

Flabellogaudryina n.gen, a new agglutinated foraminiferal genus from the Eocene of Saudi Arabia

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ABSTRACT: The newly discovered genus *Flabellogaudryina* Kaminski and Korin, n.gen., with its type species *Flabellogaudryina sirhanensis* Kaminski and Korin, n.sp., is described from the middle to upper Eocene Rashrashiyah Formation of the Sirhan–Turayf Basin in northern Saudi Arabia. The genus is defined by its triserial-to-biserial chamber arrangement, exhibiting distinct flattened, flabelliform biserial chambers, arched sutures, a coarsely agglutinated, canaliculate wall structure visible along the suture lines, and an areal opening encircled by a low rim or collar. These morphological characteristics differentiate *Flabellogaudryina* n.gen. from other representatives of the subfamily Pseudogaudryinae. High-resolution imaging reveals pseudopores in the test wall, which probably enhanced gas exchange and offered structural stability in the low-energy, outer neritic to upper bathyal depositional setting of the Rashrashiyah Formation. The species has adapted to the local geological and geochemical conditions, as evidenced by its coarsely agglutinated wall that contains selectively chosen sedimentary particles that include other foraminifera. This study highlights the taxonomic and paleoecological importance of *Flabellogaudryina* n.gen. in reconstructing Eocene outer neritic to upper bathyal depositional environments and aids in understanding evolutionary patterns within the subfamily Pseudogaudryinae.

Keywords: Foraminifera, Systematics, Taxonomy, new species, Saudi Arabia.

INTRODUCTION

Agglutinated foraminifera play a vital role in benthic marine ecosystems, particularly in outer neritic to bathyal habitats. These organisms construct their tests by cementing sedimentary particles, a process that reflects both environmental conditions and sediment availability. This way they serve as critical proxies for interpreting paleoenvironments making them valuable for reconstructing paleodepositional settings (Murray 2006; Kaminski 2014). Despite their wide distribution and significance, many agglutinated taxa remain poorly understood, particularly in understudied regions such as the Sirhan–Turayf Basin in northwestern Saudi Arabia. This study describes a novel genus and species, *Flabellogaudryina sirhanensis* Kaminski and Korin, n.gen. n.sp., from the Eocene Rashrashiyah Formation, a unit distinguished by its exceptionally well-preserved microfossil assemblages.

