# THE GENUS *NEMOCARDIUM* MEEK 1876 IN THE PLIO-PLEISTOCENE OF ITALY (BIVALVIA, CARDIIDAE)

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*Abstract* *A revision of* Nemocardium *Meek 1876 from the Mediterranean Plio-Pleistocene has led to the recognition of two species,* Nemocardium (N.) cyprium *(Brocchi 1814) and* Nemocardium (N.) italicum *nom. nov. Both species are poorly known and with a complex history of misidentifications. Brocchi's holotype of* Venus cypria*, from the Early Pliocene deposits of Siena (Italy), is the only specimen of* Nemocardium (N.) cyprium *so far known.* Nemocardium (N.) italicum *occurs in fine-grained deposits, ranging from the Early Pliocene to the Early Pleistocene. Both in the old and in the modern literature, this species has been misidentified as* Cardium striatulum *Brocchi 1814, which is synonym of* Laevicardium crassum *(Gmelin 1791).* Nemocardium *was notably diverse in the Eocene and Oligocene of England, France and Italy. The occurrence of* Nemocardium *in the Neogene-Pleistocene of Europe is a case of biogeographic disjunction, due to the closure of the eastern seaway to the Indo-Pacific in the late Early Miocene. As a consequence of the climatic cooling through the Cenozoic and Quaternary,* Nemocardium *underwent a dramatic drop in diversity. Its persistence in the Mediterranean till the Early Pleistocene, with* Nemocardium (N.) italicum*, was probably due to favourable climatic conditions in this basin.* Nemocardium (N.) bechei *(Reeve 1847) seems to be the sole living species, mainly distributed in the tropical waters of the Indo-Pacific.*

*Key words* *Cardiidae,* Nemocardium*, systematics, Plio-Pleistocene, Italy*

## INTRODUCTION

The main difference between the modern Mediterranean cardiid fauna and that of the Neogene-Pleistocene is the disappearance of some genera, namely *Afrocardium* Tomlin 1931, *Europicardium* Popov 1977, *Nemocardium* Meek 1876 and *Discors* Deshayes 1858 (here regarded as synonym of *Lyrocardium* Meek 1876), which are still present outside the Mediterranean, mainly in tropical areas. The disappearance of most warm water taxa occurred in the Mediterranean and in the adjacent Atlantic in the Middle Pliocene (3.2 My) (Monegatti & Raffi, 2001, 2007), due to the onset of the Northern Hemisphere Glaciation (Zachos *et al*., 2001). However, the disappearance of these cardiids happened in the Early Pleistocene, or most probably at the transition between the Early and Middle Pleistocene (0.9–0.6 My), when a new climatic regime, with stronger glacial and interglacial oscillations took place (Thunell *et al*., 1977; Ruddiman *et al*., 1989).

*Nemocardium* originated in late Early Cretaceous (Aptian) and is the oldest living cardiid genus (Keen, 1969; Schneider, 1995, 2002). *Nemocardium (N.) bechei* (Reeve 1847) (Fig. 1) is the best known living species of the nominal subgenus. It has a wide distribution, ranging from the Indian Ocean to the Western Pacific (Japan south to Indonesia, Philippines and Australia) (Hylleberg, 2004, 2009b). The number of extant species of *Nemocardium (N.)* is not well settled yet: Poorten (2005) reported a single species (*N. bechei*), which could consist of a species complex according to Huber (2010: p. 684), whereas Hylleberg (2009b) listed four species.

The occurrence of *Nemocardium*, and of many other taxa with a present-day Indo-Pacific distribution, in the Neogene-Pleistocene of Europe is clearly a case of biogeographic disjunction, due to the closure of the eastern seaway to the Indo-Pacific in the late Early Miocene (Rögl, 1998; Harzhauser *et al*., 2002, 2007), since which *Nemocardium* became a Tethyan relict in Europe.

Two *Nemocardium* species are credited to the Mediterranean Plio-Pleistocene, *N. cyprium* (Brocchi 1814) and *N. striatulum* (Brocchi 1814). Both species, poorly known and with a complex history of misidentifications, are systematically treated in the present work.

## MATERIAL AND METHODS

The present work is based on Plio-Pleistocene material, mostly from public collections: Bellardi

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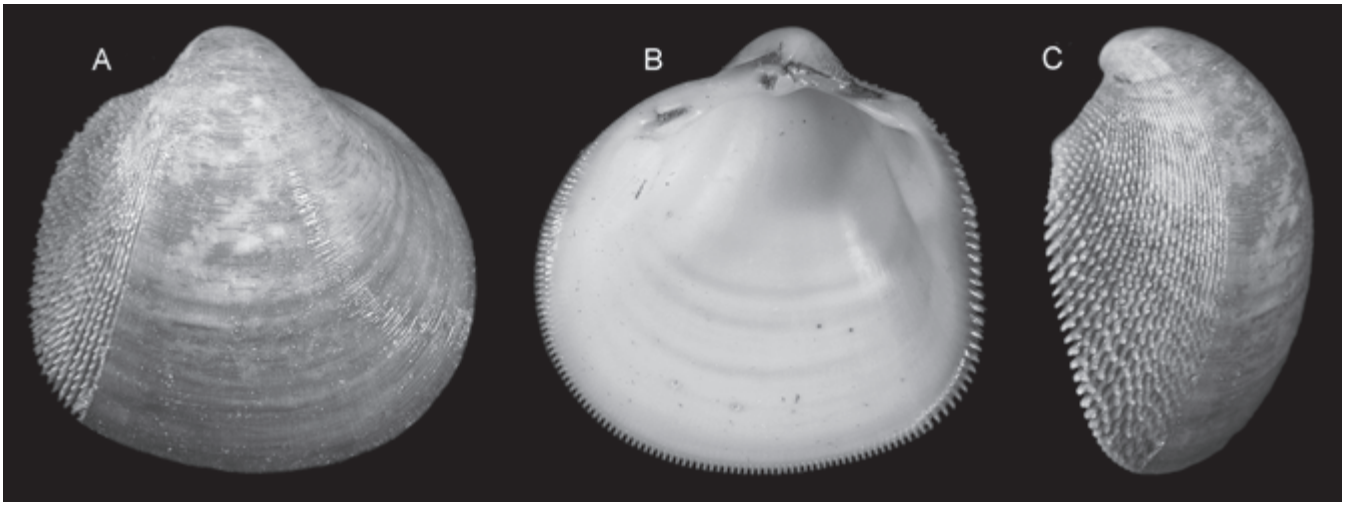


**Figure 1** *Nemocardium (N.) bechei* (Reeve 1847). Bantanayan Island, Philippines, L 42.9 mm (La Perna coll.).

& Sacco collection (Museo Regionale di Scienze Naturali di Torino); Brocchi collection (Museo Civico di Storia Naturale di Milano); Cerulli-Irelli collection (Museo di Paleontologia dell'Università di Roma "La Sapienza"); and collections from the Natural History Museum of Vienna. Other material comes from the private collection of Mauro Brunetti (Rioveggio, Bologna).

