

# History and description of *Vasticardium mindanense* (Reeve, 1844) (Bivalvia: Cardiidae), compared with *V. compunctum* Kira, 1959, *V. ngai* Thach, 2016, *V. kengaluorum* (Voskuil & Onverwagt, 1993) and *V. rubicundum* (Reeve, 1844)

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**KEYWORDS.** *Vasticardium mindanense* group. Indo-Pacific cardiids, morphometric characteristics, bulge area, standardized quadrat (SQ) analysis, revision of *Vasticardium ngai*.

**ABSTRACT.** *Vasticardium mindanense* is described from the Philippines. *Vasticardium kengaluorum* is described from Guadalcanal, the Solomon Islands. *Vasticardium compunctum* is a Japanese species. *Vasticardium rubicundum* is basically an East African species. *Vasticardium ngai* is from Vietnam. The description of the holotype of *V. ngai* is revised. The morphology of the five species is described and illustrated. Statistical tests support the division into species analyzed in standardized quadrates referred to as SQ analysis. The area measured from dent 8 to 16 is called the bulge, characteristic of this group. *Vasticardium compunctum* is significantly different from the other species regarding this character.

## INTRODUCTION

A wrong type locality has caused more than a century of confusion regarding the Indo-Pacific group of *Vasticardium mindanense* (Reeve, 1844). Reeve described and illustrated an American cardiid as if it came from the Philippines. The famous shell dealer H. Cuming had obviously mixed one specimen from Florida with two specimens from the Philippines, which caused the problem. Reeve selected the American species, which he described & illustrated.

Twelve years later, Shuttleworth (1856) described the widespread western Atlantic bivalve *Cardium egmontianum*, which clearly is identical with the specimen previously described by Reeve as *C. mindanense*.

Voskuil & Onverwagt (1993) tried to solve the problem by removing the name *C. mindanense* from usage for the Indo-Pacific species. They introduced a new species *Acrosterigma kengaluorum*. They considered the Western Atlantic species *Cardium egmontianum* a junior synonym of *C. mindanense* and designated *Cardium egmontianum* "holotype" of *C. mindanense*.

Vidal (1998) disagreed, he examined the specimens of *Cardium mindanense* in the NHMUK collection and selected a lectotype from the two Philippine specimens. Vidal solved the problem of Indo-Pacific type material of *Cardium mindanense*, but he introduced another problem. He claimed that there was only one species, viz. *Vasticardium rubicundum* (Reeve, 1844). He regarded the three species *Cardium mindanense* Reeve, 1844, *Vasticardium compunctum* Kira, 1959, and *Acrosterigma kengaluorum* Voskuil & Onverwagt,

1993 synonyms of *C. rubicundum* Reeve, 1844 (Vidal, 1999).

Lee & Petit (2007) also disagreed with Voskuil & Onverwagt (1993) and proposed that their act should be declared invalid.

Finally, in 2008, the lectotype designation proposed by Vidal (1998) was accepted by ICZN. (Opinion 2197. Case 3341). The so-called holotype of *C. mindanense* in MHMUK was declared a senior synonym of the valid species *C. egmontianum* Shuttleworth, 1856. In addition, ICZN declared *V. mindanense* valid and the specimens selected by Vidal as lectotype and paralectotype. In this paper I maintain that the lectotype and paralectotype of *Vasticardium mindanense* (Reeve 1844) are from Mindanao, the Philippines. *Vasticardium kengaluorum* occurs in Guadalcanal, the Solomon Islands and possibly in Papua New Guinea, *V. compunctum* is from islands in southern Japan, *V. rubicundum* is an East African species studied here from Tanzania and Mozambique, while *V. ngai* is recorded from Vietnam.

## MATERIAL AND METHODS

**Material.** Adult and subadult specimens of *Vasticardium compunctum*, *V. kengaluorum*, and *V. rubicundum* were provided by Jan Johan ter Poorten who also provided a number of photos of the lecto- and paralectotype of *V. mindanense*, NHMUK, London. Photos of type material of *V. compunctum* from Japan (Hylleberg, 2004, courtesy of the late J. Vidal). *V. ngai* was collected by Kaare Hylleberg and supplemented by two specimens courtesy of J.J ter Poorten and NBC. The holotype of *V. ngai* was on loan from MNHN, Paris.

**Methods.** Numbered dents begin at the first rib on the posterior side of shells. Interior views of shells were scanned on a high-resolution flatbed scanner to ensure that shells were horizontal. Shell dimensions were analysed according to Hylleberg (2014, 2015) and referred to as SQ analysis. The nymph was turned into horizontal position and the image reduced to fit into a 10 x 10 cm square. Horizontal and vertical lines were drawn. The bottom part of the square was extended to accommodate the elongated ventral part of the valve. A line touching the anterior and posterior laterals marks the inclination relative to the horizontal nymph line. Horizontal and vertical dimensions were measured on hard copies. One mm corresponds to 1% of the measurement. Scanned specimens were converted to grayscale “find edges” in Photoshop. A line from tip of dent 8 to dent 16 marks the area referred to as the bulge (Fig. 1K).

**Statistical data.** Means and standard deviations according to:

(<https://www.easycalculation.com/statistics/standard-deviation.php>). Analysis of variance between groups (ANOVA) according to:

(<http://www.physics.csbsju.edu/stats/anova.html>).

#### ABBREVIATIONS

#### Depositories

JH: collection of Jorgen Hylleberg.

JJTP: collection of Jan Johan ter Poorten.

NBC = RMNH, Naturalis Biodiversity Center, Leiden, The Netherlands.

NHMUK: Natural History Museum, London, United Kingdom.

NMHN: Muséum national d'Histoire naturelle, Paris, France.

NMR: Natural History Museum, Rotterdam, The Netherlands.

OCM: Osaka City Museum (Natural History), Osaka, Japan.

#### Other abbreviations

L: length measured along the y axis

bu: bulge measured from dent 8-16

s.d.: standard deviation

SQ: standard square analysis

X: width, horizontal bulge measurement, the x-axis.

Y: length, vertical bulge measurement, the y-axis.

**Ral:** anterior laterals of the right valve. **Ral 1:** tooth close to the shell margin. **Ral 2:** small tooth or swelling at the base of the junction of Ral 1 and Ral 3. **Ral 3:** large posterior tooth. Horizontal dimensions. **AK:** anterior side of shell to umbo. **KL:** umbo to end of the nymph. **LB:** end of the nymph to posterior side of shell. Vertical dimensions: **BI:** top of shell to horizontal nymph line. **BD:** horizontal nymph to bottom line of the standard square. **DF:** part of shell outside the standard square. °T = inclination of anterior shell part.

#### SYSTEMATIC ACCOUNT

Family **CARDIIDAE** Lamarck, 1809

Genus *Vasticardium* Iredale, 1927

Type species: *Cardium elongatum* Bruguière, 1789, by original designation, Indo-West Pacific.

*Vasticardium mindanense* (Reeve, 1844)

Fig. 1A-N, Tab. 1

*Cardium mindanense* Reeve, 1844: pl. 4, fig. 19 (err. = *C. egmontianum* Shuttleworth, 1856).

*Trachycardium* (*Vasticardium*) *mindanense* (Reeve, 1844) — Springsteen & Leobrer, 1986: 306, pl. 87 fig. 2. *Vasticardium mindanense* (Reeve, 1844) — Hylleberg, 2004: vol. 1, p. 127, fig. 19, Vol. 2 p. 627, vol. 3 p. 857, 858, 923; Ter Poorten, 2011: pl. 1093 figs 2-3.

*Vasticardium rubicundum* (Reeve, 1844) — Vidal, 1998: figs 18-20.