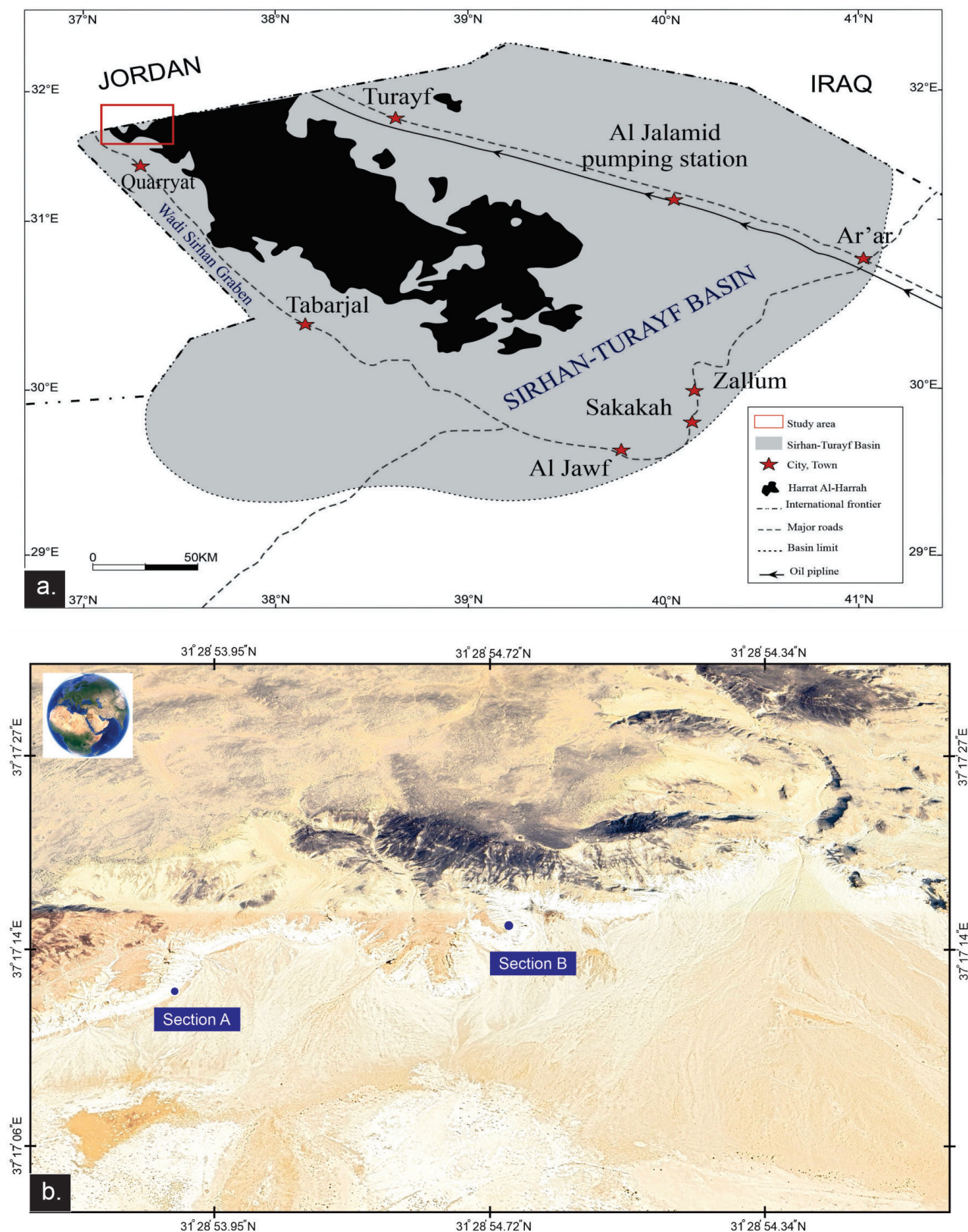
The Sirhan–Turayf Basin, also known as the Azraq–Sirhan Basin, is a prominent geological structure in the northern Arabian Peninsula that extends from Saudi Arabia to Jordan. This basin provides a record of Eocene sedimentation, with the Rashrashiyah Formation offering key insights into the paleoenvironmental processes of the region (Powers et al. 1966; Meissner et al. 1989). The formation's lithology, comprising chalky limestone, calcareous bituminous claystone (marl), and siliceous limestone interbeds, suggests deposition in a somehow calm deep marine environment characterized by variable sedimentation rates and environmental conditions (Alsharhan and Kendall 1991). Until now, research on this formation has largely focused on the planktonic foraminifera (Wade et al. 2021) and broader lithological characterizations, leaving its benthic foraminiferal component inadequately explored.

In the Rashrashiyah Formation, the agglutinated foraminiferal assemblage, while comprising a modest proportion of the over-

all fauna, is notable for its taxonomic diversity and morphological heterogeneity. The identification of over sixty benthic foraminiferal species from this formation supports an interpretation of deposition in an outer neritic to upper bathyal environment (Korin, PhD project in progress). Among these, *Flabellogaudryina sirhanensis* n.gen., n.sp. is particularly remarkable for its unique triserial-to-biserial chamber arrangement, flattened flabelliform morphology, and coarsely agglutinated, canaliculated test structure. This study contributes to the taxonomy of Eocene agglutinated foraminifera, shedding light on the ecological and evolutionary dynamics of benthic foraminifera during this period. The purpose of this study is to use high-resolution imaging to document the diagnostic features of *Flabellogaudryina sirhanensis* n.gen., n.sp. and emphasize its role as a possible paleoenvironmental indicator for outer neritic to upper bathyal marine settings on the southern Tethyan margin. By studying the taxon within its stratigraphic and paleogeographic context, this research highlights the importance of regional studies in advancing our global understanding of foraminiferal diversity, evolution, and paleoecology.