The following abbreviations are used: coll. = collection; v(s) = valve; sh(s) = shell(s); L = antero-posterior lenght; H = dorso-ventral lenght; MCSM = Museo Civico di Storia Naturale di Milano; NHMW Naturhistorisches Museum Wien; MRSN = Museo Regionale di Storia Naturale di Torino; MPUR = Museo di Paleontologia dell'Università di Roma "La Sapienza"; Brunetti coll. = M. Mauro Brunetti collection (Rioveggio, Bologna).

## Systematic history of the genus *Nemocardium*

Deshayes (1858) described nine cardiids from the Eocene of the Paris basin within *Protocardia* von Beyrich 1845, considered as a section of *Cardium* Linné 1758. All of them show a medium-sized, subaequilateral, orbicular to subtrigonal shell, with a sculpture pattern consisting of dense, thin radial ribs on the anterior and central areas, contrasting with a stronger radial sculpture on the posterior slope.

Meek (1876: p. 167) grouped all the nine species described by Deshayes (1858) in the section *Nemocardium*, describing it as follows: "Shell closely resembling the typical forms of *Protocardia*, but thinner, with two-thirds to three-fourths of surface in front of the stronger posterior, usually echinate, radiating costae, occupied by fine, crowded, radiating striae, and the free margins crenate within all around; cardinal and lateral teeth rather slender; pallial line faintly sinuous, irregularly serrated, or nearly simple behind – *Cardium semiasperum* Desh.". The presence of strong radial ribs on the posterior slope of the shell, led Meek to consider *Nemocardium* transitional between *Protocardia* and "*Cardium*". *Protocardia* is a Mesozoic genus with radial ribs on the posterior slope and a fine commarginal sculpture on the rest of the shell (Keen, 1969; Schneider *et al.*, 2010). Actually, Meek's insight is supported by the stratigraphic distribution and the modern phylogenetic studies (Schneider, 1995, 2002), suggesting that in the Cardiidae the development of radial ribs on the posterior slope (*Nemocardium*) was the basis for the evolutionary step from the Mesozoic model of predominantly concentric sculpture (*Protocardia*), to a model of full radial sculpture that widely developed in the cardiids since the Cenozoic.

The type species, *Cardium semiasperum* Deshayes 1858, was originally designated by Meek (1876), not subsequently by Sacco (1899) as erroneously reported by Hylleberg (2004, 2009b) and other older works (e.g. Hughes, 1961). This species was described as slightly inaequilateral, with a sculpture consisting of very fine, shallow

radial ribs ("*stries obsoletes*"), changing abruptly on the posterior side where the ribs are stronger, bearing small, spiny tubercles (Deshayes, 1858).

Keen (1969, 1980) included in *Nemocardium* 12 subgenera, all with a radial sculpture throughout the shell surface, stronger posteriorly. More recently, Schneider (1995) presented a cladistic analysis of 33 cardiid taxa. *Nemocardium* was considered as a genus including 12 subgenera, almost in accordance with Keen's classification (with the exclusion of *Discors* and the inclusion of *Brevicardium* Stephenson 1941). According to Schneider's phylogenetic scheme, the group of *Nemocardium* (including the numerous subgenera) represents the greatest part of the subfamily Laevicardinae Keen 1936. Certainly, the systematics of the large group of *Nemocardium* is still confused and needs to be studied in detail (see also Hylleberg, 2009a). Some subgenera could turn out to be synonyms, others could deserve to be ranked at full genus rank, such as *Microcardium* Thiele 1934 and *Frigidocardium* Habe 1951, both considered distinct genera by Poutiers (1992, 2006).

The two species dealt with in the present work are the sole *Nemocardium* representatives known from the Mediterranean Plio-Pleistocene and belong in the nominal subgenus *Nemocardium (N.).*

## Systematics

Family Cardiidae Lamarck 1809
Subfamily Laevicardiinae Keen 1936
Genus *Nemocardium* Meek 1876
Subgenus *Nemocardium* Meek 1876
Type species *Cardium semiasperum* Deshayes 1858 (by original designation)

***Nemocardium (N.) cyprium*** (Brocchi 1814)
(Fig. 2A–C)

*Venus cypria* Brocchi 1814: 545, pl. 13, fig. 14.
*Cardium grateloupi* Michelotti 1839: 137.
*Nemocardium cyprium* Brocchi – Rossi Ronchetti, 1952: 64, fig. 25a–e.
*Venus cypria* Brocchi – Garassino, 1995: 243, fig. 55.

*Material examined* 1 sh (holotype), "Crete Senesi", Early Pliocene (Brocchi coll., MCSM).

*Measurements* L=43.9 mm, H=43.4 mm.

*Distribution* Despite the huge number of studies on the Plio-Pliestocene Mediterranean molluscs, only two records of this species are known (Brocchi, 1814; Michelotti, 1839) and Brocchi's holotype is the only specimen so far known. It comes from clayey Early Pliocene deposits cropping out near Siena (Crete Senesi).

