

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/348603234>

# New Species of Cardiidae (Bivalvia) from the Eocene of Ukraine

Article in *Paleontological Journal* · January 2021

DOI: 10.1134/S0031030121010044

---

CITATIONS

0

READS

559

1 author:



[A.A. Berezovsky](#)

Kyryvi Rih National University

143 PUBLICATIONS 64 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:



Старинная черепица города Кривой Рог [View project](#)



Gastropoda from Middle Eocene of Krivoy Rog (Ukraine) [View project](#)

# New Species of Cardiidae (Bivalvia) from the Eocene of Ukraine

A. A. Berezovsky\*

Krivoi Rog National University, Krivoi Rog, 50027 Ukraine

\*e-mail: berez-08mail.ru

Received March 17, 2020; revised April 10, 2020; accepted April 10, 2020

**Abstract**—Three new species of bivalves of the family Cardiidae are described from the Paleogene of Ukraine: *Freneixicardia picturata* (Upper Eocene, town of Dnepr), *Loxocardium marmoreum* (Middle Eocene, the town of Kanev), and *Schedocardia imperfecta* (Middle Eocene, town of Ingulets). The species *Loxocardium denticostatum* (Berezovsky, 1998) is redescribed, because its first description was based on specimens (besides the types), which are assigned in this work to the new species *L. marmoreum*.

**Keywords:** bivalves, shells, Paleogene, Ukraine

**DOI:** 10.1134/S0031030121010044

## INTRODUCTION

During the study of bivalves of the family Cardiidae Lamarck, 1809 from the Upper Eocene detrital sands of the Rybal'skii quarry of the town of Dnepr (Dnepropetrovsk) (the main data on the location and geology of this occurrence are published previously; Berezovsky, 2015), it was found that cardiids previously assigned to the species *Freneixicardia hausmanni* (Philippi) by various researchers, have ornamentation different from that of this taxon. The study of morphological features of this taxon using very well-preserved specimens allowed us to assign them to a new species, *F. picturata*, which is described below.

The additional material initiated the restudy of specimens of *Loxocardium denticostatum* (Berezovsky, 1998), which was previously described as a species of *Laevicardium* based on valves from the Middle Eocene of the towns of Ingulets and Kanev (Berezovsky, 1998). It was found that the original description of *L. denticostatum* was based on shells of two similar species. Some specimens (from the vicinity of Kanev) belong to a new species. Below, we provide a detailed description of the *L. denticostatum* and the description of a new species, based on shells from the Middle Eocene sands of the town of Kanev.

We also describe a new species *Schedocardia imperfecta*, which was found in firm silicified silty sands within the greenish gray silty clays of the Middle Eocene Saryngul Formation of a quarry of the Ingulets Mining and Processing Plant (MPP), town of Ingulets (Berezovsky, 2009). The original ornamentation of this species allowed us to assign these specimens to a new species, which is described below. No representatives of the genus *Schedocardia* have previously been described from the Paleogene of Ukraine.

## MATERIAL

All Cardiidae valves shown in this work are housed in the Geological Museum of the Krivoi Rog National University (GM KNU).

## SYSTEMATIC PALEONTOLOGY

Family Cardiidae Lamarck, 1809

Genus *Freneixicardia* Schneider, 2002

*Freneixicardia picturata* Berezovsky, sp. nov.

Plate 1, figs. 1–3

**E t y m o l o g y.** From the Latin *picturatus* (picturesque).

**H o l o t y p e.** GM KNU, no. M-150/01, young left valve with maximally developed ornamentation; Ukraine, Dnepr, Rybal'skii quarry; Upper Eocene, Mandrikovka beds.

**D e s c r i p t i o n.** The shells are up to 28 mm high, almost oval, with well-expressed nearly central beak, strongly convex. The valves are slightly higher than their length. All shell margins are arched gently transiting to each other. The posterior margin can occasionally be almost straight. The beak tip is hooked down and straightens out toward the anterior margin. The apical angle varies from 97° to 122°. The lower hinge is smooth and rounded. The posterior field is flat and central; the anterior fields are distinctly convex. The exterior surface possesses 39–42 narrow, ridgelike (up to 0.5 mm) radial ribs, which are divided approximately by troughlike intercostal spaces.

The anterior and central fields of all specimens are characterized by regular intercalation of thick and thin ribs 0.50–0.55 and 0.30–0.35 mm wide, respectively. The first rib (from the anterior branch of the cardinal