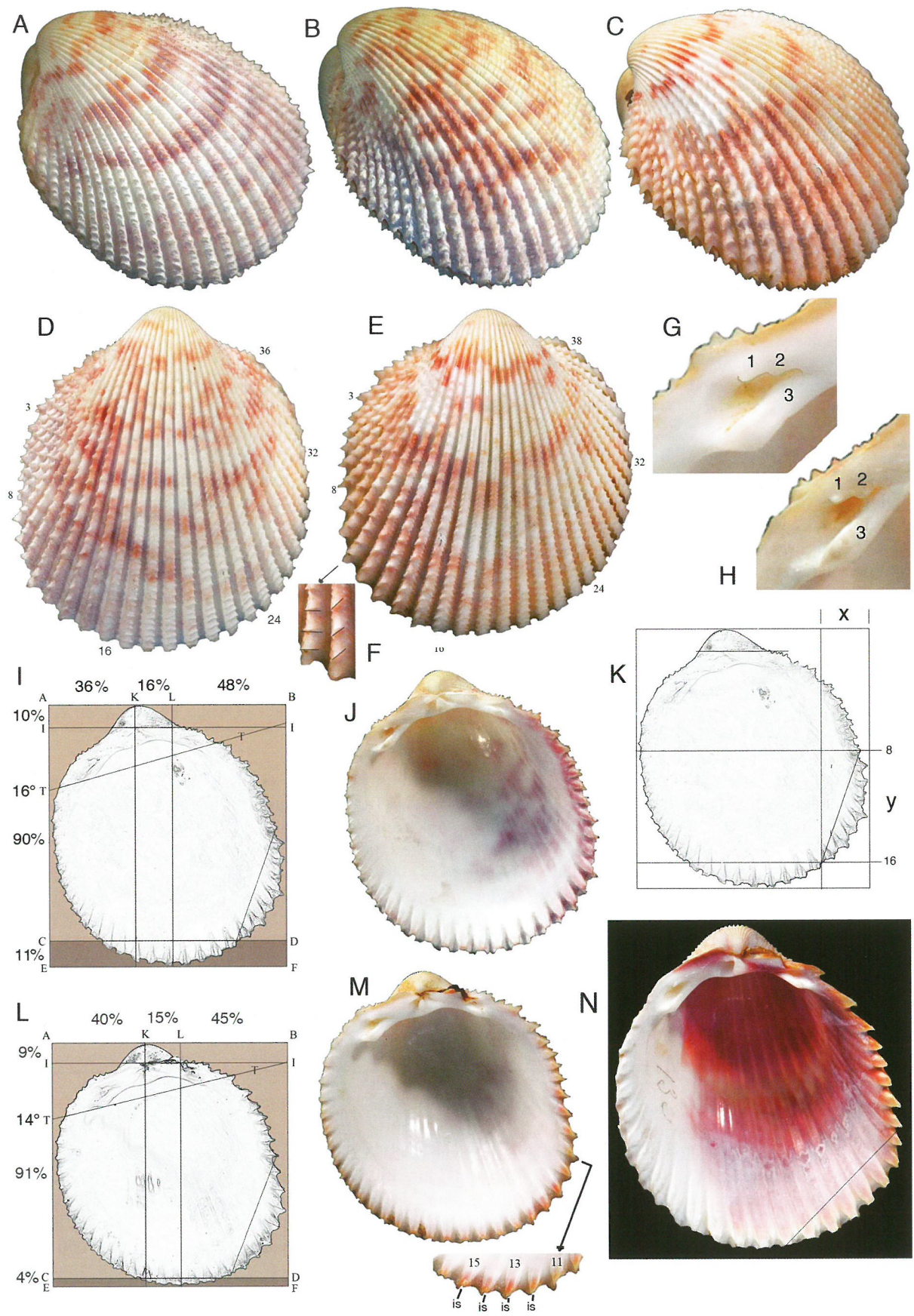
**Type material.** Lectotype and two paralectotypes NHMUK 1978.124, selected by Vidal (1998: 118, figs 18-19; ICZN Opinion 2197).

**Type locality.** Cagayan, Island of Mindanao, Philippines (found among sand at low water).

**Distribution.** It is likely that it has a wider distribution in areas of the Coral Triangle. It has been reported from other parts of the Philippines (Ter Poorten, 2011).

**Figure 1.** *Vasticardium mindanense* (Reeve, 1844)

**A.** Oblique anterior view. **B.** Posterior view. **C.** Oblique posterior view. **D.** Exterior, right valve. **E.** Exterior, right valve. **F.** Rib 11 & 12 enlarged. **G.** Right valve, anterior laterals 1-3 enlarged. **H.** Right valve, anterior laterals 1-3 enlarged. **I.** SQ analysis. **J.** Interior view. **K.** Bulge analysis, horizontal (x), and vertical (y) measurements from dents 8 to 16. **L.** SQ analysis. **M.** Interior view, dents 10-16 enlarged, is = interspace. **A-B & D, H-K.** Lectotype, NHMUK reg. 1978.124, 40 mm. **C, E, G & L-N.** Paralectotype, NHMUK reg. PLT I 1978.124, 37 mm. Photos courtesy of Jan Johan ter Poorten. **N.** Bulge line shown.





**Diagnostic characters.** Umbo white (Fig. 1C, E). Large height of umbo (% BI, Tab. 1). Small bulge area (Tab. 1). Arrangement and shape of scales differ from the nearest relative *Vasticardium kengaluorum* (Figs. 1C & 4L).

**Material examined.** Photos of lectotype and paralectotype. Lectotype 40 mm. Paralectotype 38.2 mm, slightly worn, without periostracum.

**Description.** Exterior colours, lectotype: broken, red-brown stripes and spots across shell surface, except posterior slope (Fig. 1D). Paralectotype: fewer, red-brown stripes and spots. Posterior slope light red brown (Fig. 1E).

Interior colours, lectotype: rose-purple on dents **1-16**, blackish purple spots and blotch below a weaker colour obliquely across shell and below umbo (Fig. 1J). Paralectotype: dents **9-16** red streaks on tip of dents, resemble lacquered finger nails (Fig. 1M, enlargement).

Exterior, lectotype (Fig. 1A, B, D). Ribs **1-3** spaced, scales across rib tops, flanks obscure. **4-8** tips on a slightly curved line. **9-11** scales across rib tops, anterior flanks with fine lists from interspaces to rib tops. **12-15** orientation of scales turn increasingly oblique relative to rib axis (Fig. 1F). The scales span half of the rib tops, anterior flanks with distinct lists. **16** obscure scales. **17-32** scales replaced by increasingly distinct crossbars connecting the posterior and anterior flank lists. **33-36** anterior slope, rib tops dorsally with elevated crossbars.

Exterior, paralectotype (Fig. 1C, E), similar to lectotype except tips of ribs **4-8** are on a more vertical line. **12-16** Angle of scales on ribs change from rib 11 to rib 12 (Fig. 1F). **17** obscure scales.

Interior, lectotype, SQ analysis (Fig. 1I). Dents **1-3** spaced (Fig. 1J), **4-8** close together, scales projecting. **9-15** bulge slightly projecting (Fig. 1L, Tab. 1). **16-28** anterior and posterior flanks project similarly. **29-36** flanks only slightly projecting. RAL 1-3 distinct (Fig. 1H). - Paralectotype (Fig. 1L, M). Pattern of dents, including RAL 1-3 similar to lectotype.

**Remarks.** Reeve called it “The Mindanao cockle” in the original description of the *Cardium mindanense*. However, the rib number of the pictured specimen is

only 29 (“ribs nine and twenty in number”, Fig. 1N) and the colour of the interior (“stained on the posterior side with deep purple”) is valid for the Caribbean cardiid *C. egmontianum* Shuttleworth, 1856.

*Vasticardium compunctum* Kira, 1959

Fig. 2A-M. Fig. 7C. Fig. 8C. Tab. 1

*Vasticardium compunctum* Kira, 1954: 111, pl. 55, fig. 9 (*nom. nud.*).

*Vasticardium compunctum* Kira, 1959 (Kuroda, MS): 139, pl. 55, fig. 9 (with short description in Japanese).

*Vasticardium arenicola* (Reeve, 1845) — Kuroda et al. 1971: 398-399, pl. 89 figs 1-2.

*Vasticardium compunctum* Kira, 1959 — Bieler & Petit, 1990: 142; Huber, 2010: 294, fig.

