteromorphus* in both the Martinak State Park and the Langley cores further restricts the FO of this species to mid-to-late NN5. The presence of dinoflagellate species *Habibacysta tectata*, which has its FO near the middle of dinoflagellate Zone DN5, with *Cleistosphaeridium placacanthum*, whose LO defines the top of Zone DN5, at 88.0-88.2 m in the Ashby core, corroborates a mid-to-late Zone NN5 placement. Although rare specimens of

C. virginianus are documented from one sample in lower to middle Miocene sediments of the Martinak State Park core (nannofossil Zone NN4 and dinoflagellate zone DN4; Figure 4), these occurrences are attributed either to *in situ* burrowing of the overlying Zone NN5 sediments into Zone NN4 or to drilling mud injection during drilling operations. Examination of Plum Point Member calcareous nannofossil assemblages from other cores does not confirm its presence in these sediments (Edwards *et al.*, 2005). However, *C. virginianus* is consistently identified in all four studied cores from the middle Miocene (Zone NN5 of Okada and Bukry (1980) and dinoflagellate zone DN5 of de Verteuil and Norris (1996)).

The precise last occurrence of *Catinaster virginianus* nov. sp. is unclear. Miocene sediments of the Atlantic Coastal Plain are often sandy and severely truncated, resulting in a package of unconformity-bounded units that are relatively thin, and it is often difficult to place samples within a specific nannofossil zone (Figures 3, 5, and 6). However, specimens of both *C. virginianus* and rare *C. coalitus coalitus* are documented from one sample (85.6 m) from the basal St. Marys Formation in the Ashby core, which corresponds to late Miocene calcareous nannofossil Zone NN8. This suggests that *C. virginianus* has its last occurrence within the early late Miocene (Tortonian Stage) and that it overlaps briefly with *C. coalitus coalitus*. Additionally, the co-occurrence of dinoflagellate species *Sumatradinium soucouyantiae* (LO defines the top of

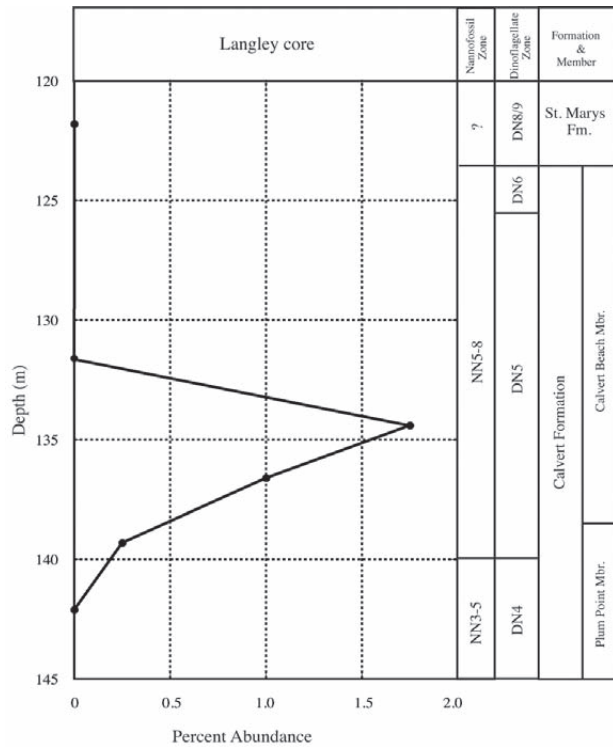


Figure 5. Graph showing percent abundance of *C. virginianus* sp. nov. to total nannofossil assemblage in the USGS-NASA Langley core. Lithostratigraphy and dinoflagellate biostratigraphy after Edwards *et al.* (2005) and Powers *et al.* (2005). The sample at 131.4 m is entirely barren of calcareous nannofossils.

Zone DN8) with *Palaeocystodinium golzowense* (LO at the top of Zone DN8), along with the absence of *Cannosphaeropsis passio* (LO defines the top of Zone DN7) at 85.0-85.1 m in the Ashby core, places this sample in Zone DN8, and corroborates a Zone NN8 placement for the LO of *C. virginianus* (Figure 2). Edwards (unpub. data, 2013) notes that the St. Marys Formation in the Ashby core is an older part of DN8 than has been previously recorded from Maryland (de Verteuil and Norris, 1996).