STUDY AREA

The Sirhan–Turayf Basin (text-fig. 1), also referred to as the Azraq–Sirhan Basin, is a significant geological feature in the northwestern Arabian Peninsula, extending across the eastern desert regions of Jordan and northern Saudi Arabia. This synclinal basin spans several hundred kilometers and is characterized by its prominent stratigraphic and structural features, making it a key area for understanding Eocene sedimentary processes (Powers et al. 1966). The Rashrashiyah Formation, which is the focus of this study, represents one of the basin's most notable stratigraphic units and provides critical insights into the paleoenvironmental history of the region. The Rashrashiyah Formation was first described by Meissner et al. (1989) and derives its name from



TEXT-FIGURE 1

Study area maps showing the location and sections of the Sirhan-Turayf Basin. (a) Regional map highlighting the extent of the Sirhan-Turayf Basin, which spans northern Saudi Arabia and extends into Jordan and Iraq. The study area (Rashrashiyah Formation) is indicated within the outlined basin. (b) Satellite imagery showing the specific locations of Section A and Section B within the Rashrashiyah region, near the Al Qurayyat area in north-western Saudi Arabia.

the Rashrashiyah scarp, situated approximately 16 kilometers north of An-Nabk, west of Turayf, at latitude 31°28'N and longitude 37°17'E. This formation has been extensively studied in outcrop and subsurface data, with an estimated thickness of approximately 75 meters near the Al Qurayyat Water well. The upper two-thirds of the formation are exposed across distinct scarps and hills, reflecting the erosional and depositional dynamics that have shaped the region.

The lithology of the Rashrashiyah Formation is diverse and reflects deposition in a marine setting with varying sedimentary regimes. The lower part of the formation is composed predominantly of grayish-white, chalky limestone interbedded with calcareous bituminous claystone (marl), while the occasional presence of siliceous limestone beds suggests periods of higher silica input, potentially linked to sea level fall. In contrast, the upper part of the formation is dominated by grayish-white calcareous claystone, indicative of a shift in sedimentation dynamics. The stratigraphic characteristics of the Rashrashiyah Formation, coupled with its location within the Sirhan-Turayf Basin, make it an invaluable resource for reconstructing the paleoenvironments of the Eocene epoch. The region's structural complexity and the excellent preservation of microfossils within the formation further enhance its importance as a site for geological and paleontological studies.

METHODS

Detailed analyses of the foraminiferal content were performed on two outcrops: 60 samples from Outcrop-A (39.4 m) and 250 samples from Outcrop-B (51.8 m) (Korin, PhD project in progress). After boiling with a detergent-based washing powder for two hours, each 100 g sample was processed, with the duration being amended as necessary based on the degree of lithification. The foraminiferal fractions were isolated from the treated material by wet-sieving it through a 63 µm mesh. Subsequently, the material was oven-dried at controlled temperatures between 70°C and 90°C. Benthic foraminifera were picked for further analysis using a stereomicroscope (Olympus SZX7). The ZEISS Axio Zoom V16 stereomicroscope, ZEISS GeminiSEM 450 scanning electron microscope, and ZEISS Xradia 620 Versa CT Scan were used to produce high-resolution X-ray images (resolution of 0.45 µm.) in the laboratories of the College of Petroleum Engineering and Geosciences (CPG) at King Fahd University of Petroleum and Minerals (KFUPM). The taxonomic identification and species descriptions were produced using reference works such as Kaminski and Gradstein (2005) and Loeblich and Tappan (1987).

RESULTS

Systematic taxonomy

The higher-order systematics follows Adl et al. (2019), whereas the systematics below the level of subclass follows Kaminski (2014).

Phylum FORAMINIFERA d'Orbigny 1826

Class GLOBOTHALAMEA Pawlowski, Holzmann and Tyszká 2012

Order TEXTULARIIDA Delage and Hérouard 1896, emended Kaminski 2004

Suborder TEXTULARIINA Delage and Hérouard 1896

Superfamily EGGERELLOIDEA Cushman 1937

Family EGGERELLIDAE Cushman 1937

Subfamily PSEUDOGAUDRYINAE Loeblich and Tappan 1985

Genus *Flabellogaudryina* Kaminski and Korin, n.gen

Type species: Flabellogaudryina sirhanensis Kaminski and Korin, n.sp.