*Acrosterigma compunctum* — Kubo & Kurozumi, 1995: 182, fig. 5.

*Acrosterigma* (V.) *compuncta* (Kira, 1959) — Higo et al., 1999, p. 470.

*Vasticardium rubicundum* (Reeve, 1844) — Vidal, 1998: 117-122 (*pars*).

*Vasticardium compunctum* Kira, 1954 — Hylleberg, 2004, vol. 2: 446, vol. 3: 859.

NOT: *Vasticardium compunctum* Kira, 1969 — Matsukuma, 2000: 949, pl. 472 fig. 5 [= *Vasticardium pectiniforme* (Born, 1780)].

**Type material.** Syntype in Osaka City Museum (Natural History), Japan. Coll. Kira. (Fig. 2A-C). Considered the holotype by Vidal (1998).

**Type locality.** Amami Oshima Isl., between Kyūshū and Okinawa, Japan.

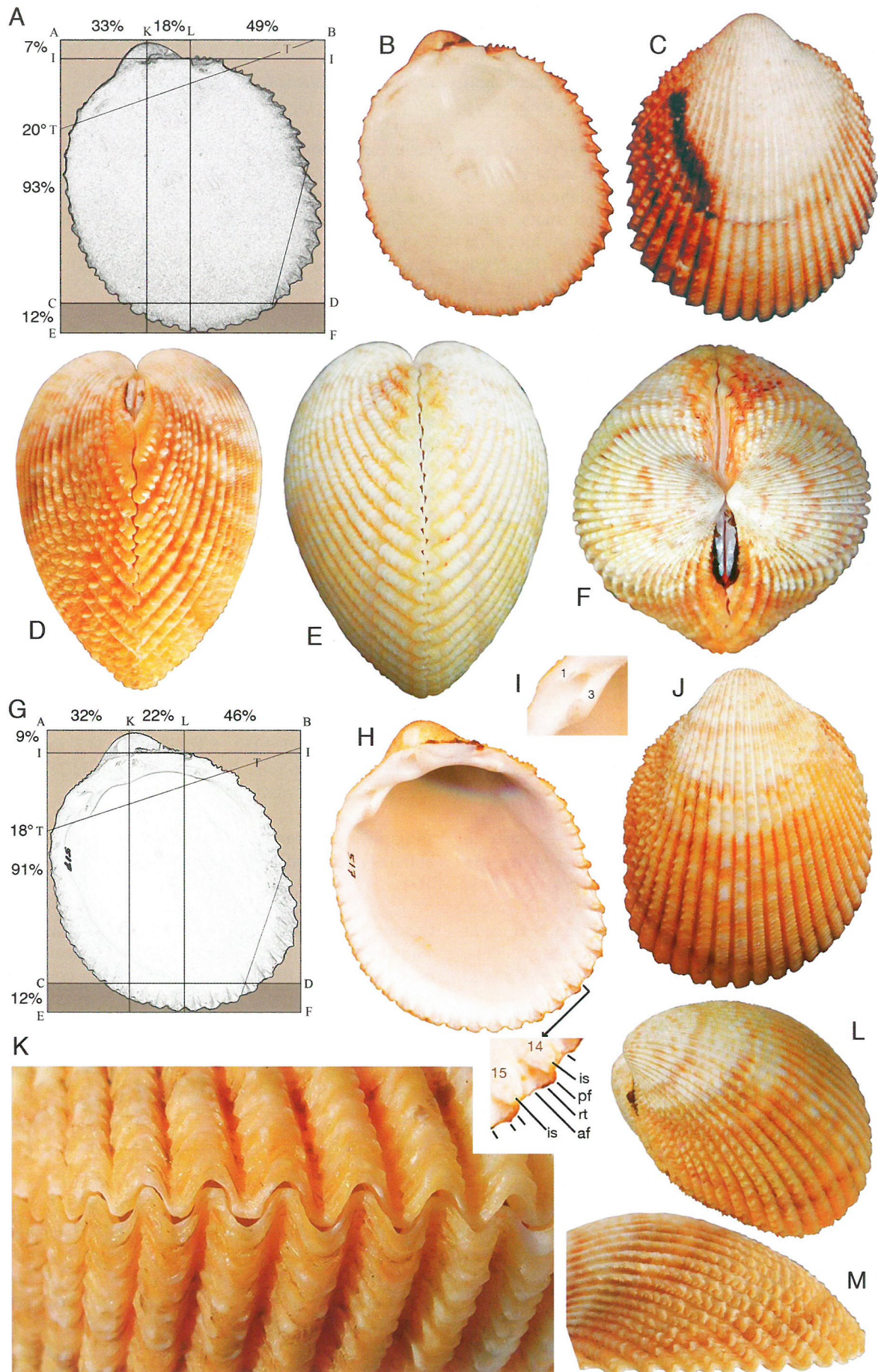
**Distribution.** Higo et al. (1999) only mention this species from the chain of islands South of Japan and not from Honshu. This suggests that it may not belong to the Japanese fauna province.

**Material examined.** Syntype, photos A-C. JJTP 55, 35 ribs, 42 mm. JJTP 55-1, 37 ribs, 40 mm. JJTP 140, 35 ribs, 39 mm. JJTP 517, topotype, 39 ribs, 43.5 mm. JJTP 2453, topotype, 33 ribs, 39.3 mm. JJTP 2454, topotype, 35 ribs, 39.3 mm. JJTP 2454-2, 35 ribs, 37.4 mm.

**Figure 2.** *Vasticardium compunctum* Kira, 1954

A. SQ analysis, bulge line shown. B. Interior view, right valve. C. Exterior view. D. Posterior view. E. Anterior view. F. Apical view. G. SQ analysis, bulge line shown. H. Interior view, right valve. Dents 14-15 enlarged: is = interspace, pf = posterior flank, rt = rib top, af = anterior flank. I. Ral area enlarged. Lamellae 1 & 3 marked. J. Exterior view. K. Vertical view, bulge area enlarged. L. Oblique view, right valve. M. Right valve, lateral view. - A-C. Syntype in Osaka City Museum (Natural History), Japan, photos courtesy of J. Vidal. D-F. JJTP coll. 517, 43.5 mm. G-M. JJTP coll. 55, 42 mm.





**Diagnostic characters.** Yellow colour of adult external shell. Nymph wide (% KL Fig. 7C). Small scales on posterior part up to rib 13, thereafter obscure scales until ribs 15-16. Highest relative shell length (% DF Fig. 7C). Small bulge area (Fig. 8C, Tab. 1C).

**Description.** Exterior colours: basically yellow, but more whitish on subadult and juvenile parts (Fig. 2F, J). Anterior slope much lighter coloured than posterior slope (Fig. 2D-E). Brown stripes and spots, more intense on posterior slope, very dark brown blotch on posterior slope with black vertical stripe (Fig. 2C). This stripe is not found on other specimens (Fig. 2J). The brown colour is supposedly intensified by deposition of iron-manganese picked up from the anaerobic part of sediment.

Interior colours: white, with a light yellow hue under umbo (Fig. 2B, H). The Figs. display too dark interior colour because of desired contrast created in Photoshop.

Exterior shell (Fig. 2C-F, J-M). Ribs **1-3** spaced, scales across rib tops, posterior flanks lists obscure, anterior flank lists distinct and fused with scale. **4-9**: scales low, spanning the rib tops, rectangular-square with a shallow ventral cavity. **10-11**, low scales on posterior side of ribs, anterior flanks with coarse lists from interspaces to poorly marked rib tops. **12-16**: low scales, positions vary from spanning half the rib tops to spanning the whole rib top. Anterior flanks with distinct lists, scales obscure on rib 16. **17-31**: scales replaced by increasingly distinct crossbars connecting the posterior and anterior flank lists. **32-34**: anterior slope, rib tops with broader and taller crossbars. **35**: obscure

Interior shell (Fig. 2A-B, G-I). Dents **1-3**: spaced, scales seen as small knobs along the edge. **4-8**: close together, tips on a straight line, scales project a little along the edge (Fig. 2B, H). **9-16** posterior flanks slightly longer than anterior flanks (Fig. 2 H right valve enlargement: is = interspace at centre of dents, pf = posterior flank, rt = rib top, af = anterior flank. **17-29**: both flanks similar length. **30-35**: dents only slightly projecting. **RAL 2**: obscure (Fig. 2 I). Small bulge (Fig. 2 A, G, Fig. 8 C, Tab. 1).