4. Paleoenvironment and Evolution

In his discussion of the genus *Catinaster*, Martini (1981) suggested that species of this genus were restricted to tropical or subtropical regions, based on known distribution patterns documented from numerous coreholes. Distribution of *C. virginianus* and other enigmatic catinasters from the Gulf of Mexico, the Mid-Atlantic region, and the Czech Republic (Denne, 2008; Edwards *et al.*, 2005; Svabenicka, 2002), which were all located in tropical to subtropical regions during the middle Miocene, supports the theory that this genus had a preference for warm water settings.

However, Peleó-Alampay *et al.* (1998) offered an alternative possible paleoenvironmental preference for *Catinaster* by suggesting that at least one species (*C. mexicanus*) preferred semi-enclosed basins or locations proximal to the continental shelf. The type locality for *Catinaster virginianus* is located in the marine-impact Chesapeake Bay impact structure. The ~85 km diameter crater is located on the continental shelf of the mid-Atlantic region

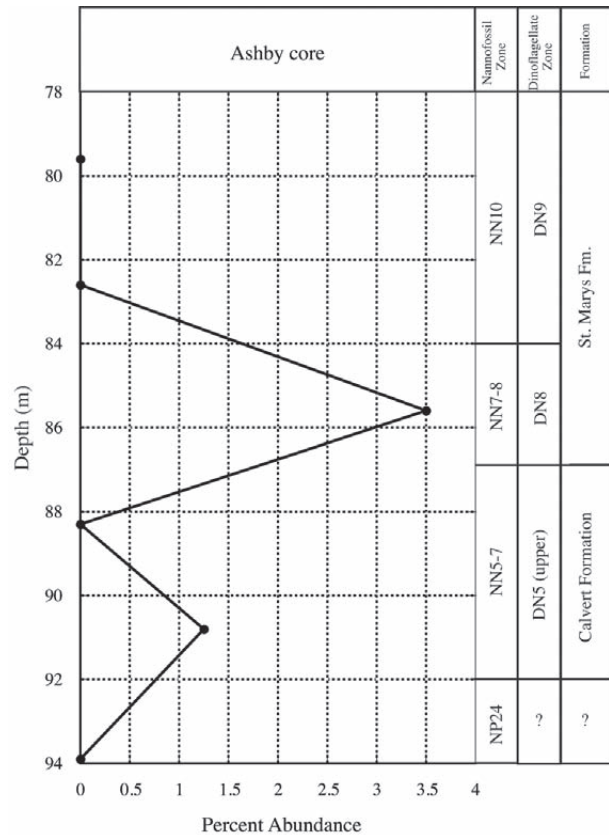


Figure 6. Graph showing percent abundance of *C. virginianus* sp. nov. to total nannofossil assemblage in the Ashby core. Lithostratigraphy and biostratigraphy after Edwards, Powars, and Self-Trail (unpub. data). The samples at 79.5 and 82.6 m are entirely barren of calcareous nannofossils.

and formed when a bolide struck the region approximately 35.4 Ma (Powars and Bruce, 1999; Gohn *et al.*, 2009). The unique compaction of sediments within the structure following impact significantly affected sedimentation and paleoenvironmental controls in the region and resulted in a deep basin that existed from the late Eocene through at least the middle Miocene, and possibly into the early late Miocene (Hayden *et al.*, 2008; Kulpecz *et al.*, 2009; Gohn *et al.*, 2009). *Catinaster virginianus* is consistently identified from cores located in the Chesapeake Bay impact crater; it is extremely rare in the one core north of the crater rim.

Peleó-Alampay *et al.*, (1998) comprehensively summarized the taxonomy and evolutionary relationship among species within the *Catinaster* group, and hypothesized that this group evolved from the *Discoasters*, in particular from *Discoaster transitus*. This publication noted that what the authors considered to be the ancestral species, *C. coalitus coalitus*, had its first occurrence in the lower part of subchron C5n.2n, at approximately 10.9 Ma, and at the base of Zone NN8 of Martini (1971; Zone CN6 of Okada and Bukry (1980)). However, older forms of *Catinaster* have been identified from other basins globally, typically from middle Miocene (NN5 or NN6) sediments. Aubry (1993) and Denne (2008) identified catinasters of middle Miocene age from the Gulf of Mexico, which was a subtropical, structurally complex fluvial-deltaic and marine