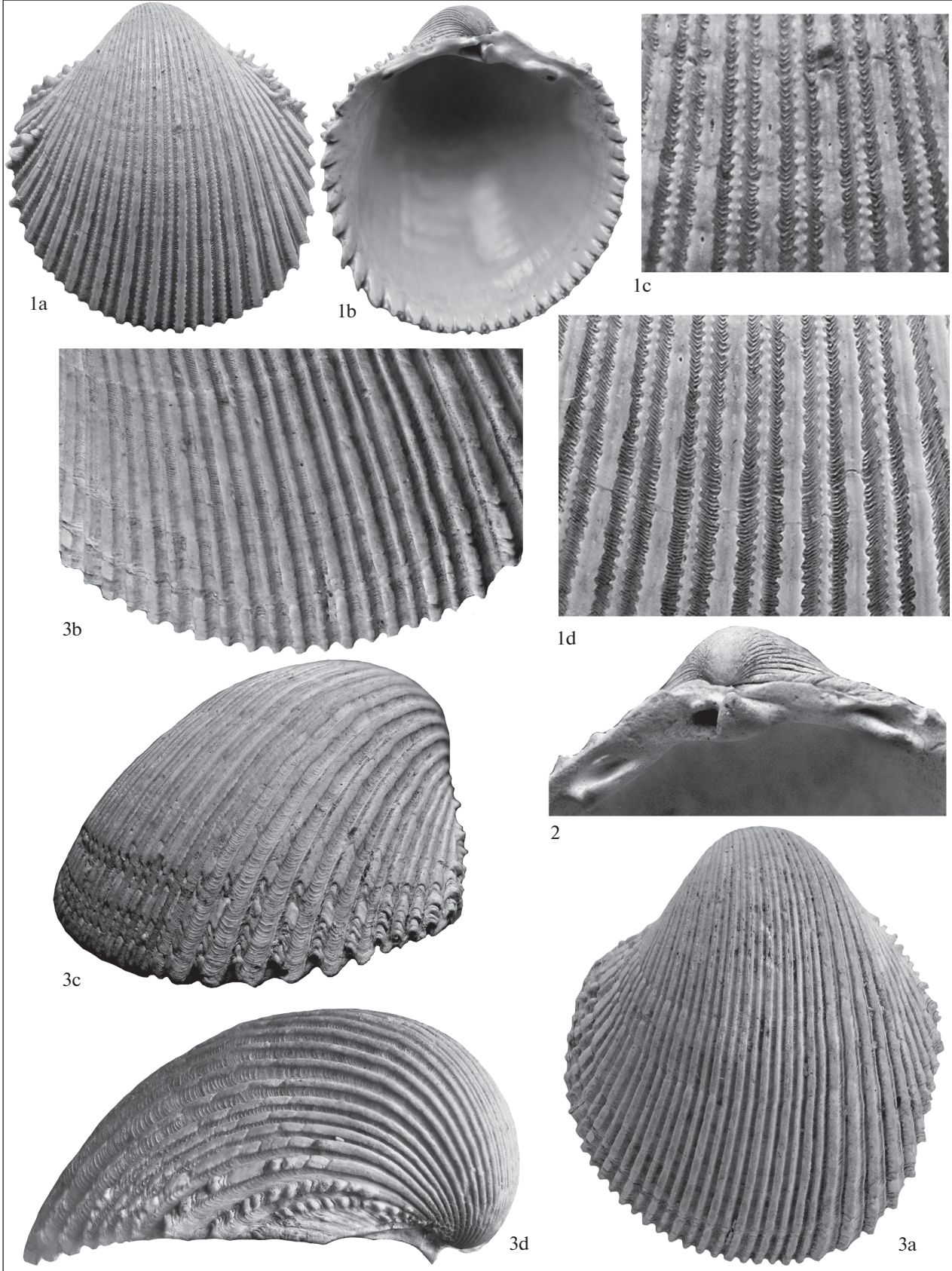
margin) is thin, the second is thick, the third is also thin, the fourth is again thick, etc. The thin and thick ribs have narrow-trapezoid (or triangular) and wide-trapezoid transverse section, respectively. The inclination of the rib slopes of these rib types is similar and, relative to the shell surface, is  $55^\circ$  in the middle of the central field. The distance between the middles of adjacent ribs in the central field of the largest shells near the lower margin is no more than 1.0 mm. The width of the bases both of thin and thick ribs attains 0.70–0.75 mm. Ten ribs occur on the central field, at 20 mm from the beak, in a zone 10 mm wide. The crests of thick ribs are flat or very weakly convex, whereas the crests of thin ribs are rounded and convex. The intercostal spaces are deep and have rounded-triangular transverse profile. The bottom of the spaces between the radial ribs is concave relative to the shell surface and gently transits to the rib slopes. Both the bases of intercostal spaces and the rib slopes are covered with short, very fine (up to 0.05 mm thick) arched or V-curved, very low platy concentric striae. The distance between the adjacent striae significantly varies even on the same valve: from 0.05 to  $\sim 0.25$  mm in various areas. The distance between these striae is typically 0.10–0.20 mm. Generally, these striae are more adjoined and more distinct on the anterior half of the central field. The largest valves from our collection have, as a rule, up to 8–10 striae on the central field near the lower margin, on a zone 1 mm high. With maximally developed ornamentation and ideal preservation, these striae are also typical of the rib crests. A narrow brim hanging above the rib slopes is often present at the place of conjunction of the rib slope with its tip in both the anterior and posterior parts. This brim can be absent or distinct.

On the central field and the posterior carina, the radial ribs are approximately similar in width and exhibit a complex transverse section. There are 10–11 similar ribs. They all have a distinct low ledge at the base of the anterior rib slopes. The edge of this ledge is very sharp and angular, its anterior slope is almost vertical, and the tip is nearly horizontal. The step is crowned by a vertical remnant part (which occupies  $\sim 2/3$  of the total height of the slope) of the rib anterior slope, which sharply transits (angular edge) to a weakly convex crest. The width of the rib crests of the posterior part of the valve (0.50–0.55 mm) gradually increases from the posterior carina to the posterior branch of the cardinal margin up to 0.7–0.8 mm. The inclination of the posterior rib slopes increases in the same direction. In the posterior carina, their inclination is  $\sim 60^\circ$ , whereas the posterior rib slopes near the posterior branch of the cardinal margin are almost vertical. No ledge, which is typical of the anterior slopes, occurs at the base of the posterior slopes. A narrow peak hanging over the rib slopes is typical of the ribs of the posterior carina and posterior field, often, in junctions of their slopes with an apex (locally, this peak is absent). By a width of intercostal spaces on

the posterior field of the valve, two zones are distinguished: an anterior, which occupies  $\sim 2/3$  part of the posterior field, and a narrower posterior. On the anterior zone, the width of intercostal spaces gradually increases from the beginning of the posterior carina to the posterior margin. The width of spaces near the margin of the largest shells varies from 0.5 to 1.5 mm in this area. There are six similar spaces. The next three spaces belong to the posterior zone. They are narrower than previous ones and have approximately similar width between them, which reaches 0.45–0.50 mm near the lower margin. Other two intercostal spaces are wider than three previous: their width reaches 0.7–1.0 mm. Like in the central field, the bases of all intercostal spaces and rib slopes (including surfaces of the step in the rib base) of the posterior carina and posterior field possess fine, low, arched, lamellar, transverse striae. Their thickness and the width are similar to those of the central field.

When ornamentation is very prominent, all ribs have brims (both from anterior and posterior parts of the ribs) in regions, where the rib slopes merge with their crests. The brims are regularly serrated. On thick and thin ribs, serrations are triangular and semirounded, respectively. When the ribs are thick, the serrations of the anterior brims are usually located opposite the serrations of the posterior brim of the same rib. When the ribs are thin, serrations of the anterior and posterior brims are typically located in a diagonal pattern (rarely, opposite each other).

