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NEW RECORDS OF THE ECHINOID *CLYPEASTER* FROM THE UPPER EOCENE-LOWER OLIGOCENE DAMUJÍ FORMATION IN RODAS, SOUTH-CENTRAL CUBA

NUEVOS REGISTROS DE EQUINODERMOS DEL GÉNERO *CLYPEASTER* DE LA FORMACIÓN DAMUJÍ DEL EOCENO TARDÍO-OLIGOCENO TEMPRANO, EN RODAS, CENTRO-SUR DE CUBA

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ABSTRACT: This study examines *Clypeaster* echinoid fossils from the Damují Formation, dating from the late Eocene-early Oligocene, in Rodas, south-central Cuba. The research aims to contribute to the understanding of the paleoecology and biogeography of echinoids during the latest Eocene in the Caribbean region. While previous investigations have largely focused on *Clypeaster* species from the Oligocene and Miocene, the specimens examined here are crucial for elucidating the early phases of echinoid evolution and geographical distribution. Our analysis of the Damují Formation's geological context and fossil content uncovered a diverse marine ecosystem comprising large foraminifera, corals, small, isolated fish teeth, and *Clypeaster* sand-dollar fossils. These findings broaden the established temporal and spatial distribution of *Clypeaster*, indicating a varied reef environment in the central Caribbean during the late Eocene-early Oligocene. The occurrence of these fossils in the Damují Formation enhances our understanding of palaeogeographical patterns, with implications for *Clypeaster* diversity and evolution.
KEYWORDS: *Clypeaster*, Cuba, Damují Formation, echinoids, Eocene.

RESUMEN: Este estudio examina fósiles de equinoideos del género *Clypeaster* de la Formación Damují, que datan del Eoceno tardío-Oligoceno temprano, en Rodas, centro-sur de Cuba. La investigación tiene como objetivo contribuir a la comprensión de la paleoecología y la biogeografía de los equinoideos durante el Eoceno tardío en la región del Caribe. Si bien investigaciones anteriores se han centrado en gran medida en especies de *Clypeaster* del Oligoceno y Mioceno, los ejemplares aquí examinados son cruciales para esclarecer las primeras fases de la evolución y distribución geográfica de estos equinoideos. Nuestro análisis del contexto geológico de la Formación Damují y su contenido fósil reveló un ecosistema marino diverso que comprende grandes foraminíferos, corales, pequeños dientes aislados de peces y fósiles de *Clypeaster*. Estos hallazgos amplían la distribución temporal y espacial previamente establecida de *Clypeaster*, indicando un entorno de arrecife variado en el Caribe central durante el Eoceno tardío-Oligoceno temprano. La aparición de estos fósiles en la Formación Damují mejora nuestra comprensión de los patrones paleogeográficos, con implicaciones para la diversidad y evolución de *Clypeaster*.
PALABRAS CLAVE: *Clypeaster*, Cuba, equinoideos, Eoceno, Formación Damují.

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Introduction

Clypeaster is a relatively large, thick-shelled, irregular echinoid known for its highly differentiated external surface and internal morphology (Mortensen, 1948; Durham, 1966; Mooi, 1989; Mihaljević *et al.*, 2011). The genus is distinguished by its remarkable species richness with approximately 400 nominal species, making it the most diverse genus among echinoids (Mihaljević and Rosenblatt, 2018). Its members are broadly distributed across tropical and subtropical waters, inhabiting all the shallow water environments of major oceans where they are infaunal, detritus feeders (Clarkson, 1998). The fossil record of *Clypeaster*, dating back to the Middle Eocene, highlights its extensive history and evolutionary import (Mihaljević *et al.*, 2011 and references therein; Lee *et al.*, 2023). Its extensive geographical distribution, along with high taxonomic diversity, excellent preservation potential, and rich fossil record makes *Clypeaster* a valuable subject for biogeographical and palaeobiological studies (Mihaljević *et al.*, 2010, 2011; Mihaljević and Rosenblatt, 2018; Lee *et al.*, 2023).