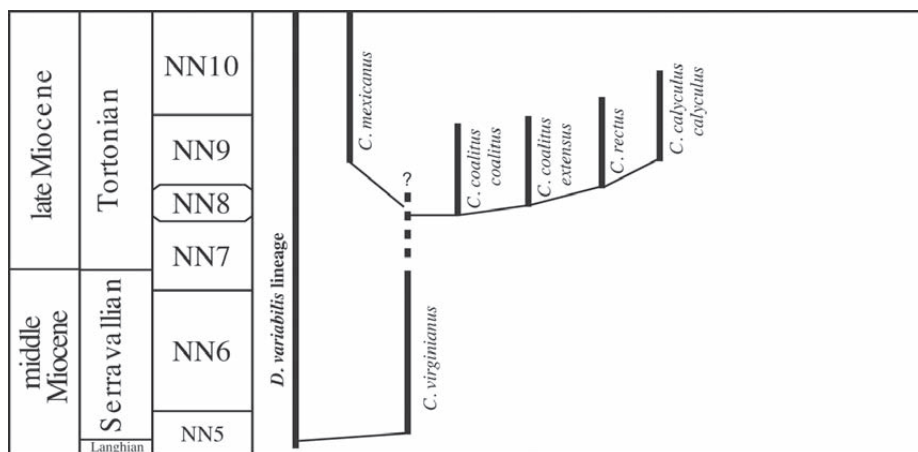


Figure 7. Possible evolutionary lineage of *Catinaster* species. Modified from Peleo-Alampay *et al.* (1998).

system of depocenters and minibasins experiencing high rates of sedimentation during the middle Miocene (Combellas-Bigott and Galloway, 2006). Svabenicka (2002) identified a similar form from middle Miocene sediments of the Carpathian Foredeep, an area that developed as a peripheral foreland basin and which contains over 3,000 m of middle Miocene marine sediments (Oszczypko and Oszczypko-Clowes, 2012). Examination of published plates from Aubry (1993), Svabenicka (2002), and Denne (2008) suggests that what they figured are specimens of *Catinaster virginianus*. In particular, the presence of extended rays is clearly illustrated by Aubry (1993; Pl. 3, figs. 13-14), Svabenicka (2002; Fig. 7, n. 13-14) and Denne (2008; Pl. 2, fig. 5a) and the basket shape is clearly illustrated by Denne (2008; Pl. 2, Fig. 5b).

Radiation and population of individual basins could easily have occurred via ocean currents such as the Gulf Stream. This warm-water current has been active since the Late Cretaceous (Pinet and Popenoe, 1985; Watkins and Self-Trail, 2005), flowing east from the Gulf of Mexico, then heading northward along the mid-Atlantic seaboard, and currently trending eastward towards Europe and the Mediterranean region at the Cape Hatteras shelf break. In the most likely scenario, *C. virginianus* evolved in the Gulf of Mexico and was carried northward to the Chesapeake Bay impact structure basin, and from there was carried eastward towards the Carpathian Foredeep. Radiation was most likely rapid, as evidenced by the presence of *C. virginianus* in middle Miocene sediments in multiple basins.

Based on the presence of this new ancestral form of *Catinaster*, which is considerably older than both *C. coalitus* and *Discoaster transitus*, it is unlikely that the evolutionary lineage of Peleo-Alampay *et al.* (1998) is entirely correct. The presence of two stems on *C. virginianus*, one each on the proximal and distal surfaces (see Systematic Paleontology section; Plate 1, figs. 3-4), along with the broad bifurcations that make up the basket edge on the proximal side and the slender, easily broken rays that extend outward from the distal side, suggests that the genus *Catinaster* did indeed evolve from the discoaster group. However, it is unlikely to have evolved from *D. transitus*, as suggested by Peleo-Alampay *et al.*, (1998), which has a first occurrence near the base of Zone NN8.

Rather, it most likely evolved from the *Discoaster variabilis* lineage (Figure 7).

5. Systematic Paleontology

All figured specimens and type species are stored in the calcareous nannofossil laboratory at the U.S. Geological Survey, Reston, Virginia. Species descriptive terms predominantly follow the terminology of Martini and Worsley (1971) and Peleo-Alampay *et al.*, (1998), with additions by Young *et al.*, (1997). Light photomicrographs of selected specimens were taken in cross-polarized (XPL) and phase contrast (PC) at the same magnification (x2000).

Order DISCOASTERALES Hay, 1977

Family DISCOASTERACEAE Tan, 1927

Catinaster virginianus sp. nov.