Description: Test triserial and triangular in the early stage, later biserial. Biserial chambers are flattened and flabelliform. Sutures flush or slightly depressed. Wall coarsely agglutinated, canalculated. Aperture an areal opening, surrounded by a low rim or collar.

Remarks: The new genus is best placed in the subfamily Pseudogaudryinae because of its triserial to biserial chamber arrangement and canalculated wall structure. Most genera in the superfamily possess a triangular and tricarinate early stage, later becoming biserial or uniserial. *Flabellogaudryina* n.gen. differs from the genus *Migros* Finley, 1939, in having flattened chambers in the biserial stage and a more flaring or flabelliform test outline. The genus *Pseudotriplasia* Małeckı, 1954 may possess later chambers that are flattened and flabelliform (see Małeckı 1954 pl. 13, fig. 10), but the genus differs in its uniserial chamber arrangement and solid, noncanalculated wall.

Flabellogaudryina sirhanensis Kaminski and Korin, n.sp.
Plate 1, figs. 1a-4c; plate 2, figs. 1a-4c; text-fig. 2

Material: Over 50 specimens from two stratigraphic sections (sections A and B).

Derivation of name: Geographical, from the Sirhan-Turayf Basin of northern Saudi Arabia

Description: Test flattened and flabelliform in outline, triserial and triangular in the early stage, later biserial with flattened chambers. Sutures flush or slightly depressed, strongly arched in later chambers. Wall coarsely agglutinated, cement calcareous, canalculated. Aperture an oval areal opening, surrounded by a low rim or collar.

Remarks: The species is distinguished from other pseudogaudryinids by its flattened chambers in the biserial part, strongly arched sutures, and rapidly expanding test outline. The wall is coarsely agglutinated and may even contain small tests of other foraminifera. These appear to be mostly juvenile trochospiral and biserial planktonic forms (text-fig. 2).

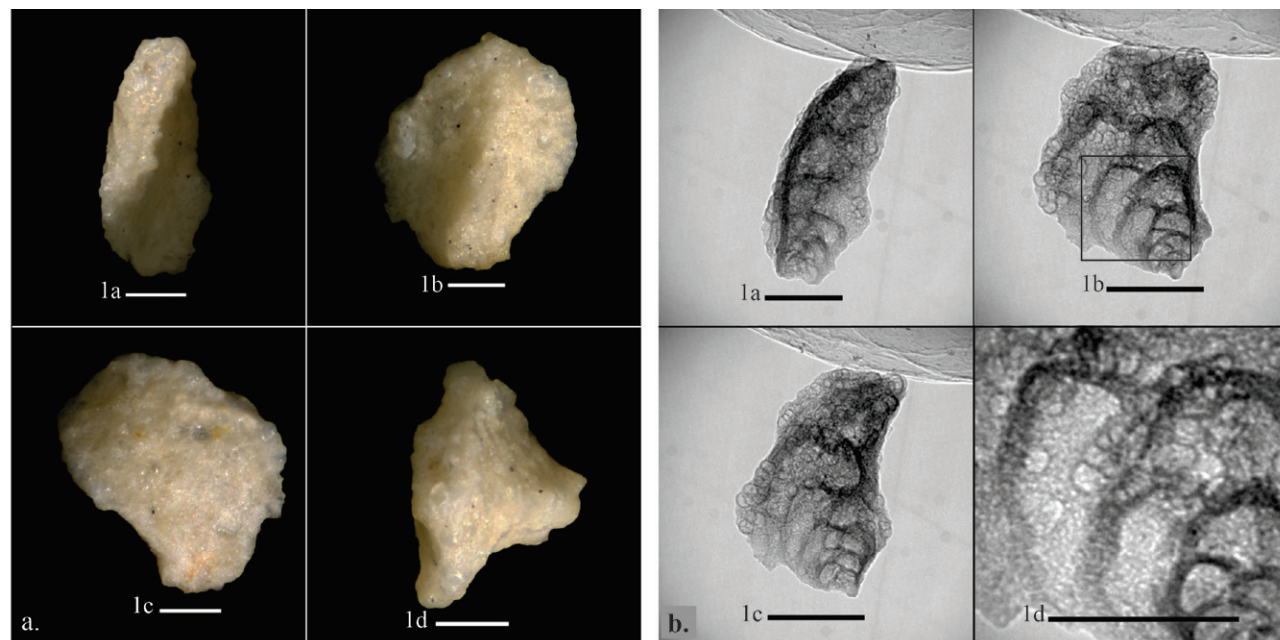
Type locality: Rashrashiyah Formation, near Al-Qurayyat village within the Sirhan-Turayf Basin at 31°28'11"N and 37°16'42"E, northwestern Saudi Arabia, near the border with Jordan.