Also, in shells with well-developed ornamentation, the crests of thick ribs are covered with a row of large, high spines in addition to many very thin evenly spaced transverse striae, which cover the entire shell surface (both ribs and intercostal spaces). These spines are easily broken and rarely preserved, even on entirely smooth shells. The spines are flat, triangular in longitudinal section, narrow ellipsoid at the base, and with an oval or round apex (in transverse section). They occupy almost the entire width of the rib crest and adjoin one another. In the center of the central field at a distance of 10 mm from the beak, the diameter of the long (radial) transverse section of spines is 1.1–1.2 mm and the height is  $\sim 0.7$  mm. The spine size increases with distance from the beak. The anterior and posterior slopes of spines (like ribs) are covered with very thin, arched transverse striae. The thin ribs are spine-free but have a clear thread-like ridge up to 0.10–0.15 mm wide running in the middle of their crests. The transverse striae, which cover the slopes and crests of the ribs, also cover the crests of these middle ridges. The intercalation of ribs with spines and ribs with middle ridges remains in the posterior field, in spite of the absence of intercalation of thin and thick ribs. The spines of the posterior field have thicker (rather than acute) disk-like apices. These disks are pressed to an ellipsoid base of the spine and are perpendicular or almost perpendicular to the plane of the rib crest. In the anterior field, all (including thin) ribs



have spines. On thin ribs, the spines on the apical middle crest are low and undeveloped. The spines on thick ribs of the anterior field have round transverse section of their apices. These spines are acicular or tuberculate. The lateral surface of the rib spines of this region of the shell are covered with very thin transverse striae, like the lateral surfaces of the rib spines of the posterior field.

The cardinal apparatus in the right valve consists of two cardinal and three clear lateral teeth. The thick and high cardinal tooth 3b is an acute triangular spine hooked towards the beak. The expanded base of the tooth is triangular in transverse section and the apex is acute. The lower edge of this tooth is convex, and the upper edges (anterior and posterior) are flat. Very small, low, and straight tooth 3a forms an unclear rectangular plate, which protrudes toward the plane of valve joining. Tooth 3a does not merge with tooth 3b. The lower lateral teeth AI and PI are very clear, well-projected, platy, flat, short, and triangular in longitudinal section. Tooth AIII is the smallest and thinnest and is clearly visible. This tooth is short, thin, and low. Some valves exhibit an indistinct incipient lateral tooth PIII, which is separated from the surface of the posterior branch of the cardinal margin by a very narrow, thin, and shallow trough.

In the left valve, cardinal teeth 2 and 4b are distinct and are not connected with each other. High tooth 2b is a flat triangular plate hooked towards the beak. Tooth 4b is significantly lower, pyramidal. Lateral tooth AII is clear, flat, short, strongly prominent, and triangular in longitudinal section. Lateral tooth PII is very low and morphologically similar to tooth AII but is approximately half its size. Two small sockets for lateral teeth AI and PI of the opposite valve occur below the lateral teeth.

The nymph is short and occurs just beyond the beak. It resembles a thickened short plate, which is gently curved up along the entire long axis. The lateral edges of this plate are approximately parallel to the plane of commissure and the upper narrow edge is directed towards the beak.

The lunule is very narrow and poorly visible, without or and is divided from the rest of the surface of the valve by a radial row of small tubercles. The escutcheon is distinct, approximately three times as wide as the lunule, and divided from the rest of the surface of the valve by a radial row of relatively thick and high

spines or tubercles. One more radial row of (smaller) tubercles occurs in the middle of the escutcheon.

The muscle scars are rounded-trapezium-shaped and poorly impressed. The posterior scar is larger and more distinct. The mantle line is very weak and is remote from the lower margin of the largest valves at 2.0–2.5 mm. The internal surface in the lower half of the valves exhibits a weak negative ornamentation. The lower margin of valves is serrated. Teeth are trapezoid in shape.

#### Dimensions in mm:

Species no.	L	H	LP	Co	LE	EE	CE
M-150/01	15.3	16.2	8.8	6.5	1.06	0.58	0.40
M-150/02	20.2	23.8	12.6	11.0	1.18	0.62	0.46
M-150/05	22.8	26.0	13.7	10.5	1.14	0.60	0.40

Hereinafter (L) valve length, (H) valve height, (LP) length of posterior margin, (Co) convexity, (LE) extent of lengthening (H/L), (EE) extent of equilaterality (LP/L), (CE) extent of convexity (Co/H).

**Variability.** This species includes specimens with both fully developed and weak ornamentation. Some valves exhibit a gradual transition between these extreme ornamentation types.

All radial ribs from the posterior and anterior sides of the shells with well-developed ornamentation are characterized by well-expressed serrated lateral brims and the rib crests have radial spines. All elements of ornamentation in these specimens are covered with distinct tightly spaced low lamellar microscopic concentric striae.

The ribs on the shells with weakened ornamentation have no lateral brims and only small length of a few ribs is serrated. No spines are present. Concentric striae are only typical of the bottom of the intercostal spaces and the lower half of the rib slopes.

It should be noted that shells with well-developed ornamentation can be interpreted as shells with weakened ornamentation because of their state of preservation, since this species has a very thin exterior layer, which is easily exfoliated, especially, from the rib crests. It is this layer that carries concentric striae, brims, and spines. As a result of the disappearance of this layer, the shells with well-developed ornamentation resemble those with weak ornamentation. It is difficult to ascertain the absence of this layer because the surface without this layer appears as natural. Exfo-

#### Explanation of Plate 1

**Figs. 1–3.** *Freneixicardia picturata* sp. nov.: (1) holotype GM KNU, no. M-150/1, young left valve with maximally evolved ornamentation: (1a) external view,  $\times 3.5$ ; (1b) internal view,  $\times 3.5$ ; (1c) ornamentation of part of valve located in the middle of the central field,  $\times 11$ ; (1d), ornamentation of part of valve located in the lower half of the central field,  $\times 11$ ; (2) specimen GM KNU, no. M-50/04, hinge apparatus of right valve,  $\times 4.8$ ; (3) paratype GM KNU, no. M-150-2, adult left valve with poorly evolved ornamentation: (3a) external view,  $\times 3.4$ ; (3b) ornamentation in the lower posterior part of the central field,  $\times 5.2$ ; (3c) ornamentation on posterior carina,  $\times 5.7$ ; (3d) ornamentation of the posterior field and escutcheon,  $\times 6.5$ ; Rybal'skii quarry, the town of Dnepr; Upper Eocene.



liation of the external layer can be identified only when relics of it remain on the shell surface.

**Comparison.** Only two species are known from the Paleogene of Europe: *Freneixicardia* (Schneider, 2002)—*F. verrucosa* (Deshayes) (Middle Eocene of France) and *F. hausmanni* (Philippi) (Lattorfian regional stage of Germany). The valves of these specimens can easily be distinguished from those of new species with fully evolved ornamentation. The valves of new species have (i) different morphology of the transverse section of thin ribs (it is triangular or narrow triangular rather than almost square), (ii) concentric striae, which cover the entire shell surface, (iii) serrated walls from the apical sides of thick ribs, (iv) middle radial ridge on crest of thin ribs, and (v) significantly wider intercostal spaces (the intercostal spaces of known species are approximately two times narrower, whereas the new species has intercostal spaces and ribs of approximately similar width).