Pl. 1 figs. 1-12

Pl. 2 fig. 1-3

Catinaster sp. Aubry, (1993), Pl. 3, fig. 13-15

Catinaster sp. *sensu* Perch-Nielsen (1985),

Svabenicka (2002), Fig. 7, n. 13-14

Catinaster sp. "A", Denne (2008), Pl. 2, figs. 5a, 5b

Catinaster cf. *C. coalitus*, Edwards *et al.* (2010),
Fig. 13G

Derivation of Name: Named after the state of Virginia, in the United States, where this species is commonly found in crater sediments that filled the basin created by the Chesapeake Bay impact event. **Diagnosis:** Small to medium-sized *Catinaster*, six-rayed and basketlike, with thicker bifurcated rays on the proximal side and more slender rays on the distal side. Occasional seven-rayed morphotypes rare (Plate 1, fig. 12). **Description:** A species of *Catinaster* having a broad usually six-rayed, star shaped central stem on the proximal side (Plate 1, figs. 3a, 4a) from which six short rays with broadly bifurcated tips extend distally at an angle, forming a broadly sub-hexagonal rim (Figure 8; Plate 1, figs. 1, 7). The bifurcate tips are typically in close proximity with each other in well-preserved samples, and occasionally touch in specimens that clearly show calcite overgrowth (i.e. thickened rays and bifurcations, higher order birefringence patterns). Inter-ray angles are somewhat rounded. The central stem on

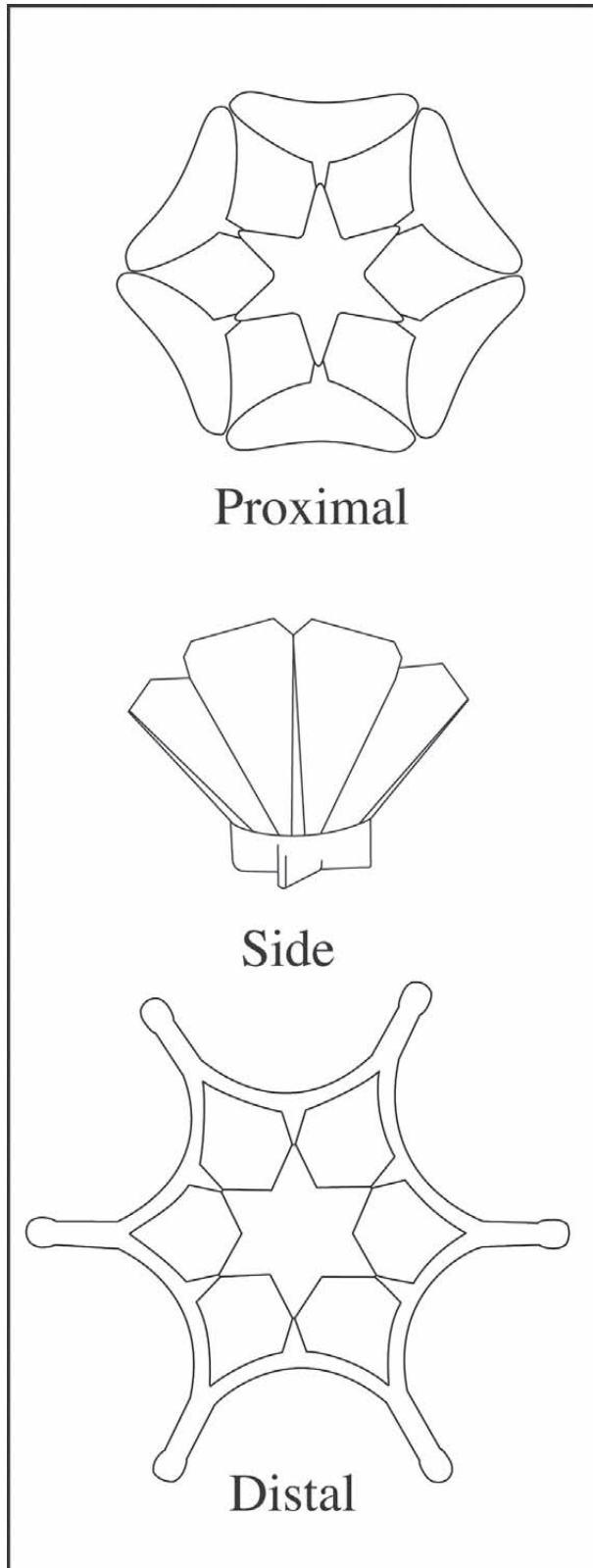


Figure 8. Schematic drawing of *Catinaster virginianus* showing proximal, distal, and side views. Proximal and distal views are on different focal planes.