Type level: middle to upper Eocene. The holotype is from sample Rh-220 of late Eocene age (planktonic foraminiferal biozones E13 to E14).

Type specimens: The holotype (pl. 1, fig. 1) and figured paratypes are deposited in the collections of the European Micropalaeontological Reference Centre, Kraków, Poland, in cabinet 7, drawer 27c. The holotype slide is registered as 7/27/C/7 and the paratypes as 7/27/C/8.

DISCUSSION

Within the subfamily Pseudogaudryinae, the newly described genus *Flabellogaudryina* n.gen. represents a significant morphological innovation, characterized by possessing a laterally com-



TEXT-FIGURE 2

Flabellogaudryina sirhanensis Kaminski and Korin, n.gen., n.sp. (a) Stereomicroscope images showing the external morphology of the test in different orientations: (1a) edge view, (1b) lateral view, (1c) opposite lateral view, and (1d) apertural view. The images highlight the overall flabelliform shape, the triangular triserial chambers in the early portion, and the compressed biserial terminal chambers with strongly arched sutures. Scale bars = 100 µm. (b) CT scan X-ray images illustrating both the internal and external features of the same test from stereomicroscope images from (a): (1a) edge view, (1b) lateral view highlighting the tri-biserial chamber arrangement, (1c) opposite lateral view, and (1d) zoomed-in view of (1b) showing internal pores along the suture lines. The high-resolution CT scans reveal the coarsely agglutinated wall texture containing small foraminifera as agglutinated particles and the presence of canaliculae. Scale bars = approx. 100 µm.

pressed, flabelliform terminal biserial section—a feature unique among closely related genera. In contrast, the genus *Migros* Finlay, 1939, displays a cylindrical biserial part while maintaining a similar areal aperture in the terminal stage. The Miocene agglutinated genus *Pavonitina* Schubert, 1914, emend. Loeblich and Tappan, 1985 exhibits a flattened, flaring test with strongly recurved sutures in the biserial part, but transitions to a uniserial chamber arrangement and has a more finely agglutinated, noncanaliculate wall texture (see Loeblich and Tappan 1985, pls. 8-9). Unlike *Pseudotriplasia* Malecki, 1954, which features a simplified biserial-to-uniserial transition, *Flabellogaudryina* n.gen. demonstrates laterally compressed biserial chambers with a pronounced test expansion. These morphological distinctions emphasize the uniqueness of *Flabellogaudryina* n.gen. in both test morphology and wall structure among other members of the Pseudogaudryininae. These morphological differences likely reflect distinct evolutionary trajectories within the subfamily, likely driven by ecological pressures. Moreover, the coarsely agglutinated test of *Flabellogaudryina* n.gen. contrasts sharply with the finely agglutinated walls observed in certain morphologically similar Miocene genera, such as *Pavonitina* and *Pseudotriplasia*. This disparity may suggest a relationship between wall structure and environmental variables, including sediment grain size and carbonate availability. These findings underscore the ecological and evolutionary significance of test morphology and wall structure within the Pseudogaudryininae and agglutinated foraminifera in general.

The distinctive morphological characteristics of *Flabellogaudryina* n.gen. emphasize the importance of chamber arrangement