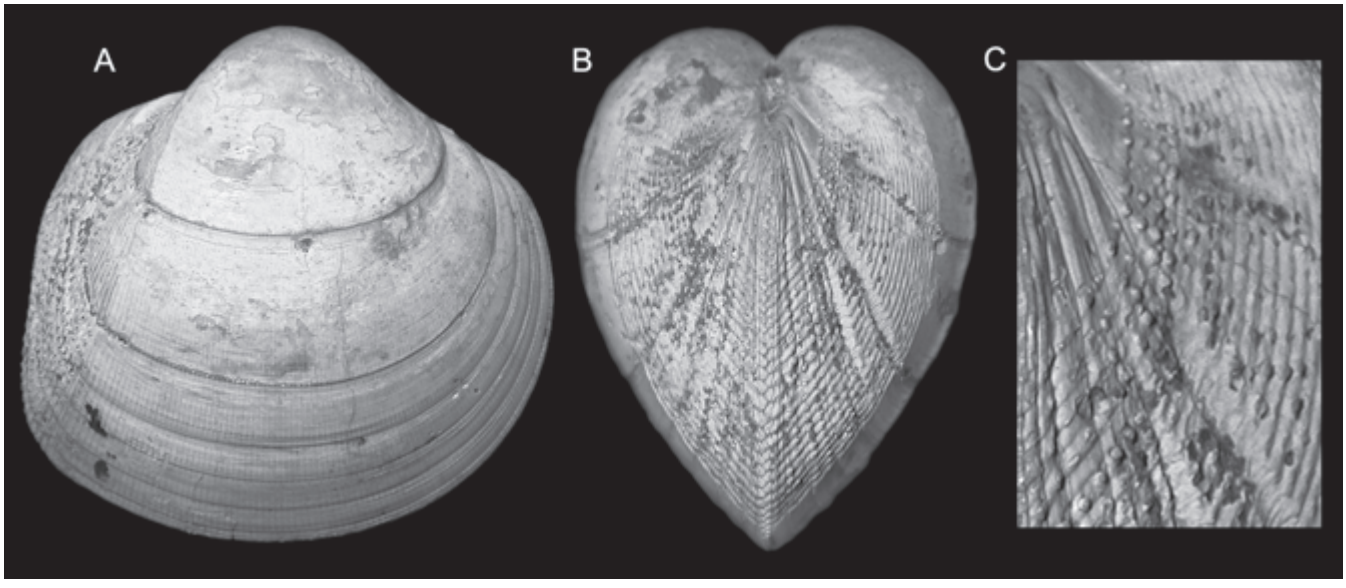


**Figure 2** *Nemocardium (N.) cyprium* (Brocchi 1814). Crete Senesi (Siena), Early Pliocene, L 43.9 mm (holotype, Brocchi coll., MCSN).

*Remarks* The holotype of *Venus cypria* was well described and illustrated by Rossi Ronchetti (1952), who revised the Brocchi collection. More recently, it was also illustrated by Garassino (1995). The shell (Fig. 2) has a slightly depressed posterior slope, with about twenty-five ribs. The posterior margin is slightly convex or almost straight, contrasting with the strongly convex anterior margin. From the postero-ventral transition to the posterior margin the ribs become progressively less dense and coarser, and with more tubercles. Tubercles are roughly roundish, blunt to slightly sharp, leaving a crater-like depression with thin edges when worn away (Fig. 2C). Few deep, well distinct growth lines are present, all through the shell surface (Fig. 2A).

Brocchi (1814: p. 545) explained clearly why he placed this species in the genus *Venus*: his single specimen was with closed valves and he held back from separating them, wishing to avoid destroying the specimen. Without examining the internal characters, he preferred to place the species in *Venus*, though suspecting it was a cardiid.

As reviewed by Rossi Ronchetti (1954), the few records of this species have been based on misidentification with *Cardium fragile* Hoernes 1870, since Sacco (1899). The material labelled as *Laevicardium cyprium* (Brocchi) in the Bellardi & Sacco coll., from the Pliocene of Northern Italy, indeed is not a *Nemocardium*, but *Laevicardium homofragile* Rossi Ronchetti 1954 (= *C. fragile* Hoernes 1870 non Brocchi 1814).

*Cardium grateloupi* was described by Michelotti (1839) in a poorly known work, from the Pliocene of Asti (Northern Italy). The description, without illustration, clearly points to *Nemocardium* ("*latere postico costis granulosis*"). The inaequilateral shape with an almost straight posterior margin, as remarked by Michelotti, suggests that *C. grateloupi* is a synonym of *Nemocardium (N.) cyprium*, rather than of the following species.

It is worth noting that Sacco (1899) described the var. *oligocenica* for *Nemocardium semistriatum* (Deshayes, 1824) from the early Oligocene of Piedmont and Liguria. The scant, poorly preserved material in the Bellardi and Sacco coll. seems to include two distinct species, both similar to *N. cyprium*, mainly differing by a stronger posterior sculpture. It can be assumed that these Oligocene species were the most direct ancestors of *N. cyprium*.

This species is notably similar in size, shape and sculpture to the type species *Nemocardium (N.) semiasperum* (Deshayes 1858: p. 573, pl. 55, figs 1, 2).

***Nemocardium (N.) italicum*** nom. nov.
(Figs 3A–P, 4A–G)

*Cardium striolatum* Calcara 1841: 28, pl. 1, fig. 7 (non Link, 1807).
*Nemocardium striatulum* (Brocchi) – Sacco, 1899: 56, pl. 12, fig. 18–23 (non *Cardium striatulum* Brocchi, 1814).
*Cardium (Nemocardium) striatulum* (Brocchi) – Cerulli-Irelli, 1908: 35, pl. 6, fig. 4.
*Nemocardium striatulum* (Brocchi) – Cavallo & Repetto, 1992: fig. 607.

*Material examined* Bellardi & Sacco coll. (MRSN): 30 vs (BS.131.11.001, BS.131.11.005, BS.131.11.006/07, BS.131.11.006/08), Colli Astesi (Asti), Pliocene; 5 vs (BS.131.11.002, BS.131.11.006/01), Zinola (Savona), Early Pliocene; 18 vs (BS.131.11.004, BS.131.11.006/02, BS.131.11.006/03), Rio Torsero (Savona), Pliocene; 1 sh (BS.131.11.006), Castell'Arquato (Piacenza), Middle Pliocene; 2 vs (BS.131.11.003, BS.131.11.006/04), Bordighera (Imperia), Pliocene; 7 vs (BS.131.11.06/05), Ceriale (Savona), Pliocene; 1 v (BS.131.11.006/06), Crescentino (Vercelli), Pliocene. Brunetti coll.: 1 v, Ca' Lametta Monteveglio (Bologna), Middle Pliocene; 10 vs, Rio Carbonaro (Piacenza), Middle Pliocene; 7 vs, Rio Crevalese (Piacenza), Middle Pliocene; 11 vs, Monte Padova (Castell'Arquato, Piacenza), Middle Pliocene; 1 v, Guidonia (Roma), Middle Pliocene; 6 vs, Villalvernia (Alessandria), Early-Middle Pliocene; 10 vs, Ciuciano (Siena), Early Pliocene. Cerulli-Irelli coll. (MPUR): 2 vs, Monte Mario (Roma), Early Pleistocene. NHMW coll.: 12 vs, Castell'Arquato (Piacenza), Middle Pliocene.