the distal side is almost identical to the proximal side, and does not extend beyond the edges of the basket (Plate 1, figs. 3b, 4b). Slender rays with slightly rounded, bifurcated tips extend from the distal edges of the basket and are easily broken or missing entirely (Figure 8; Plate 2, fig. 1). *Catinaster virginianus* occasionally has seven-rayed variants. **Differentiation:** *Catinaster virginianus* can be differentiated from all other catinasters by the presence of a stem on both the proximal and distal surfaces (Plate 1, figs. 3-4; Figure 8) and by the presence of slender rays that extend past the distal edge of the basket (Plate 2, fig. 1). *Catinaster virginianus* most closely resembles *C. coalitus coalitus*, from which it can be differentiated by the presence of a broad star-shaped central stem on the proximal side. The rim is often sub-hexagonal in *C. virginianus*, whereas it is fully hexagonal in *C. coalitus coalitus*. The bifurcate ray tips do not meet in *C. virginianus*, whereas they only occasionally have gaps in early forms of *C. coalitus coalitus*. *Catinaster virginianus* differs from *C. coalitus extensis* in lacking arms associated with the central stem that extend out beyond the edge of the basket. *Catinaster virginianus* has a rare 7-rayed morphotype not seen in any other species of *Catinaster*. **Dimensions:** *Catinaster virginianus* ranges from 4.5-8.0 μm in size, and averages 6.18 μm ($n=30$). **Holotype:** Pl. 2, fig. 1, distal view. **Paratypes:** Pl. 1, fig. 2, distal view; Pl. 1, fig. 4, side view. **Type locality:** USGS-NASA Langley Core, Hampton, VA (USA). **Type level:** Middle Miocene (Serravallian), 134.4 m. **Occurrence:** NN5-NN8.

Appendix

- Catinaster coalitus coalitus* Martini & Bramlette, 1963
- Catinaster coalitus extensis* (Martini & Bramlette, 1963)
- Peleo-Alampay *et al.*, 1998
- Catinaster mexicanus* Bukry, 1971
- Discoaster musicus* Stradner, 1959
- Discoaster sanmiguelensis* Bukry, 1981
- Discoaster transitus* Peleo-Alampay *et al.*, 1998
- Discoaster variabilis* Martini & Bramlette, 1963
- Helicosphaera ampliaperta* Bramlette & Wilcoxon, 1967
- Sphenolithus heteromorphus* Deflandre, 1953

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Plate 1

Catinaster virginianus, **figs. 1-2**: USGS-NASA Langley core, 136.6 m; **figs. 3-4**: USGS-NASA Langley core, 136.6 m, side view focused up (a), middle focus (b), focused down (c); **figs. 5-6, 12**: USGS-NASA Langley core, 134.4 m; **figs. 7-11**: Watkins ES core, 118.1 m. PC = phase contrast; TL = transmitted light.
Remaining illustrations = cross-polarized light.