The valves with weakened ornamentation or rubbed specimens are difficult to distinguish. They strongly resemble species *F. hausmanni*. In this case, the identification should be based on the width of the intercostal spaces, which, in the case of new species, are always similar to the width of the rib crests in contrast to *F. hausmanni* and *F. verrucosa*.

**Remarks.** For the genus *Freneixicardia*, Schneider (2002) indicated that its representatives are most similar to shells of the genus *Afrocardium*, but have different intercalation of thick and thin radial ribs even on the external surface of young shells (intercalation of ribs of *Afrocardium* appears at late growth stages), always convex rib crests, and different morphology of spines, which differ only on ribs of the anterior and posterior fields and which are widely spaced on a rib.

It was found for the Upper Eocene specimens of Ukraine that the spines occur compactly on all ribs. These elements of rib decorations easily drop off and can be absent even on well-preserved samples, thus the original shape and arrangement of spines can be difficult to identify.

**Material.** Twenty-seven valves from the type locality.

## Genus *Loxocardium* Cossmann, 1886

*Loxocardium denticostatum* (Berezovsky, 1998)

Plate 2, fig. 3

*Laevicardium* (*Laevicardium*) *denticostatum*: Berezovsky, 1998, p. 38, pl. 2, figs. 5, 6.

**Holotype.** GM KNU, no. Bv-176/4, young right valve; Ukraine, Ingulets, quarry of Ingulets MPP; Middle Eocene.

**Description.** The valves are up to 35 mm high, square-rounded, with thick strongly prominent central beak, strongly convex. The vertical line, which connects the center of the beak and the lower margin, is located almost perpendicular to the horizontal line, running along the tangent through an arch of the lower margin. The tip of the beak is hooked toward the shell and faces the anterior margin. The posterior margin is straight or is weakly convex outward and is connected with the posterior branch of the cardinal margin at 120°–125°. The cardinal margin is angular–curved. Other margins of the shell are arched and curved out. The apical angle is ~120°. The posterior carina is clear, angular–curved. The posterior field is weakly concave and the central and anterior fields are convex.

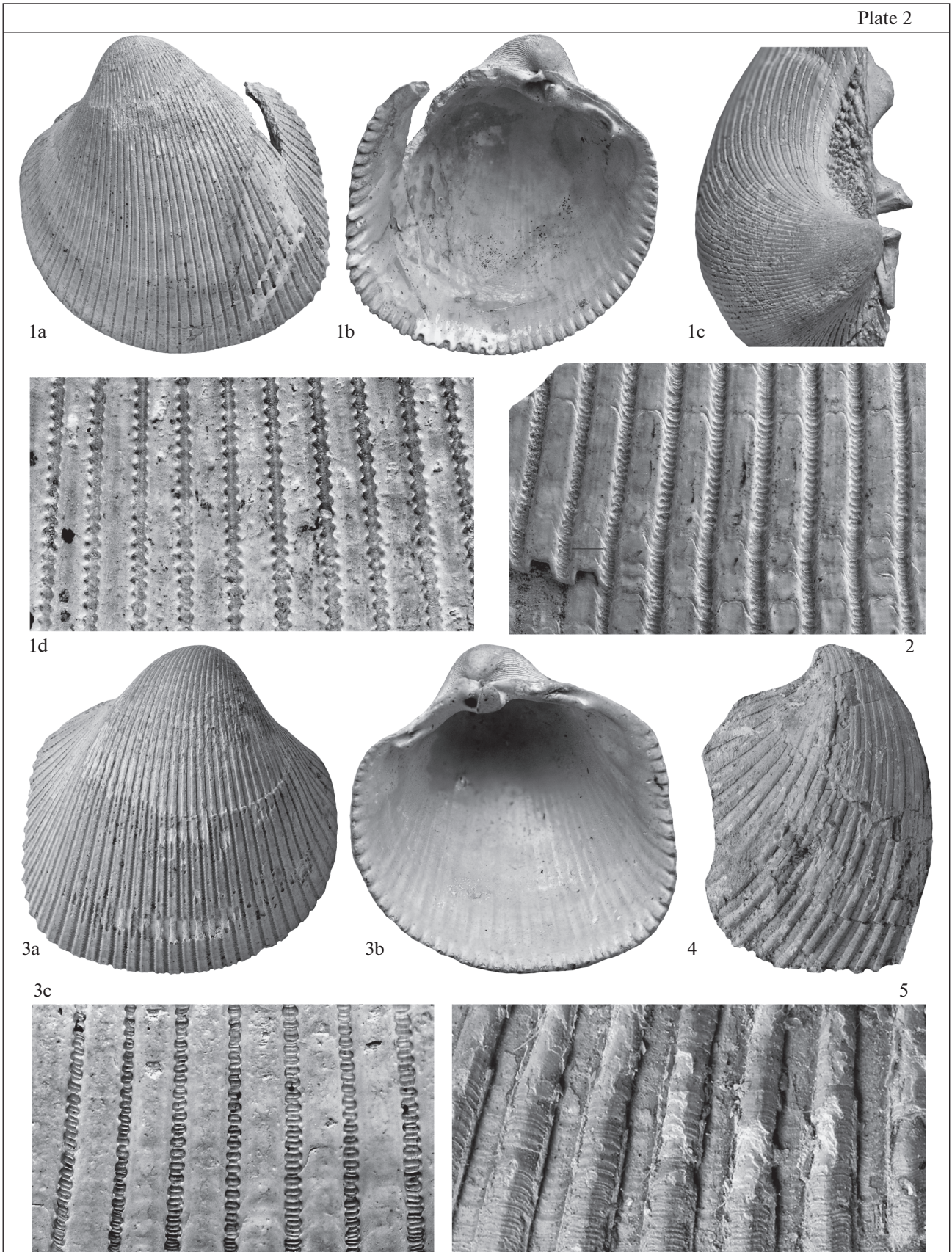
The external surface is covered with 43–49 (typically, 44–46) low, narrow band-like radial ribs up to 1.6 mm wide. The shell has intercostal spaces up to 0.4–0.7 mm wide and is regularly serrated from the sides. The widest ribs are located on the anterior carina and on the posterior part of the anterior field, whereas the narrowest ribs occur on the anterior part of the posterior field. The widest intercostal spaces are on the central field near the posterior carina and the narrowest ones are located closely to the anterior carina and on the posterior carina (because of the strong inclination of ribs along the posterior carina it seems that the intercostal spaces in this region are relatively wide). The area 10 mm long in the middle of the central field hosts nine ribs 0.8 mm wide at a distance of 25 mm from the beak (with spaces 0.20–0.25 mm wide). The ribs are rectangular or almost rectangular in cross-section. The rib crests are flat or weakly convex, smooth, without secondary ornamentation elements. The rib slopes are straight, almost perpendicular to the shell surface; their height is approximately 2.5 times smaller than the width of the