*Measurements* Specimens measured (valves only): 21. L 5.2–15.5 mm; H 4.7–14.3 mm.

*Description* Shell orbicular, aequivalve, small for the genus, slightly inaequilateral, moderately convex and slightly longer than high (length/height ratio 1.05 to 1.08). Shell wall thin, brittle. Umbo slightly prosogyrate, moderately large and prominent, slightly anterior to shell mid-length. Anterior slope regularly convex, with

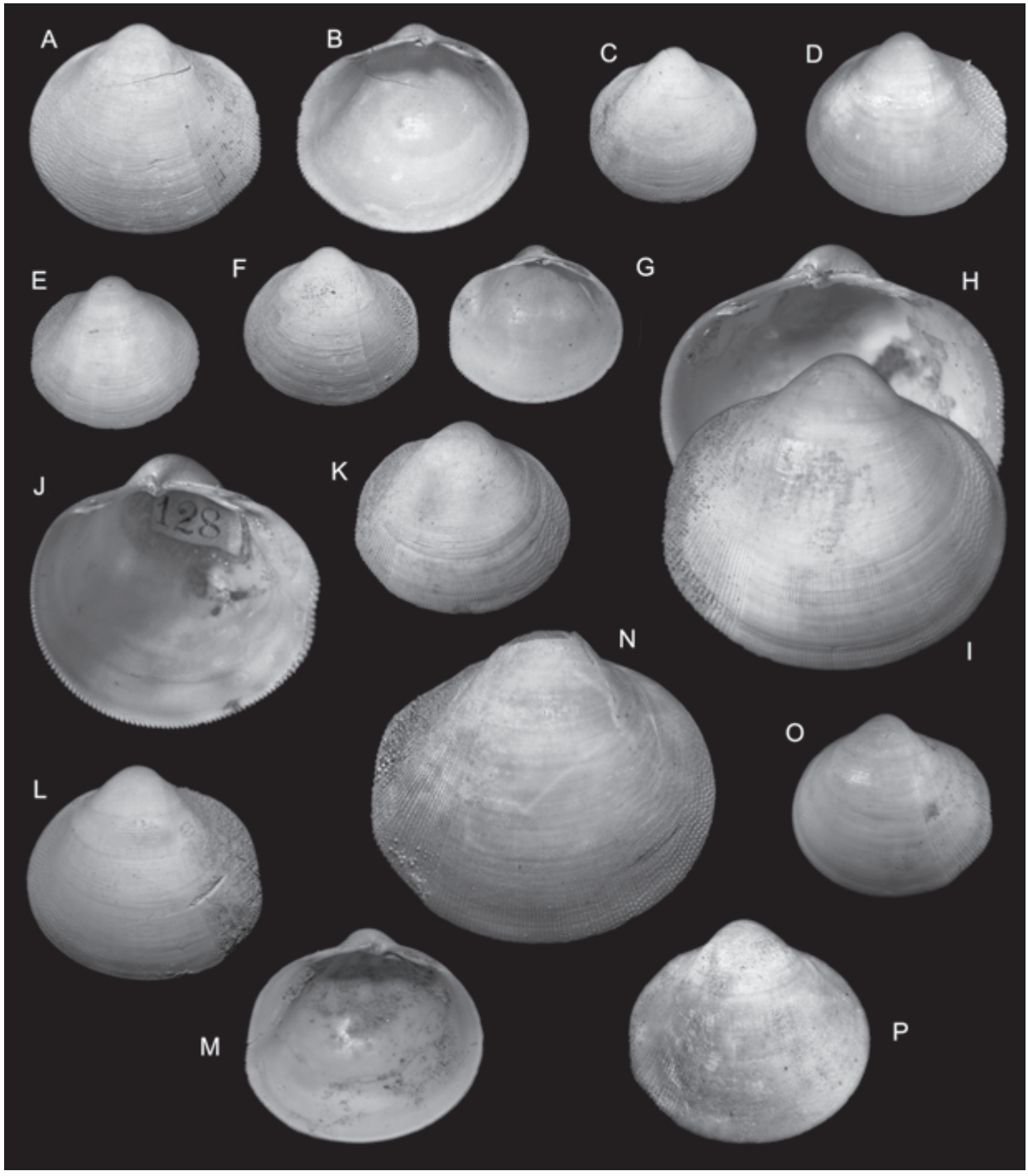


**Figure 3** *Nemocardium italicum nom. nov.* **A**, **B** Rio Carbonaro (Piacenza, Italy), Middle Pliocene, L 10.4 mm (Brunetti coll.). **C** Rio Carbonaro (Piacenza, Italy), Middle Pliocene, L 7.5 mm (Brunetti coll.). **D** Monte Padova, Castell'Arquato (Piacenza, Italy), Middle Pliocene, L 9.0 mm (Brunetti coll.). **E** Rio Carbonaro (Piacenza, Italy), Middle Pliocene, L 7.5 mm (Brunetti coll.). **F**, **G** Rio Carbonaro (Piacenza, Italy), Middle Pliocene, L 7.9 mm (Brunetti coll.). **H**, **I** Bordighera (Imperia, Italy), Zanclean, L 15.5 mm (Bellardi & Sacco coll., MRSN BS.131.11.003), original illustration in Sacco (1899: pl. 12, fig. 20a, b). **J** Rio Torsero (Savona, Italy), Zanclean-Piacenzian, L 13.0 mm (Bellardi & Sacco coll., MRSN BS.131.11.004), original illustration in Sacco (1899: pl. 12, fig. 21). **K** Colli Astesi (Asti, Italy), Pliocene, L 9.7 mm (Bellardi & Sacco coll., MRSN BS.131.11.001), original illustration in Sacco (1899: pl. 12, fig. 18). **L**, **M** Guidonia (Roma, Italy), Middle Pliocene, L 10.6 mm (Brunetti coll.). **N** Ca' Lametta Monteveglio (Bologna, Italy), Middle Pliocene, L 15.5 mm (Brunetti coll.). **O** Castell'Arquato (Bologna, Italy), Middle Pliocene, L 9.07 mm (NHMW). **P** Monte Mario (Roma, Italy), Early Pleistocene, L 10.8 mm (Cerulli-Irelli coll., MPUR), original illustration in Cerulli-Irelli (1908: pl. 6, fig. 4).