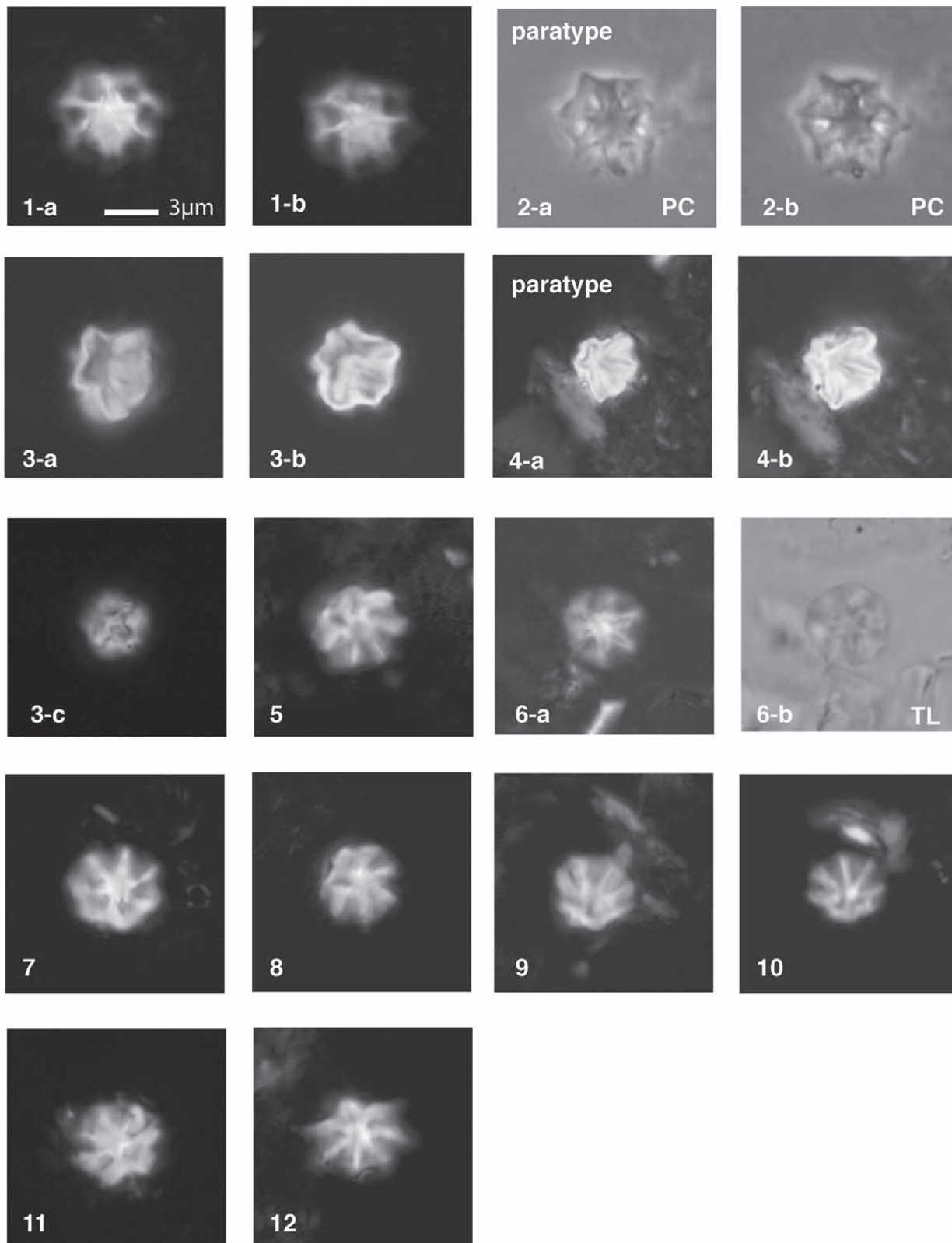
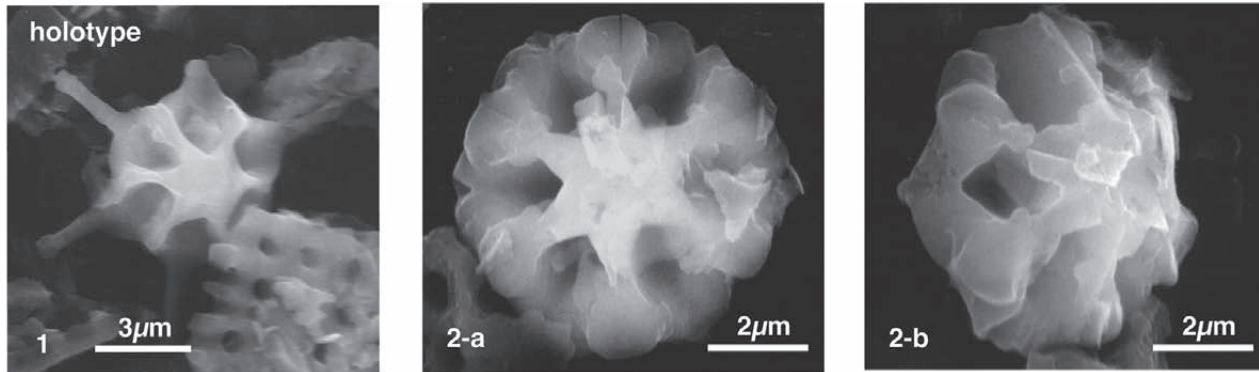


Plate 2

Plate 2. *Catinaster virginianus*, fig. 1: USGS-NASA Langley core, 134.4 m, distal view;
fig. 2: USGS-NASA Langley core, 134.4 m, proximal and side views.



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