### Explanation of Plate 2

**Figs. 1 and 2.** *Loxocardium marmoreum* sp. nov.: (1) holotype GM KNU, no. K-152/09, left valve: (1a) external view, ×1.3; (1b) internal view, ×1.3; (1c) lunule and its ornamentation, ×2.7; (1d) ornamentation in the middle of the central field with distinct laterally serrated ribs (concentric striae in intercostal spaces are absent), ×8.4; 2, specimen GM KNU, no. K-152/03, clast of left valve outside with well visible transverse striae in intercostal spaces (lateral denticles of ribs are absent), ×3.6, ravine near the town of Kanev; Middle Eocene.

**Fig. 3.** *Loxocardium denticostatum* (Berezovsky, 1998), holotype GM KNU, no. I-176/04, young right valve: (3a) external view, ×2.5; (3b) internal view, ×2.5; (3c) ornamentation in the lower half of the central field, 10.5, quarry of the MPP; town of Ingulets, Middle Eocene.

**Figs. 4 and 5.** *Schedocardia imperfecta* sp. nov.: (4) holotype GM KNU, no. I-400/01, young left valve in rock, view from the posterior carina side, ×4.5; (5) specimen no. I/400/02, external view of clast of left valve, enlarged image of ornamentation, ×9.3; quarry of the MPP; town of Ingulets, Middle Eocene.



ribs. The base of the intercostal spaces is flat, straight, locally, weakly concave, and channeled and is covered with very prominent straight or very weakly arched transverse striae up to 0.15 mm thick. The distance between these striae is 0.10–0.15 mm. In some zones of the shell, they are abundant. In this case, the distance between adjacent striae does not exceed 0.05 mm. The striae are mostly concentrated at the areas of cessation of the shell growth, which mark the position of the lower margin of the shell at various growth stages. The striae are most developed in the intercostal spaces of the posterior half of the shell. At a distance of 10–15 mm from the beak, the bottom of the intercostal spaces is smooth, without striae. The ribs are regularly serrated both from the anterior and posterior sides in junction zones of slopes with apex. The serrated surface is made up of small triangular denticles with height of up to 0.1 mm and the width of the base of 0.25–0.30 mm. The distance between the apices of adjacent denticles is no more 0.3–0.4 mm. The zone 1 mm high contains 3–4 denticles. On the anterior and central fields and on the posterior half of the posterior field, the radial ribs have symmetrical cross-profile and the plane of their crests is parallel to the shell surface. On the anterior half of the posterior field, the plane of crests of radial ribs is strongly inclined toward the anterior margin. As a result, these ribs have high posterior and low anterior slopes. The high posterior slopes possess very distinct short arched or straight striae, weakly oblique to the long axis of the rib. The low anterior slopes have no such striae.

The lunule is covered with 3–13 radial rows of spines perpendicular or almost perpendicular to its surface. On most valves, most spine rows are replaced by those composed of rare round tubercles. The spines are flat triangular and are curved along the long axis, thus they have a V-shaped cross-section. Their apices are acute. Two–four similar spine rows also occur on the escutcheon surface. The surfaces of the lunule and escutcheon are weakly concave.

In the right valve, the thick and high cardinal tooth 3b is a flat triangular plate, which is hooked toward the beak. Tooth 3a is small, low, and straight and resembles a rectangular plate protruding toward the plane of valve joining. Tooth 3a is merged with tooth 3b in the posterior part. Some right valves have no tooth 3a. Low lateral teeth AI and PI are clearly visible. They are strongly prominent, platy, flat, short, and triangular in transverse section. Tooth AIII is the thinnest and smallest but is distinct. It is narrow, low, short, and triangular in transverse section. Lateral tooth PIII is absent and its function is replaced by a walled posterior part of the posterior branch of the cardinal margin. In left valve, cardinal teeth 2 and 4b are well developed. High and hooked tooth 2 has a wide triangular base and a sharpened, subuliform apex slightly curved toward the beak. Tooth 4b is smaller, pyramidal. Lateral tooth AII is very clear, flat, short, strongly prominent, and trapezium shaped in longitudinal section.

Lateral tooth PII is poorly developed. It is low and short, in form of a flattened and elongated tubercle.

A short nymph is located just beyond the end of the beak. It resembles a thick short plate, which is gently curved toward the beak along its long axis. The side edges of the nymph are parallel to a joining plane of valves and the upper narrow edge is directed toward the beak.

The muscle scars are clear, oval. The posterior scar is bigger. The mantle line is absent even in well-preserved valves. The internal surface in the lower half of valves has clear negative ornamentation. The lower margin of the valves is serrated. The denticles are rectangular.

#### Dimensions in mm:

Specimen no.	L	H	LP	Co	LE	EE	CE
I-176/04	23.0	23.7	14.0	9.6	1.03	0.61	0.41
I-176/05	26.5	27.5	14.6	11.0	1.04	0.55	0.40
I-176/09	27.5	26.7	13.0	10.5	0.97	0.47	0.39

**Variability.** In some shells, all crests of radial ribs of the posterior field have a weak central groove, which occupies  $\sim 1/4$ – $1/3$  of the crest width (as in the holotype). The groove is channeled, very small, with gentle sides, without sharp boundaries. It is especially expressed on the ribs, which cover the posterior carina. On other valves, the crests of ribs of the posterior field (as well as other ribs) have no traces of this groove. The middle grooves are locally expressed (less frequently) on the rib crests of the anterior carina and anterior field.