**Remarks.** Kira (1954) coined the species name *compunctum*, but did not describe the species i.e.

*nomen nudum* (Bieler & Petit 1990). Kira (1959) gave the first valid description and is therefore the author.

***Vasticardium ngai* Thach, 2016**

Figs 3-4, 7B, 8B, Tab. 1

*Vasticardium rubicundum* (Reeve, 1845) — Hylleberg & Kilburn, 2003: 185, pl. 4 fig. 16.

*Trachycardium rubicundum* (Reeve, 1844) — Xu & Zhang, 2008: 143, fig. 433 (Hainan record, S. China).

*Trachycardium rubicundum* (Reeve, 1844) — Xu, 2011: 145-146, fig. 100.

*Vasticardium ngai* Thach, 2016: 81-82, figs 21, 481-486.

**Type material.** Holotype, MNHN-IM-2000-31887.

**Type locality.** Nha Trang area, Khanh Hoa Province (Central Vietnam), 15-20 m.

**Distribution.** Studied from Khan Hoa Province, South Central Vietnam, but there is also a Hainan record, S. China (as *V. rubicundum*).

**Material examined.** Holotype, MNHN-IM-2000-31887; RMNH, ZMA. MOLL. 185787 ex coll. Kool 2002; JJTP 4712 (marked JH 2955), 35 ribs, 44.1 mm; JJTP 3803, 37 ribs, 31.3 mm; RMNH, ZMA.MOLL.185787 ex coll. Kool 2002; JJTP 4712 (marked JH 2955), 35 ribs, 44.1 mm; JH 2837, 38 ribs, 45.7 mm. With periostracum; JH 2957, LV, 37 ribs, 41.9 mm; JH 2957, RV, 36 ribs, 34.1 mm; JH 2958, 36 ribs, 36.6 mm; JH 2855, 36 ribs; JH 2838, 35 ribs; JH 2839, 36 ribs.

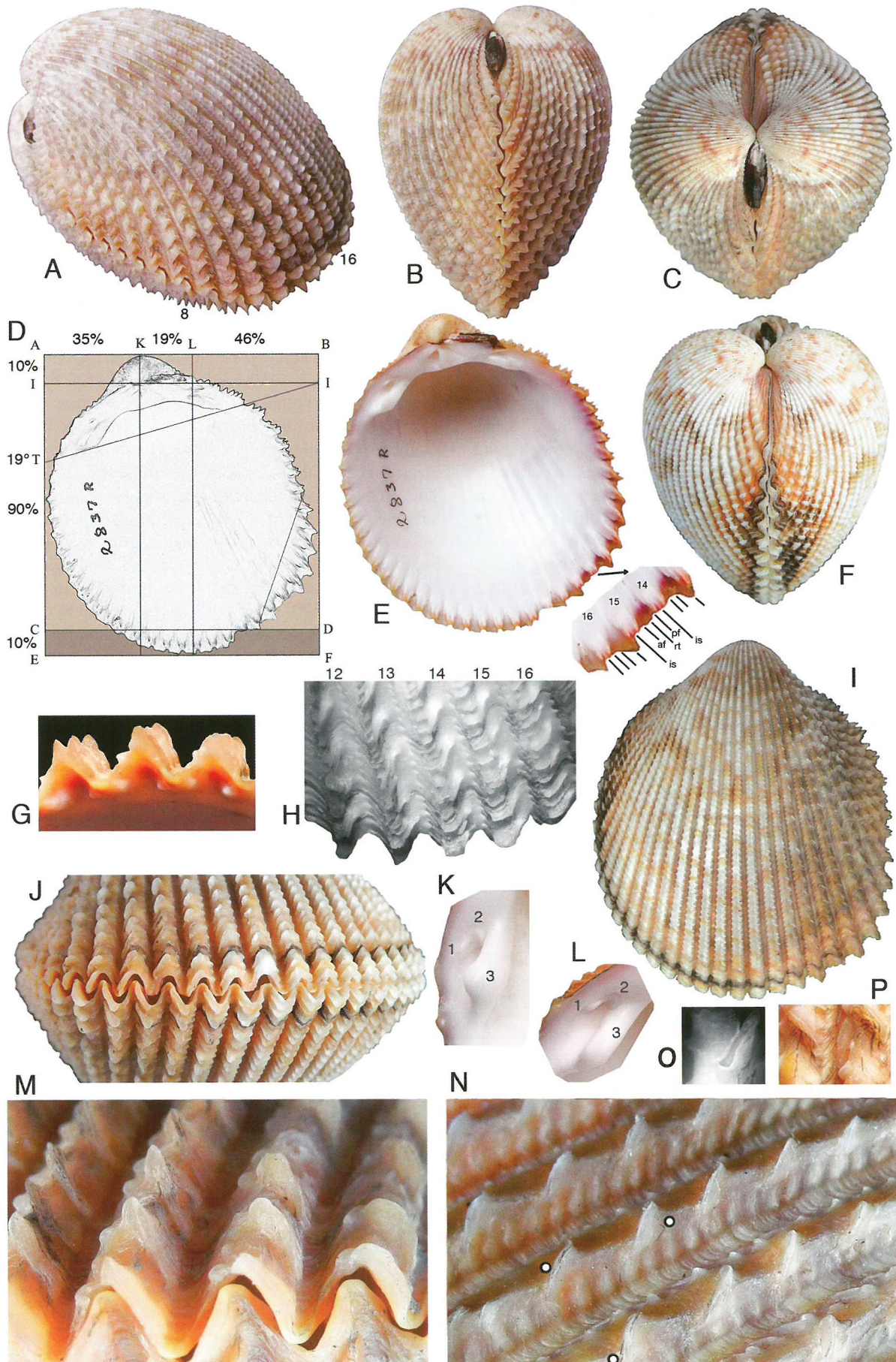
**Diagnostic characters.** Scales large, flat, rib tops obliquely rounded (Fig. 3M). Prominent bulge (Fig. 3D).

**Description.** Colour with periostracum: umbonal area whitish with small brown spots (Fig. 3F). Lunule light brown (Fig. 3C). Rib area 1-2 brown colour continues with irregular purple brown stripes across white background. Area 3-16 purple-brown blotch on posterior slope and shell surface. Dark brown spots, mainly on posterior half, fewer and smaller spots on anterior half of adult shell (Fig. 3I).

**Figure 3.** *Vasticardium ngai* (Thach, 2016)

**A.** Oblique view, right valve exterior, ribs 8 & 16 of bulge. **B.** posterior view. **C.** Apical view, **D.** SQ analysis, bulge line shown. **E.** Interior view, right valve. Enlargement dents 14-16: is = interspace, pf = posterior flank, rt = rib top, af = anterior flank. **F.** oblique, anterior view. **G.** Dents of bulge, vertical view. **H.** Scales on bulge area. **I.** Exterior view, left valve. **J.** Bulge and ventral shell, vertical view. **K & L.** Ral 1-3, two angles. **M.** Bulge area enlarged, ventral view. **N.** Black rings on scales mark deciduous, dark, periostracal strands. **O.** Single scale, oblique, ventral view of scale cavity. **P.** Enlarged scales with dark brown periostracal strands. **A-P.** Deposited at PMBC 27931 (JH 2837), 38 ribs, 45.7 mm.







Inside: shell cavity light yellow under umbo, other parts white with weak purple-brown spots mainly on interspaces of posterior shell part. (Fig. 3E). Dents **1-2** without colour. **3-7**: purple interspaces and rib flanks. **8-16**: centre of interspaces with weak, red stripe, rib flanks purple. **16-37**: faintly coloured interspaces and flanks (Fig. 3E).