The first fossil species ever documented in Cuba was a *Clypeaster*. This specimen was published in La Habana by Antonio Parra in the late 18th century (Parra, 1787: 181), and subsequently named *Clypeaster parrae* in his honor. Nearly a century later, 41 echinoid taxa had been described for Cuba, primarily by M. C. Cotteau from specimens collected by Spanish geologists working for the Commission for the Geological Map of Spain, including Pedro Salteraín, Policarpo Cía, Manuel Fernández de Castro, and Justo Egozcue (Nuñez-Jiménez, 1998). Historical accounts trace the discovery of *Clypeaster* echinoid fossils in Rodas, Cienfuegos, south-central Cuba, to 1891, based on reports by the Spanish Geological Survey (Cotteau, 1897). These initial findings, documented at the old San Lino sugar mill, included two species: *Clypeaster planipetalus* Cotteau 1875 and *C. concavus* Cotteau 1875, of Miocene age. Later, fossil records of this echinoid genus in Cuba have predominantly emerged from strata dating to the Oligocene and Miocene epochs (Jackson, 1922; Kojumdgieva and Popov, 1982; Donovan, 1994; Sanchez-Roig, 1924, 1926, 1949, 1952; Franco, 1983). Therefore, the discovery of specimens within the Upper Eocene Damují Formation at the Parque Alto locality in Rodas is particularly noteworthy. These findings, alongside significant paleontological evidence such as large foraminifera, corals, and isolated fish teeth, paint a vivid picture of a rich and dynamic marine ecosystem during the latest Eocene, and particularly during the Eocene-Oligocene Transition (EOT) cooling event.

The primary objective of this communication is to present novel *Clypeaster* specimens from the Upper Eocene deposits of Rodas. These findings are significant for enhancing our understanding of *Clypeaster*'s evolutionary history and paleobiogeographical distribution, contributing to the reconstruction of the paleoecological landscape during the latest Eocene - earliest Oligocene. This work not only expands our knowledge of *Clypeaster*'s variability and range but also underscores the paleontological richness of Cuba's Paleogene fossil record (Orihuela *et al.*, 2020, 2023).

Material and Methods

The two echinoid specimens investigated in this study are housed at the Museo Municipal de Rodas, Cienfuegos, Cuba (MMR), with the registration numbers MMR-PA-001 and MMR-PA-002. They were collected about 2015 at Parque Alto, a locality along the route to the Damují River, to the northeast of Rodas, Cienfuegos Province, south-central Cuba (Fig. 1). The locality name is due to the presence of a homonymous sugar mill since 1852. The collection site where the *Clypeaster* specimens were found is 3 km west of the old sugar mill settlement, on the banks of the Damují River. Several outcrops of the Upper Eocene Damují Formation are exposed, due to river erosion. Loose echinoid specimens are frequently encountered on the surface in this area, primarily due to the agricultural activities that disturb the land. Farmers often collect these fossils, attracted by their ambulacra, which they interpret as "flower drawings," turning them into collectibles. Additionally, other *Clypeaster* specimens remain embedded in the local rocks, indicating that the loose specimens are a result of the erosive processes affecting these strata.

The morphological characteristics of the collected specimens were compared with existing descriptions of *Clypeaster* taxa from the literature. Key references included works by Sánchez-Roig (1924, 1926, 1949, 1952), Mortensen (1948), Durham (1966), Mooi (1989), Mihaljević *et al.* (2011), and Mihaljević and Rosenblatt (2018). Specimens observed in the field embedded in the rocks were compared with cross-sections of a *Clypeaster* specimen from Matanzas, which was also used as a reference for terminology and comparisons (Fig. 2).

Geological Context

The Damují Formation consists predominantly of coarse biodetritic limestones to calcirudites, enriched with large foraminifera, bryozoan fragments, and coral remains. The thickness of this formation varies between 50 to 150 meters.