and wall composition in the classification of agglutinated foraminifera. Loeblich and Tappan (1987) and Kaminski (2014) have pointed out the importance of wall microstructure and composition in establishing the higher-level classification of agglutinated foraminifera, which in turn offers insight into evolutionary relationships when integrated with chamber arrangement. The coarsely agglutinated wall of *Flabellogaudryina*, which contain larger sedimentary grains bound by calcareous cement, indicate a probable ecological association with the distinct geochemical and sedimentological conditions of the Eocene Sirhan-Turayf Basin. The flabelliform morphology of *Flabellogaudryina* n.gen. seems to be an adaptation to the outer neritic to upper bathyal depositional environment of the Rashrashiyah Formation, where agglutinated foraminifera were likely affected by substrate type, oxygen levels, as well as water depth (Murray 2006; Jones and Charnock 1985). The accompanying foraminiferal assemblage is rich in uvigerinids and buliminids, suggesting reduced oxygen conditions in the basin. The morphological adaptation of this genus in the form of its flattened adult chambers and the existence of pseudopores in its test wall presumably evolved to improve gas exchange under dysoxic conditions. These characteristics highlight the fact *Flabellogaudryina* n.gen. is a key taxon that reveals both ecological preferences and evolutionary trends in agglutinated foraminifera. The genus is likely restricted to an outer neritic to upper bathyal depositional environment with reduced oxygen. No pseudogaudryinids or any other agglutinated forms with canaliculate wall structure have been observed in Eocene abyssal assemblages from the North Atlantic (Kaminski et al. 1989, 1990; Kaminski and Ortiz 2014) or from the Tasman Sea (Kaminski et al. 2024a,b).

The application of X-ray micro-computed tomography (CT) scanning has revolutionized the study of foraminiferal morphology by providing unprecedented insights into structural features that are often indiscernible using traditional microscopic techniques (e.g., Speijer et al. 2008; Briguglio et al. 2011). The X-ray images generated from CT scans enable detailed analyses of test adaptations to depositional environments, revealing features such as pseudopores or canaliculae within the test wall of the characteristic flabelliform chambers (text-fig. 2-b). These images also illustrate the selective incorporation of coarsely agglutinated grains within the test (including the small tests of other foraminifera), reflecting the availability and utilization of local sediment particles. The fine-scale textural details captured by CT imaging underscore its significance in refining taxonomic classifications and enhancing paleoecological interpretations.

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PLATE 1 (page 99)

Scale bars = 100 µm.

1 a-c *Flabellogaudryina sirhanensis* Kaminski and Korin, n.gen., n.sp., Specimen 1 is the Holotype (EMRC 7/27c/7): (1a) lateral view, (1b) apertural view, (1c) opposite lateral view, Rashrashiyah Formation, Section B, Sample no. Rh-220.

2 a-c *Flabellogaudryina sirhanensis* Kaminski and Korin, n.gen., n.sp., Specimen 2 (paratype): (1a) lateral view, (1b) apertural view, (1c) opposite lateral view, Rashrashiyah Formation, Section B, Sample no. Rh-88.

3 a-c *Flabellogaudryina sirhanensis* Kaminski and Korin, n.gen., n.sp., Specimen 3 (paratype): (1a) lateral view, (1b) apertural view, (1c) opposite lateral view, Rashrashiyah Formation, Section B, Sample no. Rh-216.

4 a-c *Flabellogaudryina sirhanensis* Kaminski and Korin, n.gen., n.sp., Specimen 3 (paratype): (1a) lateral view, (1b) apertural view, (1c) opposite lateral view, Rashrashiyah Formation, Section B, Sample no. Rh-216.

PLATE 2 (page 100)

Scale bars = 100 µm.

1 a-c *Flabellogaudryina sirhanensis* Kaminski and Korin, n.gen., n.sp., paratype, (1a) lateral view, (1b) apertural view, (1c) opposite lateral view, Rashrashiyah Formation, Section A, Sample no. A-20.

2 a-c *Flabellogaudryina sirhanensis* Kaminski and Korin, n.gen., n.sp., paratype, (2a) lateral view, (2b) apertural view, (2c) opposite lateral view, Rashrashiyah Formation, Section B, Sample no. Rh-120.

3 a-c *Flabellogaudryina sirhanensis* Kaminski and Korin, n.gen., n.sp., paratype, (3a) lateral view, (3b) apertural view, (3c) opposite lateral view, Rashrashiyah Formation, Section B, Sample no. Rh-92.

4 a-c *Flabellogaudryina sirhanensis* Kaminski and Korin, n.gen., n.sp., paratype, (4a) lateral view, (4b) apertural view, (4c) opposite lateral view, Rashrashiyah Formation, Section B, Sample no. Rh-88.