The width of the ribs of the central field on shells from various occurrences is slightly variable. For example, the width of the ribs on the right valves 30 mm high on the central field slightly differ and the width of the intercostal spaces in this part of the shell of these specimens is also slightly different (intercostal spaces of the valve with wider ribs will be slightly narrower). The width of the middle ribs of the central field near the lower margin is 0.80–0.85 (the width of the spaces between them is 0.50 mm) and 1.0–1.2 (the width of the spaces between them is 0.35–0.40 mm) mm of different valves. Due to this compensation of the width of the ribs by that of the intercostal spaces, the amount of ribs on one horizontal level per unit of the length of the reviewed valves will be approximately similar. At a distance of 30 mm from the beak, in the middle of the central field of 10 mm in size, the valves with narrow and wide ribs will contain 7.5 and 7 ribs, respectively.

**Comparison.** This species differs from other taxa, which are similar in morphology of shells and habit of ribs, by the constant presence of distinct regular triangular denticles on sides of flat smooth ribs and the presence of clear transverse striae in intercostal spaces.



It is mostly similar to species *L. beaknatum* Cossmann (Lower Eocene, Cuis of the Gan area, Alpine region of France), which also exhibits laterally serrated ribs. However, this taxon differs from *L. beaknatum* by a gentler posterior bend.

**Remarks.** This species was moved from the genus *Laevicardium* to the genus *Loxocardium* because of an observation by S.V. Popov, an expert in the area of cardiid systematics, who reviewed the first version of this paper and noted the different microstructure of this species from that of typical shells *Laevicardium*. According to Popov (1977, p. 19), the microstructure of the valves of *Laevicardium* shows two main layers and their growing lines in radial section are straight rather than curved to the beak (group A). The microstructure of the valves of the above described species has three layers: a relatively thin external layer, a very thick middle layer (occupying ~80% of the thickness of the valve), and a thin internal layer. The growth lines of the external layer are curved to the beak. According to Popov (1977, p. 24), similar microstructure is typical of group G, which also includes the genus *Loxocardium*.

In the original description of *L. denticostatum* (Berezovsky, 1998) along with typical specimens of this species, we used valves from the sands of Buchak Formation of Ukraine, which, as was found later, should be assigned to a new species (its description is provided below). In this paper, we describe the species *L. denticostatum* only on the basis of its typical representatives (from the Middle Eocene of the southern slope of the Ukrainian Shield). The structure of a geological section with holotype and most specimens of this genus are described by (Berezovskii and Pacaud, 2019).

**Occurrence.** Middle Eocene of Ukraine (the upper part of the Lutetian Stage): Malinovskaya and Sary Ingul formations of the southern slope of the Ukrainian Shield.

**Material.** Fifteen valves from sands of the quarry of the Ingulets MPP and outskirts of the town of Nikopol.

*Loxocardium marmoreum* Berezovsky, sp. nov.

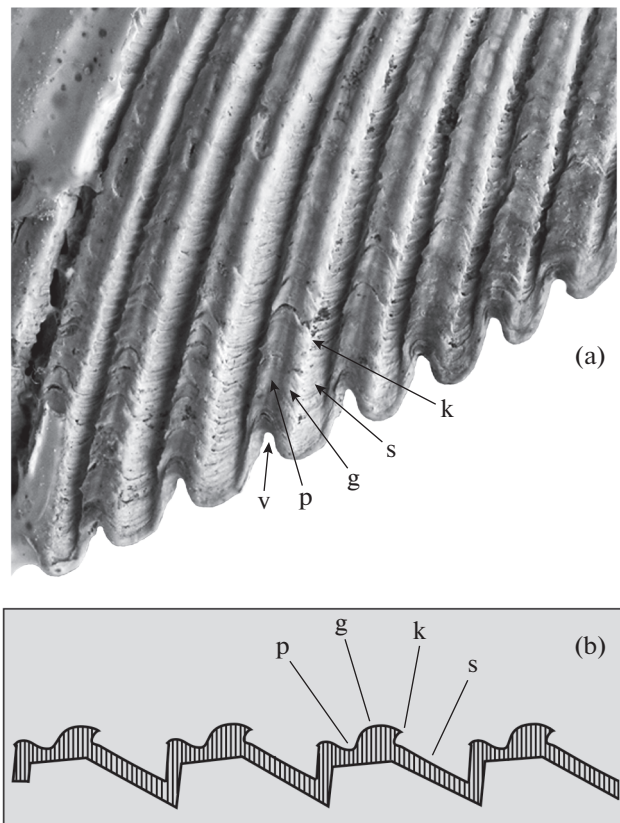
Plate 2, figs. 1 and 2

*Cardium gigas* DeFrance: Makarenko and Zelinskaya, 1982, p. 68, pl. 11, Fig. 7, pl. 12, Fig. 2.

**Etymology.** From the Latin *marmoreous* (marble).

**Holotype.** GM KNU, no. K-152/09, left valve; Ukraine, a ravine near the town of Kanev; Middle Eocene, Buchak Formation.

**Description** (Fig. 1). The valves up to 62 mm high, square-rounded, with thick prominent beak shifted forward, strongly convex. The beak is inclined toward the anterior margin. The end of the beak is hooked (is curved inside the shell) and is turned



**Fig. 1.** Ornamentation in the lower part of the posterior field near the posterior carina of left valve of *Loxocardium marmoreum* sp. nov., holotype GM KNU, no. K-152/09: (a) posterior field,  $\times 6$ ; (b) cross-section of the ribs,  $\times 7$ ; explanations: g, posterior part of the rib apex located between the apical groove and posterior rib slope; k, peak above the posterior rib slope; p, channeled apical groove on the rib; s, posterior rib slope covered with transverse arched striae; v, a notch opposite to apical middle groove.

ahead. The posterior margin is straight in the middle, is arched in margins, and is connected to the posterior branch of the cardinal margin at an angle of  $125^{\circ}$ – $127^{\circ}$ . The cardinal margin is angular-curved (the carina occurs below the beak). Other margins of valve are gently arched. The apical angle is  $116^{\circ}$ – $118^{\circ}$ . The posterior carina is clear and angular-rounded. The posterior field is weakly concave; the central and anterior fields are convex.