Exterior: **ribs 1-3**: widths gradually decreasing. Posterior flanks very low, without vertical sculpture. Erect scales across rib tops, base thickened and broad, distally flat and rounded. Heights decrease gradually from rib 1-3. Flanks nearly flat on rib 1, increasingly sloping on ribs 2-3. Oblique leaf-like lists, thickened, curved and fused with scales at base. Interspaces narrow. **4-8**: low, rounded tops. Posterior flanks very low, smooth border to interspace. Juvenile part of shell with small vertical bars distinct on pigmented background, irregularly distributed on the flank. Scales flat, rib tops obliquely rounded. Small scales present on juvenile part. Anterior flanks with long, oblique, leaf-like projections running nearly parallel to ribs. Interspaces: very narrow between ribs 4-6, larger between ribs 6-8. Striped across. **9-19**: tops of ribs sloping on ribs 10-18, narrow on 9-12, broader on 13-16. Posterior flanks sloping towards the interspace, 2-3 strong lists for each scale. Lists are broader at their bases. Scales start with a slender leg rooted at the interspace on the posterior side of ribs (Fig. 3G), oblique, broadly erect petal shaped in posterior view, rounded triangular in ventral view (Fig. 3N). The central part of scales depressed, resembling an oblong dish or gravy boat (3O). Scales span half the rib tops (Fig. 3M), size gradually decreasing until diminutive on rib 16-19 (Fig. 3J). Anterior flanks sloping towards the interspace, low, oblique legs of crossbars, enlarged at transition to rib tops, forming rows of knobs along the edges (Fig. 3H). Lower part of flanks swollen. Interspaces wider from rib 9, striation starts at rib 10. **20-31**: narrow, oblique, higher posteriorly. Posterior flanks erect. Scales absent. Anterior flanks slightly sloping. Interspaces faintly striped or smooth between ribs 26-31. Crossbars distinct, posterior and anterior legs sharp edged, protruding and connected across rib tops. **32-37**: tops rounded. Posterior flanks

increasingly flattened. Crossbars: gradually taller across rib tops, tallest on rib 37.

Interior: dents **1-3**: cone shaped dent, scales project along edge, interspaces well spaced (Fig. 3E). **4-7**: interspaces close together, scales project along edge. **8-16**: referred to as the bulge (marked on Fig. 3 D). Distance between dents increased. Dents stronger than other dents. **17-37**: outline wavy, rib flanks only slightly longer than interspaces (Fig. 3D).

**Lunule** small. - **Ral 2**: variable, spanning from small (Fig. 3K-L) to distinct in other specimens.

Rib numbers vary from 35-38.

**Remarks.** *Vasticardium ngai* does not display any highest or lowest values in comparisons encompassing the 5 species (Table 1). However, in the SQ analysis (Fig. 7B) means and confidence intervals do not overlap with the other species in the characters % KL and % DF. The dull brown colour and dark brown filaments on scales are good distinguishing characters in specimens with undamaged periostracum.

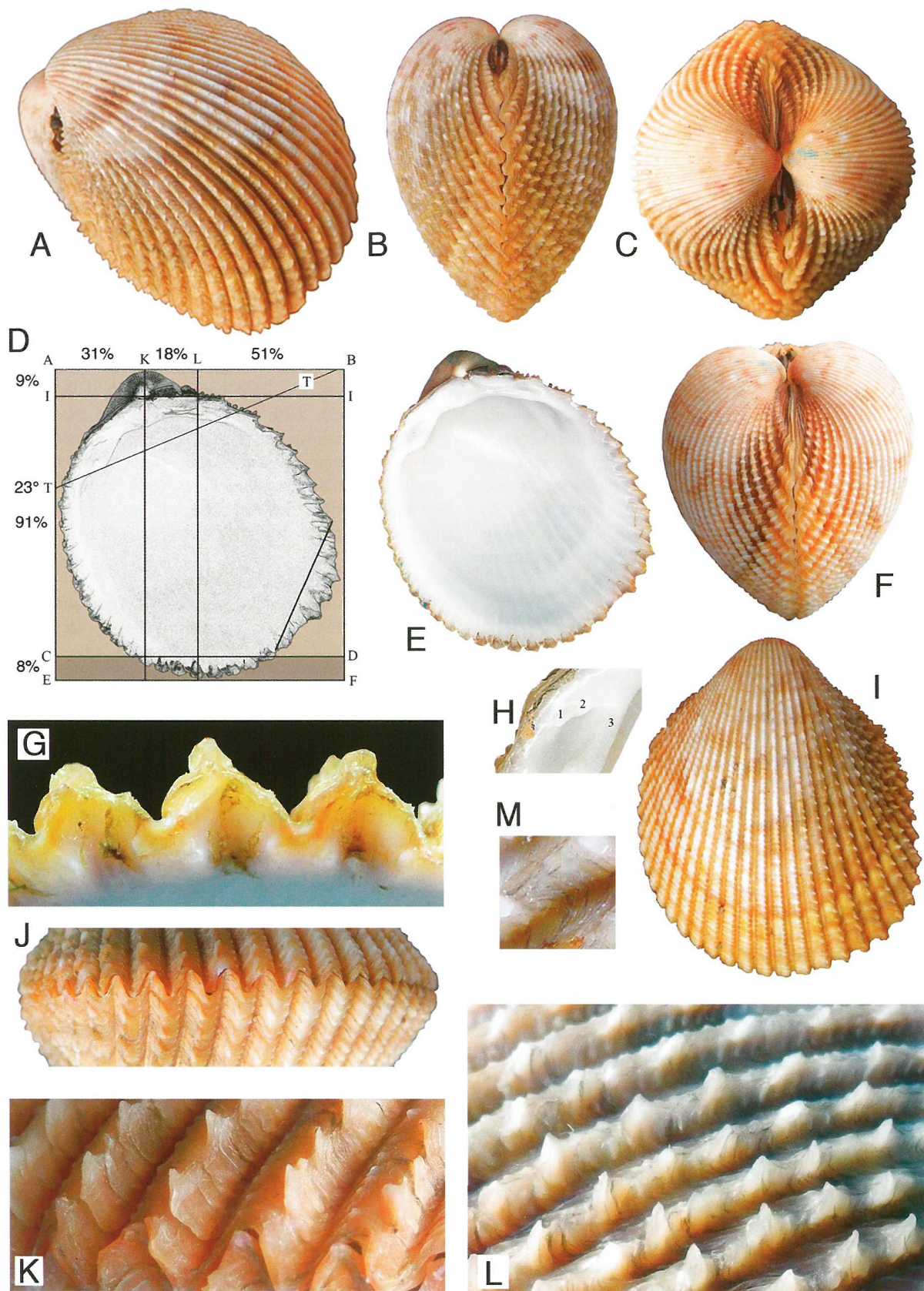
The Vietnamese specimens were originally considered new and prepared for the 2016 October issue of NOVAPEX. However, the publication was halted because Thach (2016) had published *Vasticardium ngai* in June and deposited the holotype in Paris (MNHM-IM-2000-31887). It was impossible to obtain the holotype within the available time frame in order to compare the above material with the type. According to Thach's description my material differed from his. However, after examination of the holotype (Fig. 4) I have concluded that many of the supposed differences could not be found. They were a result of Thach's inaccurate description and the unavoidable intraspecific variation. Below, I have extracted sentences from the original description of the holotype of *V. ngai*. My comments are within brackets:

- Cardiids have two cardinal teeth at each valve and three lateral teeth at right valve, two laterals at left valve (*three right lateral teeth is not valid for cardiids in general*).

- Sculpture consisting of about 30 inverted V-shaped radial ribs (*Thach also refers to 16 posterior plus 16 anterior ribs, but there are 35 ribs*).

**Figure 4.** *Vasticardium ngai* (Thach, 2016)

**A.** Oblique view, right valve exterior. **B.** Posterior view. **C.** Apical view, **D.** SQ analysis, bulge line shown. **E.** Interior view, right valve. **F.** Oblique, anterior view. **G.** Bulge area, vertical view. **H.** Ral 1-3, enlarged, right valve interior. **I.** Exterior view, left valve. **J.** Bulge and ventral shell, vertical view. **K & L.** Scales enlarged, posterior ribs, left valve. **M.** Scales with deciduous black stripes. **A-M.** Holotype, MNHN-IM-2000-31887, Paris, 35 ribs, 45.1 mm.