well rounded anterior margin. Antero-dorsal margin short, smoothly passing to anterior margin. Posterior slope slightly depressed. Postero-dorsal margin slightly longer than antero-dorsal, straight, forming an obtuse angle at the transition to posterior margin. Posterior margin subtruncate, slightly convex to almost straight, then with an obscure sinuation and a bluntly angular postero-ventral transition. Ventral margin strongly and regularly convex. Sculpture mostly consisting of closely set radial riblets, abruptly changing from fine and shallow on anterior and central shell area, to coarser, with deeper interspaces on the posterior area. The fine sculpture covers about 75% of shell surface, with a density of radial rib from about 25/mm anteriorly to about 15/mm towards the posterior area. The posterior sculpture consists of about 35 radial ribs, subrectangular in cross section, with deep interspaces slightly narrower than ribs. Antero-dorsally, a fine sculpture of small, scattered tubercles is often present, giving a granulate pattern. Anteriorly and antero-ventrally, tubercles tend to become commarginally aligned, slightly coalescent, forming short, discontinuous, wavy ridges. Under high magnification, tubercles are crescent-shaped, concave towards umbo, originating from interspaces and tending to overlap the adjacent radial ribs. Other tubercles, bluntly spiny to slightly spoon-shaped, are present postero-dorsally, becoming finer and poorly ventrally, only within the coarsely sculptured area. Also the posterior tubercles originate from interspaces, tending to overlap the adjacent ribs. The growth lines have variable strength, generally fine, and are mostly seen ventrally. Lunula and escutcheon narrow, slightly convex, with only growth striae. Hinge arched. Right valve with two cardinal teeth, the lowermost strong, hook-shaped, the other small, tubercle-like; an elongate posterior lateral tooth, with a deep socket; an anterior, strong, subtriangular tooth with a short socket. Left valve with two cardinal teeth, similar to those on right valve, an anterior, notably elongate, strong lateral tooth with a shallow socket; a small, weak posterior lateral tooth. Lunule flap well developed partly overlapping the beak. Ligament opisthodetic. Ligament nymph narrow, slightly concave. Muscle scars poorly distinct, roughly oval in outline, of similar size. Pallial line entire, poorly distinct. Internal margin crenulated, slightly coarsely posteriorly.

*Derivation of name* After the Latin *italicus* (= from Italy).

*Distribution* The study material ranges from the Early Pliocene to the Early Pleistocene of Italy. The species seems to be relatively common in fine-grained deposits of the continental shelf.

Sacco (1899) recorded this species, as "somewhat rare", from the Late Miocene of Stazzano (Piedmont), but no Miocene material of "*Nemocardium striatulum*" is present in the Bellardi & Sacco coll.

*Remarks* This species, hitherto known as *Nemocardium striatulum* (Brocchi, 1814) has a rather complex history. *Cardium striatulum* was described from the Pliocene of Valle Andona (Asti, Northern Italy), as follows: "*Testa subrotundata, gracilis, pellucida, subtilissime longitudinaliter costata, costis quinquaginta, margine argute crenato*" (Brocchi, 1814: p. 507). The author remarked that the radial ribs, numbering 50, are thin ("*capillari*"), but raised and with rather deep interspaces, and that the shape is roundish, slightly oblique, higher than long. Size was reported as "*Lunghezza lin. 4, larghezza lin. 5*", i.e. about 10.5 mm in height and 8.5 mm in length. The original drawing (Brocchi, 1814: pl. 13, fig. 5; Hyllberg, 2004: p. 96) is poor, but a fine radial ribbing pattern, uniform throughout the valve surface, can be clearly seen. Unfortunately, no material of *C. striatulum* is present in the Brocchi coll. (MCSN).

Sacco (1899: p. 56, pl. 12, figs 18–23) reported *Nemocardium striatulum* from the Pliocene of Northern Italy. The material in the Bellardi & Sacco coll. (MRSN) (Fig. 3H–K) shows the typical sculpture of *Nemocardium (N.)*, with coarser ribs on the posterior side and very fine, almost microscopic ribs on the rest of shell, much more numerous (about 170) than "fifty" as in the original description. It is worth noting that Brocchi (1814) considered the number of ribs of great importance for separating the species ("*il numero delle coste, tranne qualche leggiero divario, è un carattere costante che si debbe avere in gran conto per distinguere le specie*", p. 506). Moreover, when describing *Venus cypria* (see above), he underlined the different sculpture between the posterior side and the remaining shell surface. If the same pattern of *Venus cypria* was present in *C.*

*striatulum*, Brocchi would most probably assign the two species to the same genus. It is then clear that *N. striatulum* of Sacco (1899) is not *Cardium striatulum* Brocchi 1814. Most probably, Brocchi's description was based on juvenile material of a *Laevicardium* species and *C. striatulum* could be tentatively synonymised with *Laevicardium crassum* (Gmelin 1791). Comparing the original drawing of *Cardium striatulum* with that of *C. fragile* Brocchi 1814 (p. 505, pl. 13, fig. 4), which was identified as *Laevicardium (L.) norvegicum* var. *fragilis* by Rossi Ronchetti (1952), a close resemblance in sculpture and shape can be recognised. The examination of *Cardium fragile* confirmed the synonymy with *L. crassum* ( = *L. norvegicum* Spengler 1799).

The material of *Cardium (Nemocardium) striatulum* of Cerulli-Irelli (1908: p. 35, pl. 6, fig. 4) (Fig. 3P) consists of two valves, corresponding to the species present in the Bellardi & Sacco coll. Cerulli-Irelli only remarked a different ornamentation between anterior and posterior side, without giving any other indication.

There are few other records from the Mediterranean Plio-Pleistocene. Bronn (1831) recorded *C. striatulum* from the Pliocene of "Southern France", without any comments. In recent times, Cavallo & Repetto (1992: fig. 607) reported *N. striatulum* from the Pliocene of Piedmont. It is the same species as that occurring in the Bellardi & Sacco and Cerulli-Irelli collections.