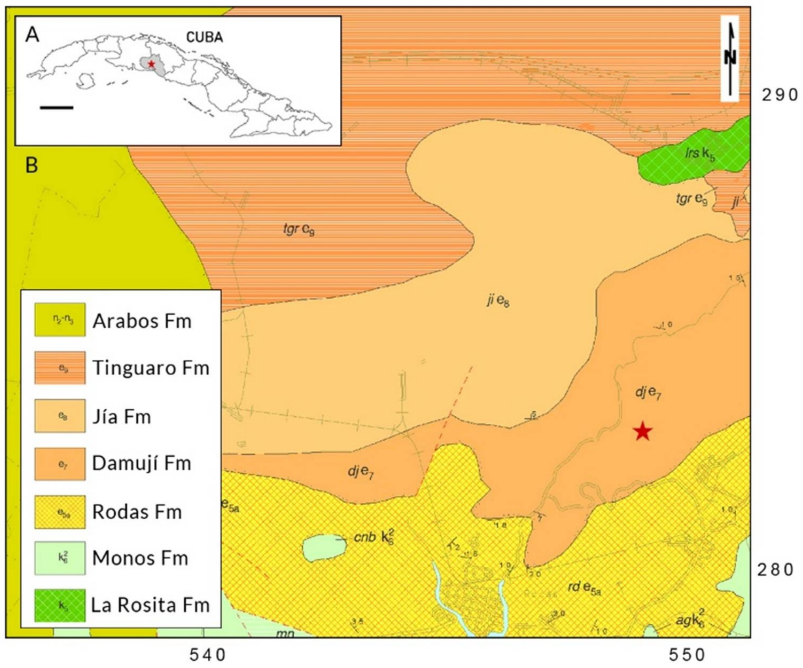

FIGURE 1. A. General map of Cuba, scale bar = 200 km (insert on left upper corner). B. Geologic map of the study area. The red star indicates the Parque Alto locality, where the fossils investigated in this work were found.

FIGURA 1. A. Mapa general de Cuba, barra de escala = 200 km (inserto en la esquina superior izquierda). B. Mapa geológico del área de estudio. La estrella roja indica la localidad Parque Alto, donde fueron encontrados los fósiles estudiados.

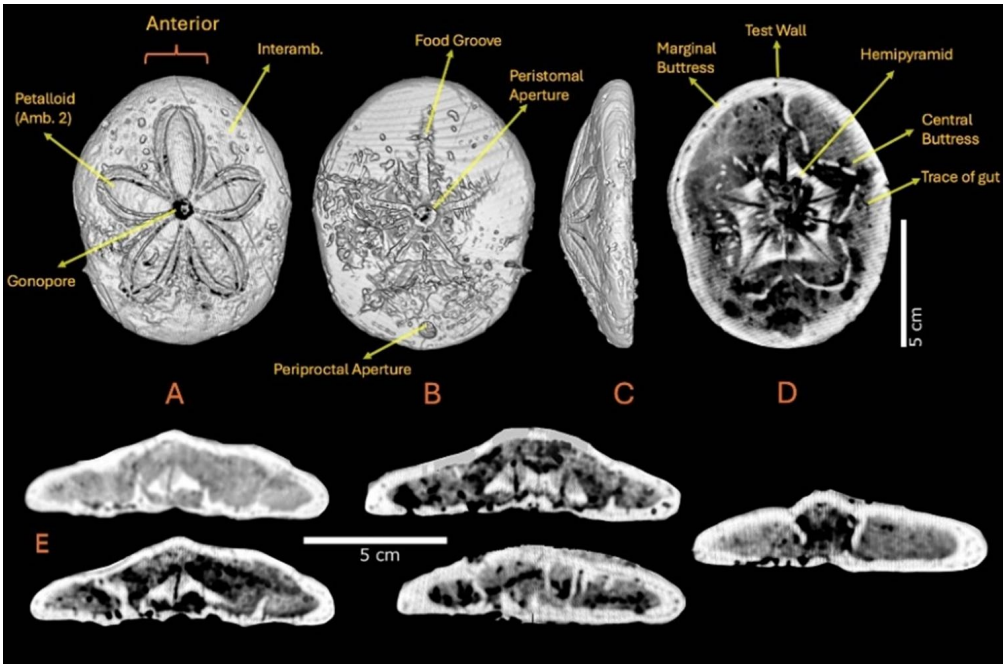

FIGURE 2. *Clypeaster* sp. from the Miocene of Matanzas, Cuba, used for comparative analysis. Specimen discovered by Ricardo Viera Muñoz in sediments of the Colón Formation.

FIGURA 2. *Clypeaster* sp. del Mioceno de Matanzas, Cuba, usado para el análisis comparativo. El espécimen fue descubierto por Ricardo Viera Muñoz en sedimentos de la formación Colón.