- posterior ribs bearing sharp oblique spines (*there are no spines but rounded or truncated scales which constitute the ornamentation*).

- anterior ribs are more curved and strongly nodulose (*it must be the edges of crossbars he refers to as nodulose*).

- Color exteriorly yellowish with pink stripes on radial ribs and interiorly white.

(*I only see some brown bands across the adult shell surface, but the colour may have faded since collection. The holotype has a weak yellow interior colour under umbo*).

- The new species is close to *Vasticardium hyllebergi* Thach, 2014 (*They are not close except they belong to the same family. It is like comparing apples with pears*).

- Posterior ribs: oblique spines (*there are only flat scales, which may appear as spines when seen from the edge*).

In conclusion, the intensity of the external colours constitutes the most conspicuous difference between the holotype of *V. ngai* and the other Vietnamese specimens. The holotype of *V. ngai* has a larger and more deep brown posterior brown blotch (Fig. 4) while the anterior half has a yellowish brown colour compared to a more greyish colour of the specimens shown in Fig. 3.

***Vasticardium kengaluorum***

(Voskuil & Onverwagt, 1993)

Fig. 5A-P, Fig. 7D, Fig. 8D, Tab. 1

*Acrosterigma kengaluorum* Voskuil & Onverwagt, 1993: 34, figs 1-2, 4.

*Vasticardium rubicundum* (Reeve, 1844) — Vidal, 1998: 117-122 (*pars*).

**Type material.** Holotype RMNH.MOL.56769, 37 mm.

**Type locality.** Honiara, Solomon Islands, Guadalcanal.

**Distribution.** Voskuil & Onverwagt (1993) also include Papua New Guinea in their distribution (about 50 km SE of Port Moresby, Kapakapa – paratypes 14-15 in coll. NMR Rotterdam).

**Material examined.** All specimens with worn periostracum. Guadalcanal. JJTP 2458, 36 ribs, 43.1

mm; JJTP 2455, paratype 1, 37 ribs, 27.8 mm; JJTP 2456, paratype 4, 36 ribs, 30.7 mm; JJTP 2456, paratype, 37 ribs, 28.3 mm; JJTP 138, paratype 6, 38 ribs, 31.6 mm; JJTP 138, paratype 7, 37 ribs, 21.6 mm; JJTP 2457 paratype 8, 37 ribs, 27.1 mm; JJTP 2457 paratype 9, 36 ribs, 26.7 mm; JJTP 2457 paratype 11, 37 ribs, 25.6 mm; JJTP 2457 paratype, 38 ribs, 25.6 mm; JJTP 430, 37 ribs, 24.9 mm.

**Diagnostic characters.** Umbo stained light rose to purple, ranging from weak to strong colour. Scales form a narrow line on the posterior rib side when viewed from shell edge. Scales on bulge ribs with 1-2 strong lists at bases.

**Description.** Colour, exterior: posterior part brown with darker blotches (Fig. 5A,L,M), central and anterior parts lighter colour with darker spots (Fig. 5H,K), anterior part light brown-greyish with brown spots (Fig. 5C). With worn periostracum: the brown colour is weaker on posterior slope and blotches, more pure white ground colour. Umbo stained rose to light blue (Fig. 5B,N). Interior: white, faint yellow-orange hue under umbo. Several subadult paratypes have a deep pink or purple umbonal cavity (Fig. 5G).

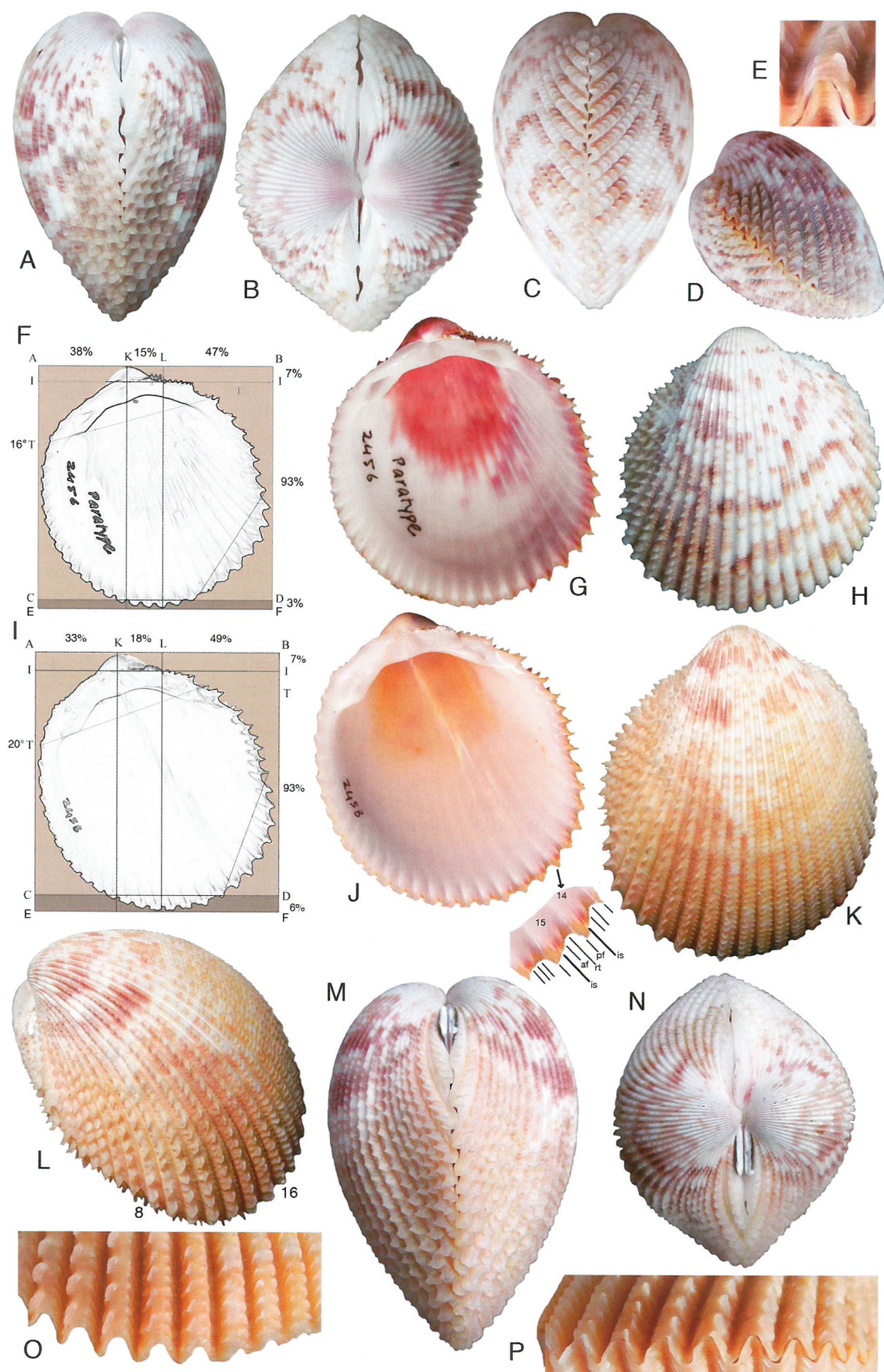
Exterior. Fig. 5, A-E, H, K, L-P.