*Cardium striatulum* of Sacco (1899) and Cerulli-Irelli (1908) corresponds well with an obscure species, *Cardium striolatum*, described by Calcara (1841: pp. 28–29, pl. 1, fig. 7) from the Early Pliocene of Altavilla, near Palermo. Calcara gave a good description ("*C. testa aequilatera sub-rotunda, tenui, longitudinaliter striata, marginibus superioribus subdepressis, obsolete papillis et striatis, antice magis impressis, apicibus recurvis, saepe crebriusculis*") and a fairly clear illustration. He remarked the almost orbicular shape, the sculpture consisting of fine radial ribs, stronger "anteriorly" (i.e. posteriorly, as shown in the illustration; in the nineteenth century, anterior and posterior sides were often inverted in the descriptions of bivalves). Size was reported as 9 lines in width (height) and 8 lines in length, i.e. about 18×16 mm.

*Cardium striolatum* Calcara 1841 is pre-occupied by *C. striolatum* Link 1807 (Link, 1807: p. 19) and a replacement name is herein proposed.

The relatively abundant material examined in the present work shows a wide range in size, from about 5 to 15 mm in shell length, but most specimens are 8–10 mm in length. In this respect, the size reported for *Cardium striolatum* by Calcara is slightly larger than the maximum size herein recorded.

The occurrence of a granulose anterior sculpture in *Nemocardium* seems an unusual character, never described in the literature. However, the examination of a valve of *Nemocardium (N.) fraterculum* (Deshayes 1858), from the Eocene of Paris (NHMW), revealed poorly distinct, discontinuous ridges near the antero-ventral margin (*"stries transverses un peu tremblées, excessivement étroites"*), similar to those of *Nemocardium (N.) italicum* but almost regularly commarginal. Recently, in *Nemocardium (Microcardium) doelense* Marquet & Van Niulande 2005 from the Early Pliocene of Belgium, the poorly preserved anterior sculpture was described as follows: "approximately 120 fine radial ribs, crossed by narrow undulating laminae, breaking up towards the posterior part of the shell into separate small scales; laminae running down slightly excentrical" (Marquet, 2005: pp. 46, 47, pl. 26, fig. 1). This species is a representative of *Nemocardium (N.)*, not of *Microcardium*, and its anterior sculpture recalls that of *N. italicum*.

The anterior, non radial sculpture of *N. italicum* is variable in strength, from apparently absent in few cases to dense. Antero-dorsally, the granulations are roundish, becoming crescent-shaped ventrally (Fig. 4F), then forming punctuate or discontinuous, wavy ridges (Fig. 4E). A preliminary hypothesis on two sibling species differing in the occurrence/absence of such a sculpture was not supported by the careful examination of all the available material, showing a gradual change in this character.

Another puzzling aspect of the sculpture of *N. italicum* is that either the posterior short spines (Fig. 4C, D, G), and the anterior granulations (Fig. 4F) originate from the radial interspaces, whereas in *N. bechei* (Fig. 1A, C), in *N. cyprium* and in the other species of *Nemocardium (N.),* the posterior spines or tubercles arise, or they are described as originating, from the ribs. This must be an important taxonomic character but, due to a lack of other data, we can only remark on it.

*Nemocardium (N.) italicum nom. nov.* seems the smallest species so far known for *Nemocardium*