The formation presents a transgressive relationship over the Rodas Formation and grades upward into the Jía Formation. Lateral transitions to the contemporaneous Jicotea Formation occur through sections featuring intercalations of limestones, sandstones, and sandy marls. Further information on this unit is provided in Kantchev *et al.* (1978). In the type-section, an orderly sequence is observed commencing with white to cream-yellowish limestones over the Rodas Formation. These limestones, distinctly cemented in thick layers, contain large foraminifera. Proceeding upward, the formation transitions into other biodetritic limestones, also rich in large foraminifera, bryozoans, and corals. The upper sections are characterized by light creamy to white limestones, comprising coarse debris up to breccias, housing large Oligocene foraminifera characteristic of the Jía Formation.

The paleontological content, as delineated by Kantchev *et al.* (1978), includes corals such as *Antiguastrea cellulosa*; the large benthic foraminifera *Nummulites* (=*Camerina*) *cubensis*, *Nummulites* (=*Camerina*) *petri*, *Heterostegina ocalana*, *Pseudophragmina (=Orthophragmina) floridana*, *Asterocyclina* sp., *Eulepidina chapel* (*sensu* Mitchell *et al.*, 2022), *Lepidocyclina pustulosa*, and *Helicolepidina spiralis* (BouDagher-Fadel, 2018). The index taxon *Helicolepidina spiralis* is believed to have emerged during the late Eocene, with extinction occurring in the early Oligocene (Rupelian, P18). Conversely, *Eulepidina* first appeared in the early Oligocene (BouDagher-Fadel, 2018). The detection of *Lepidocyclina pustulosa* and *Heterostegina ocalana* further indicates a stratigraphic age from the late Eocene to the earliest Oligocene (lower Rupelian) (Benedetti *et al.*, 2018; BouDagher-Fadel, 2018). This assemblage is characteristic of a warm, tropical reef-forereef carbonate shelf environment (BouDagher-Fadel, 2018).

Results

Systematic Paleontology

Class Echinoidea Leske, 1778
Order Clypeasteroida Agassiz, 1835
Suborder Clypeasterina Desor, 1857
Family Clypeasteridae Agassiz, 1835

Material: MMR-PA-002, incomplete echinoid test (Fig. 3C).

Locality: Parque Alto, Upper Eocene Damují Formation, Rodas, Cienfuegos Province, south-central Cuba.

Description: Specimen MMR-PA-002 is identified as a member of the family Clypeasteridae: The test is medium to large, ovoid in shape, with a concave oral surface and secondary bilateral symmetry. It is exocyclic, with an infra-marginal periproct. The apical system includes five genital pores with fused plates. The ambulacra are petaloid, composed of regularly alternating primary plates and demiplates, with the latter adjacent to the adradial but not to the perradial suture. The interambulacra have significantly reduced primordial plates. The peristome is centrally located in a deep depression. The test also features internal structural supports. Its length is 12.7 mm, and diameter is 9.6 mm.

Systematic paleontology

Genus *Clypeaster* Lamarck, 1801

Material: MMR-PA-001, complete, well-preserved test showing plate boundaries and tuberculation (Fig. 3A-B), and four specimens observed in the field embedded in the rocks with cross-section exposed (Fig. 4)

Locality: Parque Alto, Upper Eocene Damují Formation, Rodas, Cienfuegos, south-central Cuba.

Description: The specimen MMR-PA-001 exhibits a flattened and discoidal test, with a distinctive circular or oval shape. The ambulacral areas are petaloid, forming petal-like patterns on the aboral (upper) surface. This characteristic includes five petals radiating from the center, which is typical of *Clypeaster* species (Mihaljević *et al.*, 2010, 2011; Mihaljević and Rosenblatt, 2018; Lee *et al.*, 2023). The test measures approximately 4.1 mm in length, and 3.2 mm in diameter. Several specimens were observed in the field exhibit similar morphological features to MMR-PA-001, indicating a consistency within the genus.

Discussion

The morphological features of MMR-PA-001 (Fig. 3 A-B) and the field specimens (Fig. 4) align closely with those described for the genus *Clypeaster*. Specifically, specimen MMR-PA-001 exhibits strong morphological similarities to *Clypeaster*, particularly in its oval shape and dense tuberculation. Due to the incomplete preservation of specimen MMR-PA-002 (Fig. 3C), it has been broadly assigned to the family Clypeasteridae. The missing fragment in this specimen may be a sign of predation, as suggested by comparison with the scientific literature (Nebelsick and Mancosu, 2022), but this feature requires further investigation with additional specimens exhibiting similar characteristics from other localities.