The external surface is covered with 53–56 low and narrow-banded radial ribs up to 1.8–2.0 mm wide. Their height is no more than 0.5 mm. The valves of up to 45–48 mm high have ribs, which are regularly serrated along the sides. The larger specimens are characterized by poorly serrated ribs in the lower part of shells and some ribs are even not serrated. The widest ribs occur on the posterior half of the anterior field and the narrowest ribs are located on the anterior part of the posterior field (where their width is ~60% lower than the width of the ribs of the anterior field). The widest intercostal spaces are in the central field near the pos-

terior carina, while the narrowest spaces are located on the central field near the anterior carina (here, they are approximately half as wide as near the posterior carina). At a distance of 25 mm from the beak on an area 10 mm long, the middle of the central field hosts ten ribs. At this horizontal level, the thickness of the ribs is 0.8 mm and the spaces between them are no more than 0.15 mm wide. In the transverse section, the ribs are trapezoid and less-commonly rectangular. The crests of the ribs are smooth, without secondary ornamentation elements, mostly flat, and rarely weakly convex. The bases of the ribs are typically slightly wider than their crests and the rib slopes are inclined to the center of the ribs. In the lower part of large shells, the bottom of intercostal spaces is weakly concave and channeled. The transverse profile of the intercostal spaces is trapezoid in shape. The valves up to 40 mm high are characterized by very narrow groove-like bottom of intercostal spaces, whereas the transverse profile of intercostal spaces is triangular. The bottom of the intercostal spaces in the lower part of mature shells is typically covered with clear prominent, very low, arched or V-shaped short concentric striae with apices up to 0.1 mm thick. The distance between these striae is 0.10–0.20 mm. Their number increases locally, thus the distance between them decreases to 0.05 mm. They are concentrated just above the line of growth cessation, which marks the position of the lower margin of the shell during one of the growth stages. Below a band with strongly joined striae (just below the line of cessation of growth), there is a band (~1 mm high) with poorly visible strongly smoothed striae. This band is followed by a wide (~10 mm and more) horizontal band with distinct, well-developed striae. This band is followed by a narrow zone with numerous striae, which again registers the moment of the next stage of cessation of growth, etc. At a distance of 15–20 mm (up to 35 mm on some specimens) from the beak, the base of the intercostal spaces has no striae. Morphologically, these striae resemble low thin plates, which are located on low expanded triangular base. At some growth stages, no striae formed, thus the external surface has horizontal bands up to 5 mm only with striae traces. Five to six striae typically occur in the bottom of the intercostal space, 1 mm high.

The ribs are serrated both anteriorly and posteriorly, at a distance of 10–15 mm from the beak at the upper half of the rib slopes. The regular serrated structure includes small triangular denticles protruding beyond the ribs at a distance of ~0.15 mm. The width of the base of the denticles reaches 0.35 mm. At one side of the rib, the distance between the apices of adjacent denticles is no more than 0.3–0.4 mm. Three denticles fit the area of the rib 1 mm high.

The radial ribs on the central field, the posterior half of the posterior field, and the anterior half of the anterior field have similar height of anterior and posterior slopes and their crests occur parallel to the shell surface. The crests of the radial ribs on the anterior

half of the posterior field and the posterior half of the anterior field, near the carinae of the shell are inclined to the shell surface (towards the anterior margin). As a result, these ribs have relatively high posterior and very low anterior slopes (Fig. 1). The posterior slopes of these ribs are covered with distinct, weakly arched, and short transverse striae, which are similar in morphology, size, and distance between them to those of the bases of the intercostal spaces of the ribs of the central field. The low anterior slopes have no striae, but they are also locally visible.

All rib crests of the posterior and anterior fields and posterior and anterior carinae have a distinct radial groove up to 0.25 mm wide (Fig. 1). On the posterior margin, this groove is marked by a deep prominent notch (see *v* in Fig. 1a). There is no middle groove on the crests of the ribs running along the central field.

The lunule is clear and its surface contains up to 13 radials rows of sharpened spines, which are perpendicular or almost perpendicular to the lunule surface. Some valves have no spine rows. They only have unclear low irregular tubercles. The spines are flat and triangular and are curved along their long axis, thus exhibiting a V-shaped cross-section. Two–four rows of similar spines occur on the narrower escutcheon surface. The surfaces of the lunule and escutcheon are weakly concave.

In left valve, cardinal teeth 2 and 4b are well-developed. Tooth 2 is high and hooked and has a wide triangular base, a sharp apex, and is slightly curved towards the beak. The smaller tooth 4b is pyramidal. Lateral tooth AII is very clear, short, strongly prominent, trapezium shaped in longitudinal section. Lateral tooth PII is slightly distinct, low, short, flattened and elongated tubercular. The hinge apparatus of the right valve was not studied due to the preservation of our specimens.

The nymph is short, occurs just beyond the tip of the beak and resembles a thick short plate, which is gently curved upward along its long axis. The side edges of the nymph are located approximately parallel to the plane of valve joining, whereas the upper narrow edge is directed toward the beak. It is flat, often with relics of ligament.

Muscle scars are clear, oval. The posterior scar is bigger. The mantle line is very weak and is visible only in the anterior half of perfectly preserved valves. The internal surface in the lower half of valves has a weak negative ornamentation. The low margin of valves is serrated. The denticles are distinctly trapezoid in shape.

#### Dimensions in mm:

Specimen no.	L	H	LP	Co	LE	EE	CE
K-152/09	41.4	43.6	26.0	16.0	1.05	0.63	0.37
K-152/01	—	62.3	—	26.0	—	—	0.42
K-152/02	—	37.5	—	15.3	—	—	0.41

**Variability.** On a greater upper part of one valve (37 mm high), the intercostal spaces are smooth in contrast to very weak low inexpressive transverse striae in the lower part. The spaces between the ribs are typically characterized by clear transverse striae, although each valve has areas (in the lower part of specimens), where the striae are either absent or weak. Almost always, the striae between the ribs are clearly arched or V-shaped curved. Only between the ribs of the anterior carina, there are low areas with two–five almost straight or straight striae.

**Comparison.** By shell morphology, the presence of side regular denticles on side rib slopes and transverse striae of intercostal spaces, and similar width of the ribs, this species is similar to above described *L. denticostatum* (Berezovsky), but differs in the significantly higher inclination of the beak toward the anterior margin and narrower intercostal spaces (Table 1), which results in a greater number of radial ribs of the new species (on 4–13 ribs). The number of ribs of *L. denticostatum* and *L. marmoreum* is 43–49 and 53–56, respectively (no specimens with a transitional number of ribs have been found).