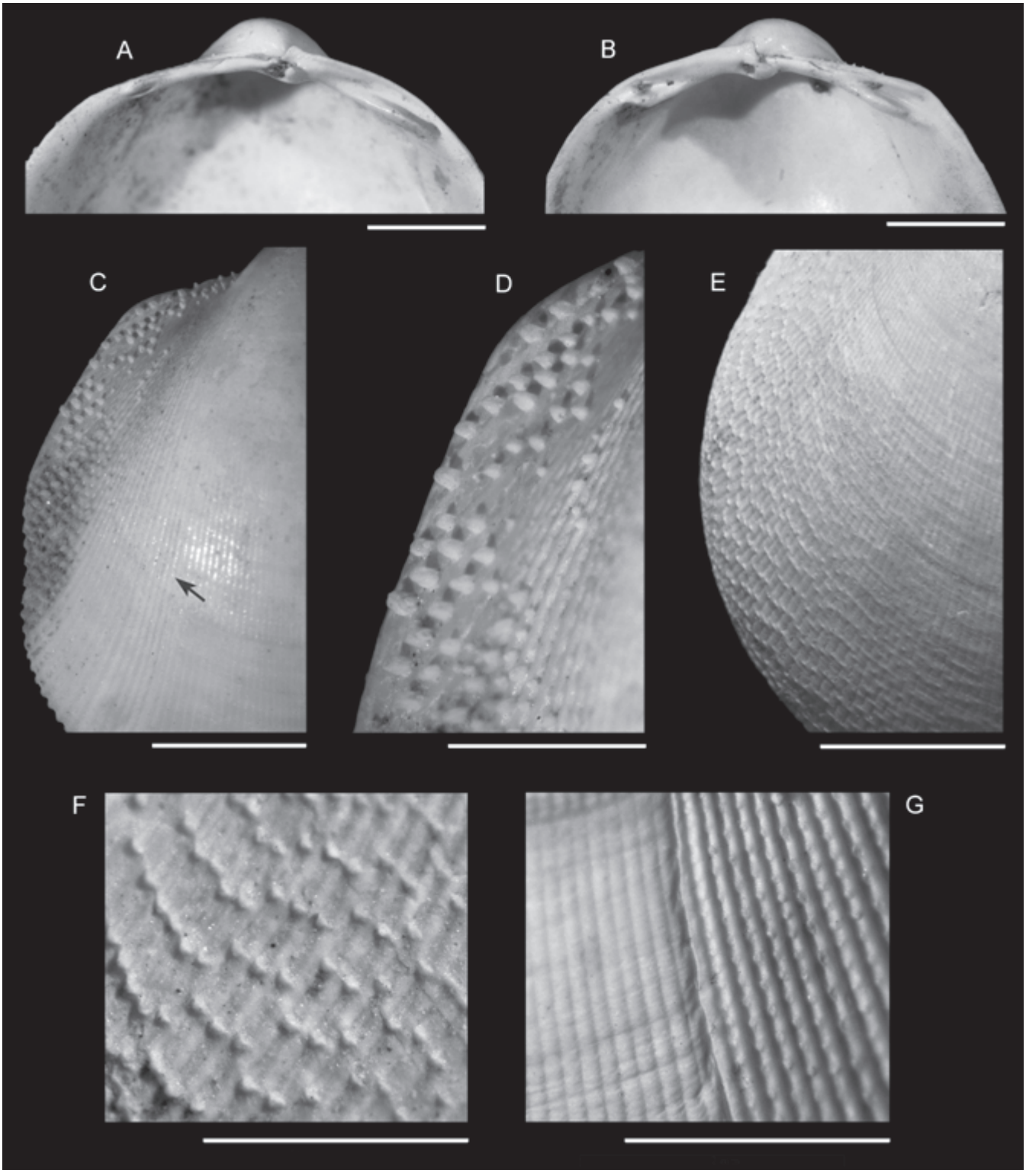


**Figure 4** *Nemocardium italicum nom. nov.* **A** Rio Carbonaro (Piacenza, Italy), Middle Pliocene (Brunetti coll.), hinge of left valve. Scale bar = 2 mm. **B** Rio Carbonaro (Piacenza, Italy), Middle Pliocene (Brunetti coll.), hinge of right valve. Scale bar = 2 mm. **C**, **D** Ciuciano (Siena, Italy), Early Pleistocene (Brunetti coll.), sculpture on the posterior side. Arrow indicates the transition to the coarse radial sculpture. Scale bars = 1 mm. **E**, **F** Rio Carbonaro (Piacenza, Italy), Middle Pliocene (Brunetti coll.), sculpture on the anterior side (E) and details of the crescent-shaped tubercles (F). Scale bars = 1 mm. **G** Rio Carbonaro (Piacenza, Italy), Middle Pliocene (Brunetti coll.), detail of the transition between fine and coarse (posterior) radial sculpture. Scale bar = 1 mm.

*(N.)*. The living Australian species *Nemocardium thetidis* (Hedley 1902) is similar in shape and size, but this species is referred to the subgenus *Pratulum* Iredale 1924, with a more uniform radial sculpture. However, the distinction between *Nemocardium (N.)* and *Nemocardium (Pratulum)* needs to be clarified.

## Discussion

*Nemocardium (N.) italicum* was the latest representative of *Nemocardium* in Europe, becoming extinct in the Early Pleistocene. The stratigraphic distribution of *N. cyprium* is too lacunose, but probably it was restricted to the Pliocene. These were not the sole European Pliocene species of *Nemocardium*, as another species, discussed above, should be included: *Nemocardium (N.) doelense* Marquet & Van Niulande 2005. Another Neogene species, *Cardium spondyloides* von Hauer 1847, sometimes reported as *Nemocardium* (e.g. Höltke, 2009) is a representative of *Discors*, as also suggested by Schultz & Piller (2003) and Marquet (2005).

*Nemocardium (N.)* was notably diverse in the Eocene and Oligocene of France, England and Italy (Deshayes, 1858; Sacco, 1899; Tremlett, 1950; D'Abramo, unpubl. data) and it surely occurred also in the Early Cenozoic of southeastern U.S.A. (Alabama and Mississippi) (Hughes, 1961). We are aware of only two Miocene records: "*N. striatulum*" from the Late Miocene of Piedmont (discussed above) by Sacco (1899), and *Nemocadium* sp., based on a fragment apparently similar to "*N. striatulum*", by Cossmann & Peyrot (1909) from the Helvetian of Aquitania.

Though incomplete, our data on the stratigraphic distribution and diversity of *Nemocardium (N.)* in Europe testify to a dramatic drop in diversity through the late Paleogene and the early Neogene, which led to the present day low diversity of this taxon on a world scale. Such a trend, which was already observed by Sacco (1899) and Cossmann & Peyrot (1909), can be related to the cooling trend which started at the Eocene/Oligocene boundary, going on till the Quaternary (Zachos *et al*., 2001). The persistence of *Nemocardium* in the Early Pleistocene of the Mediterranean area was probably due to favourable climatic conditions related to the mid-latitude position of this basin.

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## References

Brocchi G 1814 *Conchiologia fossile subappennina con osservazioni geologiche sugli Appennini e sul suolo adiacente*. Vol. 2. Stamperia Reale, Milano. 472 pp.

Bronn HG 1831 *Italiens Tertiär-Gebilde und deren organische Einschlusse*. K Groos, Heidelberg. 176 pp.

Calcara P 1841 *Memorie sopra alcune conchiglie fossili rinvenute nella contrada d'Altavilla dal dottor Pietro Calcara socio di varie accademie*. Stamperia d'Antonio Muratori, Palermo. 86 pp.

Cavallo O & Repetto G 1992 *Conchiglie fossili del Roero. Atlante iconografico.* Associazione Naturalistica Piemontese e Amici del Museo "Federico Eusebio", Alba. 251 pp.

Cerulli-Irelli S 1908 Fauna Malacologica Mariana. Parte seconda. *Palaeontographia italica* **14**: 1–64.

Cossmann MM & Peyrot A 1909 *Conchologie Néogénique de l'Aquitaine*. Vol. 1. Pélécypodes. *Actes de la Société Linnéenne de Bordeaux*, Bordeaux. 718 pp.

Deshayes GP 1858 *Description des animaux sans vertèbres dans le basin de Paris*. Tome premiere. J-B Baillière et fils, Paris. 909 pp.

Garassino A 1995 Catalogo dei tipi del Museo Civico di Storia Naturale di Milano. XII. I Lamellibranchi della Collezione Brocchi. *Atti della Società italiana di Scienze naturali e del Museo Civico di Storia naturale di Milano*, **134**(2): 233–264.

Harzhauser M, Piller WE & Steininger FF 2002 Circum-Mediterranean Oligo/Miocene Biogeographic Evolution – the Gastropods' Point of View. *Palaeogeography, Palaeoclimatology, Palaeoecology* **183**: 103–133.

Harzhauser M, Kroh A, Mandic O, Piller WE, Göhlich U, Reuter M & Berning B 2007 Biogeographic responses to geodynamics: A key study all around the Oligo-Miocene Tethyan Seaway. *Zoologischer Anzeiger – Journal of Comparative Zoology* **246**: 241–256.