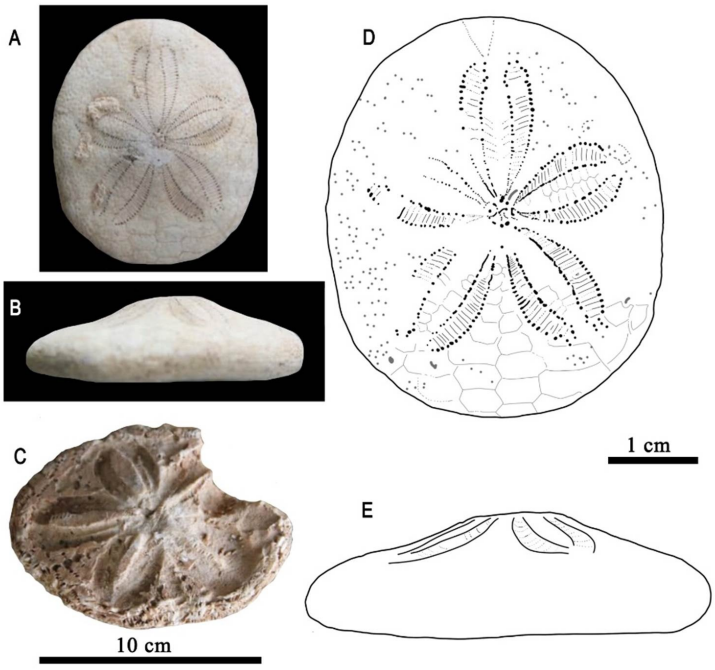

FIGURE 3. Clypeasterids from Parque Alto, Upper Eocene Damují Formation, Rodas, Cienfuegos, south-central Cuba. A. MMR-PA-001, *Clypeaster* sp., aboral side, B lateral side, C. MMR-PA-002, Clypeasteridae indet., aboral side, D-E Sketches of the *Clypeaster* test of MMR-PA-001, aboral and lateral side.

FIGURA 3. Clypeasterids de Parque Alto, formación Damují del Eoceno superior, Rodas, Cienfuegos, centro-sur de Cuba. A. MMR-PA-001, *Clypeaster* sp., vista aboral, B vista lateral, C. MMR-PA-002, Clypeasteridae indet., vista aboral, D-E Esquemas de *Clypeaster* MMR-PA-001, vista aboral y lateral.

FIGURE 4. Field specimens of fossil echinoids *Clypeaster* partially embedded in rock, often exposed in cross-section and frequently displaying signs of erosion. Located in Parque Alto, within the Upper Eocene Damují Formation, Rodas, south-central Cuba.

FIGURA 4. Especímenes de equinoides fósil del género Clypeaster parcialmente incrustados en la roca, a menudo expuestos en sección transversal y mostrando signos de erosión. Localizado en Parque Alto, dentro de la formación Damují del Eoceno Superior, Rodas, centro-sur de Cuba.

The genus *Clypeaster* is well-documented in the geological and paleontological literature of Cuba (Donovan, 1994; Sanchez-Roig, 1924, 1926, 1949, 1952; Franco, 1983). However, assigning specimens to specific species within this genus is often challenging due to the proliferation of nominal species. This difficulty is exacerbated by paleontologists who have described new species based on minor morphological differences observed in poorly preserved fossil specimens (Mihaljević *et al.*, 2011; Mihaljević and Rosenblatt, 2018). Consequently, many records lack detailed descriptions or illustrations. Furthermore, the genus is challenging to subdivide taxonomically due to the extensive gradation and variation in test characteristics across species (Rose and Poddubiuk, 1987). These variations include differences in test size and profile, medial outline, tuberculation, ambulacral shape, and the positions of the peristome and periproct (Mihaljević *et al.*, 2011). For these reasons, MMR-PA-001 and the four specimens in the field have been classified only at the genus level.