Ribs **1-3**: rib tops rounded, widths & heights gradually decreasing (Fig. 5M). Posterior flanks very low, without vertical bars, at level with the narrow interspaces. Base of scales thickened and broad, slightly oblique to rib axis. Anterior flanks low, broad, leaf-like, flank projections point ventrally. Flanks on ribs 1-3 without vertical bars. Interspaces without striation. **4-8**: rib tops rounded. Posterior flanks very low, irregularly beaded at transition to interspace. Small, vertical, irregularly distributed lists extend from the interspace to the lower part of scales. Lists obscure on uncoloured surfaces in the juvenile part of the shell. Distinct when pigment is present. This pattern appears from rib 4 and onwards. Scales flat, heights smaller than scales on ribs 1-3. Distally truncated when observed from umbo toward ventral edge. Anterior flanks low, long leaf-like lamellae. Interspaces narrow, faintly striped across, bordered by long, oblique leaf-like projections from anterior flank. **9-16**: ribs 9-12 height gradually increasing. Anterior side of rib tops slope, like a broad shoulder on ribs 9-11, nearly horizontal on ribs 12-16 (Fig. 5O-P).

**Figure 5.** *Vasticardium kengaluorum* (Voskuil & Onverwagt, 1992)

**A.** Posterior view. **B.** Apical view. **C.** Anterior view. **D.** Oblique posterior view. **E.** Vertical view of scales. **F.** SQ analysis. **G.** Interior view, right valve. **H.** Exterior view, right valve. **I.** SQ analysis. **J.** Interior view, right valve. Enlargement: is = interspace, pf = posterior flank, rt = rib top, af = anterior flank. **K.** Exterior view, right valve. **L.** Oblique posterior view, the bulge ribs 8 & 16 marked. **M.** Posterior view. **N.** Apical view. **O.** Ventral edge enlarged. **P.** Ventral edge, vertical view. **A-H.** Paratype 5, JJTP coll. 2456, 28.3 mm. **I-P.** JJTP coll. 2458, 43.1mm.





Posterior flanks low, sloping towards the interspace, 1-2 strong lists at the base of scales. Lists thicker along the transition to interspace. In subadult shell, the lists appear as a beaded structure lining the interspace. Scales flat. Outline rounded square or with one corner curved. Scales increasingly parallel to ribs, aligned in a narrow vertical line on the posterior side (Fig. 5O). Very small scales on rib 16. Anterior flanks flat, with long leaf-like lamellae. Transition from rib top to the flank is marked by tiny terminal swellings of flank lists. The base of flanks without beaded structure. Interspaces wider from rib 9, striation of the space starts at rib 10 and continues until the last two ribs. **17-36:** rib tops flat and tilted from a high posterior to a lower anterior flank. Both rib flanks carry oblique lamellae projecting laterally. The corners of lamella resemble diminutive scales. Interspaces: wide and horizontally striped. Crossbars on ribs 22-36 strong and prominent across rib tops (Fig. 5 F). Dorsal edges of each crossbar broader and elevated, resembling a reversed tile roof. Rib tops overhanging.

Interior (Fig. 5F, G, I, J).

**Dents 1-3:** spaced, **4-8** close together. The bulge, **8-16**, well spaced, forming the bulge area (Fig. 5 F, I). **17** to last dent gradually smaller, the last two dents very small. **Right anterior laterals:** ral 1 distinct, ral 2 obscure, ral 3 distinct (Fig. 5G, J).

*Vasticardium rubicundum* (Reeve, 1844)

Figs. 6A-M, 7A, 8A, Tab. 1

*Cardium rubicundum* Reeve, 1844: Pl. IX, fig. 44.

*Cardium (Vasticardium) (Regozara) rubicundum* — Spry, 1964: p. 143, pl. 2 [sic! = *rubicundum*].

*Trachycardium rubicundum* (Reeve, 1844) — Kilburn & Rippey, 1982: p. 178, pl. 40, fig. 10; Abbott & Dance, 1986, p. 328, text fig.

*Trachycardium rubicundum* (Reeve, 1845) — Oliver, 1992: pl. 23 fig. 7a-b.

*Trachydardium rubicundum* (Reeve, 1844) — Steyn & Lussi, 1998: 222, fig. 900 [sic! = *Trachycardium*].

*Vasticardium rubicundum* (Reeve, 1844) — Vidal, 1998: 117-122, figs 12-14, 18-20, 27, 31. (*pars*); Hylleberg, 2004 Vol. 1: 132, pl. 9, fig. 44. Vol. 2: 744, Vol 3: 865, 926; Huber, 2010: 296, figured.

**Type material.** 3 syntypes NHMUK reg.no. 1978128.

**Type locality.** Zanzibar.

**Distribution.** Indian Ocean. Reported along the East coast of Africa from Zanzibar to South Africa, and the Red Sea.

**Material examined.** Photos of syntypes NHMUK 1 & 2 (Hylleberg 2004, Vol. 3: 865); JJTP 2269, 35 ribs, 46.1 mm; JJTP 3285, 36 ribs, 46.2 mm.

**Diagnostic characters.** Light rose ground colour with many red brown spots and stripes (Fig. 6J). Lunule raised, dark purple colour (Fig. 6I). Small %AK and high inclination °T (Fig. 6A). Large bulge area (Fig. 7A. Tab.1A).

**Description.** Colour. Exterior without periostracum, whitish purple. Many dark purple-brown stripes and blotches (Fig. 6C, G, H).

Interior. White with two more or less marked red stripes under umbo. Conspicuous red, elevated lunule (Fig. 6F, I). Dents intense red along the shell edge (Fig. 6B, E).

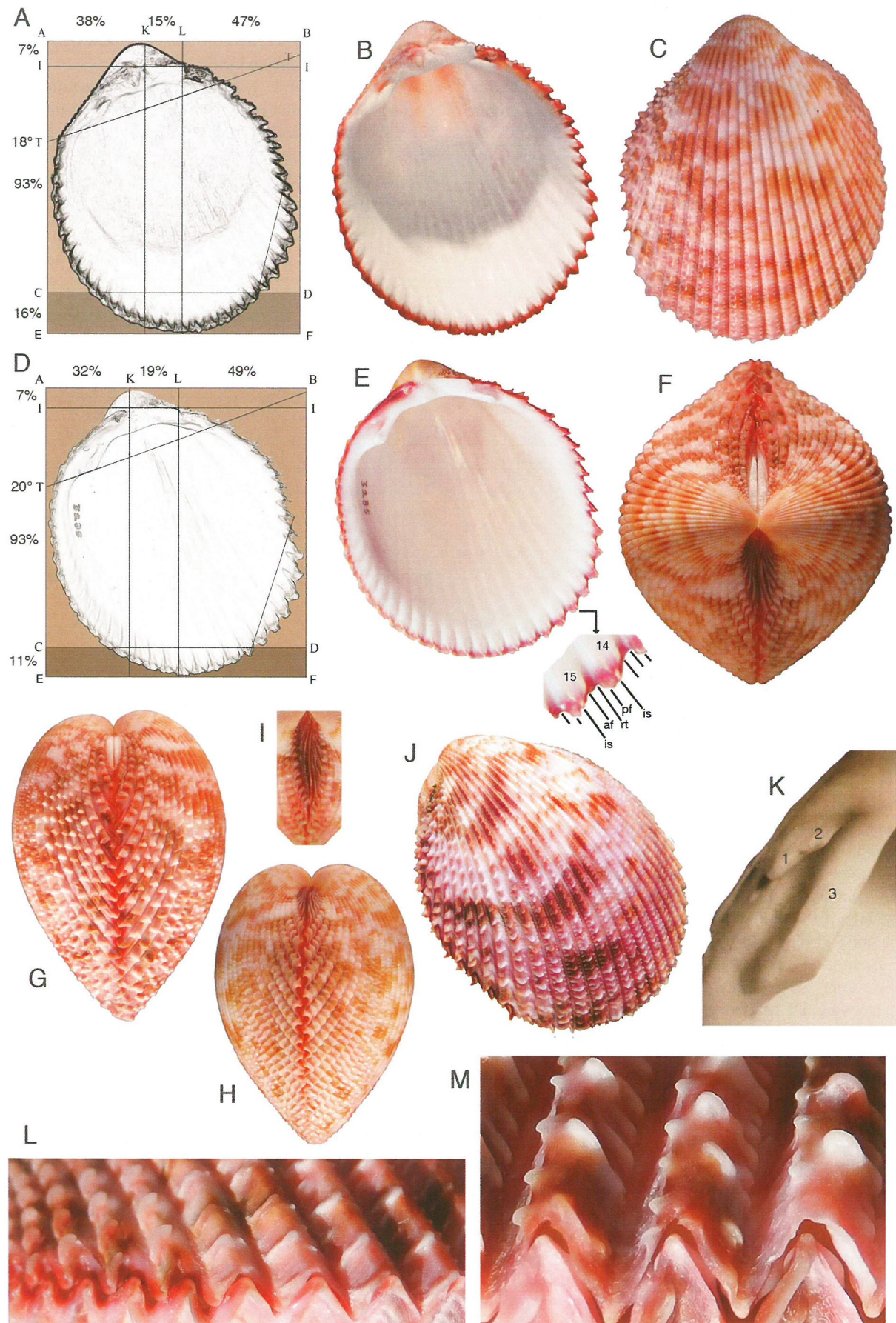
Exterior (Fig. 6C, F-J, L-M). Ribs **1-3:** close together, scales with truncated edges, across rib tops, posterior flanks lists obscure, anterior flank lists flat on level scales. **4-9:** scales low, spanning the rib tops, rounded edge with without ventral cavity. **10-11:** posterior flanks raised, low scales on posterior side of ribs, narrow rounded rib tops, anterior flanks with coarse lists from interspaces to rib tops, yielding a triangular appearance to rib profiles (Fig. 6L-M). **12-16:** scales increasingly low, spanning the posterior flank only to half the rib tops. Anterior flanks with distinct lists. Scales obscure on rib 16. **17-31:** scales replaced by increasingly distinct crossbars connecting the posterior and anterior flank lists. **32-36** crossbars larger, flattened, slightly raised at dorsal edges.