Höltke O 2009 Die Molluskenfauna der Oberen Meeresmolasse (Untermiozän) von Ermingen und

Ursendorf (SW-Deutschland). *Palaeodiversity* **2**: 67–95.

Huber M 2010 *Compendium of bivalves*. ConchBooks, Hackenheim, Germany. 901 pp., 1 CD.

Hughes RJ 1961 *Nemocardium nicolletti* from the Paleocene Matthews Landing Marl in Mississippi. *Journal of Paleontology* **35**(2): 385–390.

Hylleberg J 2004 Lexical approach to Cardiacea: illustrated and annotated bibliography of living and fossil shells, with emphasis on the families Cardiidae and Lymnocardiidae (Mollusca, Bivalvia). Vols 1–3. *Phuket Marine Biological Center*, special publ. 29, 30: 1–939.

Hylleberg J 2009a Cardiidae (Mollusca: Bivalvia) in the collection of Statens naturhistoriske Museum, previously the Zoological Museum, University of Copenhagen (ZMUC). Annotated and revised. *Steenstrupia* **31**(1): 1–101.

Hylleberg J 2009b Cardiidae (Mollusca: Bivalvia) in the collection of Statens naturhistoriske Museum, previously the Zoological Museum, University of Copenhagen (ZMUC). Annotated and revised. *Steenstrupia* **31**(2): 103–324.

Keen AM 1969 Treatise on invertebrate paleontology. *In* Moore RC *The Geological Society of America, Inc.* and *The University of Kansas*, Part N, Vol. 2, Mollusca 6, Bivalvia: 583–594.

Keen AM 1980 The pelecypod family Cardiidae: a taxonomic summary. *Tulane Studies in Geology and Paleontology* **16**: 1–40.

Link HF 1807 *Beschreibung der Naturalien-Sammlung der Universität zu Rostock*. Abtheilung 4, Adler, Rostock. 30 pp.

Marquet R 2005 The Neogene Bivalvia (Heterodonta and Anomalodesmata) and Scaphopoda from Kallo and Doel (Oost-Vlaanderen, Belgium). *Palaeontos* **6**: 1–142.

Meek FB 1876 *A report on the Invertebrate Cretaceous and Tertiary Fossils of the Upper Missouri Country.* Report of the United States Geological Survey of the Territories, Washington – Government Printing Office, Vol. 9. 629 pp.

Michelotti G 1839 Brevi cenni di alcuni resti delle classi Brachiopodi ed Acefali, trovati fossili in Italia. *Annali delle Scienze del Regno Lombardo-Veneto* **9**: 119–174.

Monegatti P & Raffi S 2001 Taxonomic diversity and stratigraphic distribution of Mediterranean Pliocene bivalves. *Palaeogeography, Palaeoclimatology, Palaeoecology* **165**: 171–193.

Monegatti P & Raffi S 2007 Mediterranean-middle Eastern Atlantic facade: molluscan biogeography & ecobiostratigraphy throughout the Late Neogene. *Açoreana* **5**(supplement): 126–139.

Poutiers J-M 1992 The Australasian Protocardiinae revisited (Bivalvia: Cardiidae). *American Malacological Bulletin* **9**: 139–144.

Poutiers J-M 2006 Two new species of protocardiine cockles (Mollusca, Bivalvia, Cardiidae) from the tropical Southwest Pacific. *Zoosystema* **28**(3): 635–654.

Rögl F 1998 Palaeogeographic Considerations for the Mediterranean and Paratethys Seaways (Oligocene to Miocene). *Annalen des Naturhistorischen Museums in Wien* **99**(A): 279–310.

Rossi Ronchetti C 1952 I tipi della "conchiologia fossile subappennina" di Brocchi. *Rivista Italiana di Paleontologia e Stratigrafia, Memorie* **5**(1): 1–89.

Rossi Ronchetti C 1954 Revisione critica del *Nemocardium cyprium* (Brocchi, 1814). *Rivista Italiana di Paleontologia e Stratigrafia, Memorie* **60**(1): 21–28.

Ruddiman WF, Raymo ME, Martinson DG, Clement BM & Backman J 1989 Pleistocene evolution: Northern hemisphere ice sheets and North Atlantic Ocean. *Paleoceanography* **4**(4): 353–412.

Sacco F 1899 *I molluschi dei terreni terziari del Piemonte e della Liguria*. Parte 27. Cardiidae. Carlo Clausen, Torino. 25 pp.

Schneider JA 1995 Phylogeny of the Cardiidae (Mollusca, Bivalvia): Protocardiinae, Laevicardiinae, Lahilliinae, Tulongocardiinae subfam. n. and Pleuriocardiinae subfam. n. *Zoologica Scripta*, 24(4): 321–346.

Schneider JA 2002 Phylogeny of cardiid bivalves (cockles and giant clams): revision of the Cardiinae and the importance of fossils in explaining disjunct biogeographical distributions. *Zoological Journal of the Linnean Society* **136**: 321–369.

Schneider S, Fursich FT & Werner W 2010 Marking the Kimmeridgian-Tithonian transition with a bivalve – *Protocardia gigantea* sp. nov. (Bivalvia: Cardiidae) and its relatives from the Lusitanian Basin (Portugal). *Neues Jahrbuch fur Geologie und Palaeontologie Abhandlungen* **258**: 167–184.

Schultz O & Piller WE 2003 *Catalogus Fossilium Austriae – ein systematisches Verzeichnis aller auf österreichischem Gebiet festgestellten Fossilien*. Band 1, Teil 2 Bivalvia neogenica (Lucinoidea-Mactroidea). Verlag der österreichischen Akademie der Wissenschaften, Wien. 306 pp.

Poorten JJ Ter 2005 Outline of a Systematic Index – Recent Cardiidae (Lamarck, 1809). *Visaya:* 13 pp.

Thunell RC, Williams DF & Kenneth JP 1977 Late Quaternary paleoclimatology, stratigraphy and sapropel history in Eastern Mediterranean deep-sea sediments. *Marine Micropaleontology* **2**: 371–388.

Tremlett WE 1950 English Eocene and Oligocene Cardiidae. *Journal of Molluscan Studies* **28**(4–5): 115–133.

Zachos J, Pagani M, Sloan L, Ellen Thomas E & Billups K 2001 Trends, rhythms, and aberrations in global climate 65 Ma to Present. *Science* **292**: 686–693.