In addition, these species are distinct in the morphology of the cross-section of the ribs: trapezoid in *L. marmoreum* (thus non-serrated rib bases from sides are distinct below the lateral denticles of the upper rib slopes) and rectangular in *L. denticostatum* (no rib base is seen below the denticles of upper rib slopes). Due to different cross-sections of the ribs of the species compared, the morphology of denticles of the lower margin also differs, i.e., trapezoid and rectangular in *L. marmoreum* and *L. denticostatum*, respectively. The morphology of the transverse rib section affects the contours of the transverse section of the intercostal spaces. The cross-section of spaces between the ribs on the central field is triangular and semi-round in *L. marmoreum* and rectangular or semiround (on posterior and anterior halves of the central field, respectively) in *L. denticostatum*. The middle groove on the rib crests of the posterior and anterior fields and posterior and anterior carinae is present in all specimens of *L. marmoreum*. In *L. denticostatum* specimens, all rib crests are without grooves, however, some specimens (e.g., the holotype) have very weak middle groove of rib crests on the posterior and anterior parts of the shell. The shells of the species described are larger. For example, the largest specimen of *L. marmoreum* is 62 mm high, whereas valves of *L. denticostatum* in our collection are 35 mm high.

**Occurrence.** Middle Eocene of Ukraine (the lower part of the Lutetian Stage): Buchak Formation of the northeastern slope of the Ukrainian Shield.

**Material.** Fourteen valves from sands and sandstones from ravines of the town of Kanev.

**Table 1.** Width of intercostal spaces in *Loxocardium marmoreum* and *L. denticostatum* at different distances from the beak

Width of intercostal spaces	Species	
	<i>L. marmoreum</i>	<i>L. denticostatum</i>
At a distance of 15 mm	0.15 mm	0.15–0.20 mm
At a distance of 20 mm	0.15 mm	0.20–0.25 mm
At a distance of 25 mm	0.15–0.20 mm	0.25–0.30 mm
At a distance of 30 mm	0.20–0.25 mm	0.35–0.45 mm
At a distance of 40 mm	0.25–0.30 mm	–
At a distance of 50 mm	0.40–0.45 mm	–
At a distance of 60 mm	0.60–0.70 mm	–

#### Genus *Schedocardia* Stewart, 1930

*Schedocardia imperfecta* Berezovsky, sp. nov.

Plate 2, figs. 4 and 5

**Etymology.** From the Latin *imperfectus* (incomplete).

**Holotype.** GM KNU, no. I-400/01, young left valve in rock; Ukraine, town of Ingulets, western wall of quarry of Ingulets MPP; Middle Eocene, Stary Ingulets Formation.

**Description.** The shell is up to 30 mm high, rounded-rectangular, distinctly convex. The height of valves is slightly greater than the length. The beak is thick, rounded, moderately prominent. The posterior carina is rounded. The external surface of the central and posterior fields is covered with relatively divaricate low radial ribs with pentagonal transverse profile. The ribs of valves 25–30 mm high are 1.0 mm thick and the space between them is 0.5 mm (hereinafter, the various parameters of ornamentation are measured on the external surface of valve clasts, which had an intact external layer, because those extracted from silicified rock were mostly without a thin external layer). On the beak, the width of intercostal spaces is as approximate as the width of the ribs. For example, at a distance of 1 mm from the beak, the rib thickness and the width of spaces between them are ~0.1 mm. The ribs have very low vertical slopes and convex angular-rounded crests. The middle region of each rib exhibits a thin threadlike radial stria. The intercostal spaces have slightly convex bottom. The thinnest (0.05 mm) arched concentric striae with a space of ~0.1 mm appear at a distance of 0.6–0.7 mm from the beak first on the ribs of the ante-

rior field and their spaces and then on the ribs of the central fields and their spaces. On the ribs, these striae span the apical ridge and are convexly directed to the beak. In the intercostal spaces, these striae are convexly directed to the lower margin. On the ribs and in the intercostal spaces, the thickness of the transverse striae is similar. With expansion of the shell, the ribs become higher due to increasing height of the triangular upper part of the ribs and a thin threadlike radial stria forms in the middle of the intercostal spaces. In addition, the base of each rib slope hosts a deep thin groove. These grooves increase relief of the slightly convex base of the intercostal spaces. The character of ornamentation of the anterior field is unclear. The internal structure is not studied; it was only possible to identify that this species belongs to Cardiidae.

**D i m e n s i o n s.** Specimen no. I-400/01: length of 12 mm, height of 14 mm, convexity of 5 mm.

**C o m p a r i s o n.** No Schedocardia species with a similar ornamentation of the external shell surface are known, namely: a pentagonal transverse rib profile, a middle ridge on the rib crests, a convex bottom of intercostal spaces, a clear central ridge in the middle of the base of each intercostal space (it becomes more distinct only in the lower part of valves, which are more than 20 mm high), and orientation of concentric striae (on the ribs and in rib spaces, they are convexly directed toward the beak and the lower margin, respectively).

**M a t e r i a l.** Four specimens from the type locality.

#### ACKNOWLEDGMENTS

The author is deeply grateful to S.V. Popov (Borissiak Paleontological Institute, Russian Academy of Sciences) for help and valuable remarks during the study of cardiids.

#### REFERENCES

- Berezovsky, A.A., New species Carditidae and Cardiidae (Bivalvia) from the Middle Eocene of the Ukraine, *Paleontol. J.*, 1998, vol. 32, no. 3, pp. 248–254.
- Berezovsky, A.A., Stary Ingulets Formation (Middle Eocene, Krivbass): division, age, and correlation, *Geol.-Mineral. Visnyk*, 2009, nos. 1–2 (21–22), pp. 35–66.
- Berezovsky, A.A., Upper Eocene bivalves from Dnepropetrovsk, Ukraine: Nuculida and Arcida, *Paleontol. J.*, 2015, vol. 49, no. 9, pp. 987–1099.
- Berezovsky, A.A. and Pacaud, J.-M., New species of the genus *Chelotia* (Pleurotomariidae, Gastropoda) from the Middle Eocene of Ukraine, *Paleontol. J.*, 2019, vol. 53, pp. 593–597.
- Makarenko, D.E. and Zelinskaya, V.A., *Mollyuski srednego eotsena platformennoi Ukrainy* (Mollusks of the Middle Eocene of Platform Ukraine). Kiev: Naukova Dumka, 1982.
- Popov, S.V., Microstructure of shell and systematics of cardiids, *Trudy Paleontol. Inst. Akad. Nauk SSSR*, 1977, vol. 153, pp. 1–124.
- Schneider, J.A., Phylogeny of cardiid bivalves (cockles and giant clams): revision of the Cardiinae and the importance of fossils in explaining disjunctive biogeographical distributions, *Zool. J. Linn. Soc.*, 2002, vol. 136, pp. 321–369.

*Translated by I. Melekestseva*

SPELL: 1. ok