Of particular interest is the abundance of specimens at the locality that are partially embedded in the rock, often exposed in cross-section and frequently showing signs of erosion (Fig. 4). The orientation and partial exposure of these specimens offer valuable insights into the taphonomic processes that occurred during and after fossilization. The way these specimens are embedded can indicate sedimentary processes, such as the direction of current flow or the degree of burial over time (Nebelsick, 1999). For instance, the orientation might suggest post-mortem transport or in situ burial under relatively low-energy conditions, which could explain the lateral exposure observed in the field. The exposed specimens have also suffered erosion, as indicated by the wear patterns on their surfaces. This suggests prolonged exposure to environmental elements, which further complicates their extraction and study. The partial exposure poses challenges for extraction and study, emphasizing the potential value of non-invasive techniques in future research. Such approaches would not only preserve the integrity of the specimens but also provide a more accurate context for their analysis.

The discovery of *Clypeaster* specimens within the Upper Eocene Damují Formation at the Parque Alto locality in Rodas holds paleontological importance, as these may represent the oldest known specimens of the genus reported from Cuba. While some foraminifera within the formation suggests a stratigraphic age ranging from the late Eocene to the earliest Oligocene (lower Rupelian), the reported specimens likely belong to an Eocene section, offering new insights into the evolutionary history of the genus in the Caribbean. This interpretation is supported by previous studies that have consistently classified the formation as Upper Eocene, based on the identification of index foraminifera of this epoch. Furthermore, the overlying Jia Formation, considered Oligocene in age, crops out several kilometers from the Parque Alto locality. The presence of large foraminifera, bryozoans, and coral remains within the Damují Formation, along with *Clypeaster*, suggests a warm, tropical, shallow-water, soft-sediment, reef-forereef carbonate shelf environment during the late Eocene. This assemblage reflects a rich and diverse marine ecosystem, consistent with findings by BouDagher-Fadel (2018) and other studies.

Additionally, the new records provide significant insights into the biogeographical and evolutionary history of this group, not only in the Caribbean region. The presence of *Clypeaster* fossils from these epochs suggests that the genus was already widely distributed across the tropical belt. This finding supports the hypothesis that *Clypeaster* and related taxa likely originated in the tropical regions of the eastern Tethys Sea and subsequently expanded their range during the Eocene (Lee *et al.*, 2023). The Cuban fossils, therefore, represent an important biogeographical link, indicating that the Caribbean may have served as a migration route, refugium, or diversification center during periods of global climatic change, contributing to the evolutionary persistence and radiation of *Clypeaster* and other Luminacea echinoids in the Cenozoic era (Op. cit.).

Lee and colleagues proposed that the major range expansion of *Clypeaster* and other Luminacea echinoids occurred primarily during the Miocene (Lee *et al.*, 2023). Thus, the presence *Clypeaster* fossils since the late Eocene of Cuba could indicate an earlier diversification event and/or range expansion. Is possible that *Clypeaster* may have begun its dispersal earlier than previously thought. This earlier expansion could have been restricted by the cooler climatic conditions of the late Eocene and early Oligocene, which may have limited or halted the spread of these taxa into new regions, farther from the Caribbean. This finding provides a crucial piece of evidence that may challenge or refine existing hypotheses about the timing and pathways of echinoid biogeography and evolution.

Conclusions

The new records of *Clypeaster* specimens from the locality Parque Alto within the Damují Formation provide valuable insights into the diversity and distribution of this genus during the late Eocene. Their well-preserved morphological features contribute to a better understanding of

the evolutionary history and paleobiogeography of *Clypeaster* in the Caribbean, further emphasizing the untapped paleontological richness of Cuba's Paleogene fossil record. Moreover, the discovery of Late Eocene *Clypeaster* fossils in Cuba offers valuable insights into the biogeographical and evolutionary history of this group. The presence of these fossils in the Caribbean from the Late Eocene suggests the possibility of an earlier wave of range expansion. The favorable climatic conditions of the Eocene could have driven this earlier dispersal, coinciding with significant speciation, evolution, and migration events. The Cuban fossils, therefore, not only serve as an important biogeographical link but also challenge the current understanding by indicating that *Clypeaster* may have begun expanding its range earlier than previously thought, or it may have done so in several waves. In this sense, this evidence could suggest that the Caribbean might have played a crucial role as a migration route or speciation hot spot, contributing to the evolution and radiation of *Clypeaster* and related taxa well before the Miocene.

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