Interior (Fig. 6A-B, D-E). Dents **1-3:** spaced, scales seen as small knobs along the edge (Fig. 6B, E). **4-8:** close together, tips on a straight line (Fig. 6B, H). **9-16:** interspaces level with posterior flanks (Fig. 6E, enlargement), slightly shorter on dents 14-16. **17-29:** both flanks similar length. **30-35:** dents only slightly projecting. **RAL 2** obscure (Fig. 6K). **Bulge** large (Fig. 6A,D. Fig. 8A. Tab. 1A).

**Figure 6.** *Vasticardium rubicundum* (Reeve, 1845)

**A.** SQ analysis, bulge line shown. **B.** Interior view, right valve. **C.** Exterior view. **D.** SQ analysis, bulge line shown. **E.** Interior view, right valve. Dents 14-15 enlarged: is = interspace, pf = posterior flank, rt = rib top, af = anterior flank. **F.** Apical view. **G.** Posterior view. **H.** Anterior view. **I.** Lunule enlarged. **J.** Oblique view. **K.** Ral 1-3 extracted and enlarged from B. **L.** Ribs enlarged, bulge area to the right. **M.** Bulge ribs enlarged. **A-C & K:** Syntype NHMUK. **D-I:** JJTP 3285 46.2 mm., **JLM:** JJTP 2269 46.1 mm.







**Remarks.** Reeve (1844: 169) gave the following description of *Cardium mindanense* (verbatim): an extremely pretty species, remarkable for its vivid colouring and for the elaborate character of its sculpture. Shell oblong-ovate, very slightly oblique, radiately ribbed, ribs sharply convex, 37 in number, the anterior third portion squamously crenated, the middle portion obtusely scaled on both sides, the posterior portion obliquely tubercled; bright red, whitish towards the umbones, spotted with reddish brown margins edged with bright pinkish red

interiorly. (Hylleberg, 2004: 744). Vidal (1998) considered *Vasticardium mindanense* to be a synonym of *Vasticardium rubicundum* which he referred to as coloured with purple and pink. Two specimens of *V. rubicundum* from Tanzania and 2 from Mozambique is a low number. The confidence values become large compared to the other species (Figs. 7A, 8 A). However, the analyses indicate that *V. rubicundum* clearly differs from the geographically closest species *V. ngai* regarding %KL and %DF (Fig. 6A).

	A <i>V. rubicundum</i>	B <i>V. ngai</i>	Holotype <i>V. ngai</i>	C <i>V. compunctum</i>	D <i>V. kengaluorum</i>	Type mat. <i>V. mindanense</i>
%	n = 4	n = 11	n = 1	n = 9	n = 11	n = 2
AK	33.5 ± 3.4	34.2 ± 2.0	31	33.2 ± 1.7	<b>39,3</b> ± 3.8	38.0 ± 2.8
KL	17.5 ± 1.9	16.8 ± 2.1	18	<b>20.1</b> ± 2.0	15.3 ± 1.8	15.5 ± 0.7
BI	8 ± 1.4	8.6 ± 1.2	9	8.7 ± 1	7.7 ± 0.8	<b>9.5</b> ± 0.7
DF	11 ± 4,5	7.1 ± 3	8	<b>12.7</b> ± 1.8	4.2 ± 1.8	7.5 ± 4.9
°T	19.3 ± 1.0	18.4 ± 2.1	<b>23</b>	17.3 ± 2.4	14.5 ± 3.1	15 ± 1.4
Bu	<b>1329</b> ± 260	1288 ± 196	1058	1077 ± 131	1258 ± 155	1092 ± 119

Table 1. Measurements and ratios

DISCUSSION

Shell characters are related to size (age), and individual variation is pronounced. Hence, the ideal situation would be a high number of specimens from each locality and fully grown specimens, which is rarely the case. Statistical analyses can only be considered hints, such as ANOVA analyses (Figs. 7, 8). Many size classes are involved, e.g. in *Vasticardium kengaluorum*, where data are derived from subadults and one adult, while data for *V. rubicundum* and *V. compunctum* only stem from adults.

Another complicating factor in studies on distribution of species is related to events during low-sea-level stands of the Holocene. Barber et al. (2000) discussed genetic breaks, showing that populations of a stomatopod north and south of the Flores and Java Seas are distinguished by a broad genetic break perpendicular to Wallace’s line. Northern populations are significantly differentiated with genetically distinct populations in the bay of Tomini and in the Celebes, Flores and South China Seas, contradicting the hypothesis of strong connectivity among localities. These localities were partially enclosed during low-sea-level stands and have long been thought to be crucibles of species formation. It indicates that reef populations throughout Indonesia cannot simply be assumed to be interconnected units; biogeography and historical oceanography should be taken into account. Unfortunately there is a long way to go before molecular techniques can be applied on the cardiids in question. Until this happens we have to rely on traditional tools used to separate populations into

species, i.e. stick to the Linnean concept of classification.

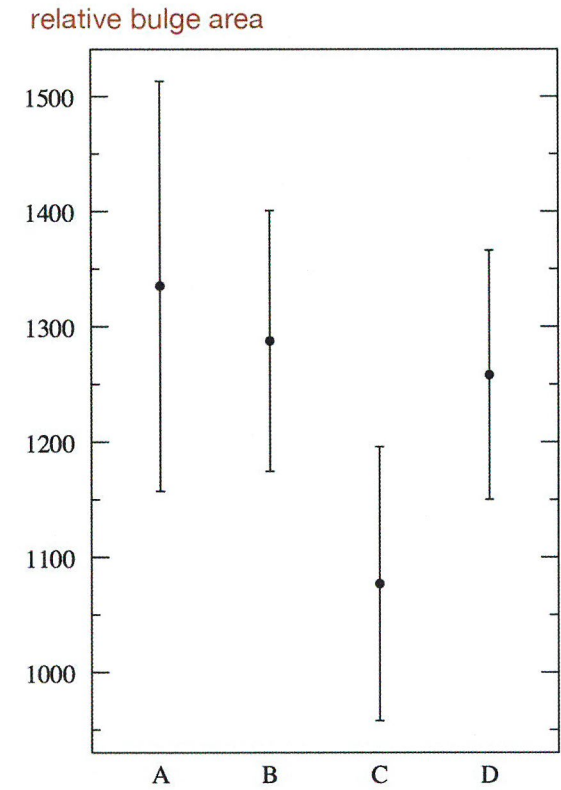
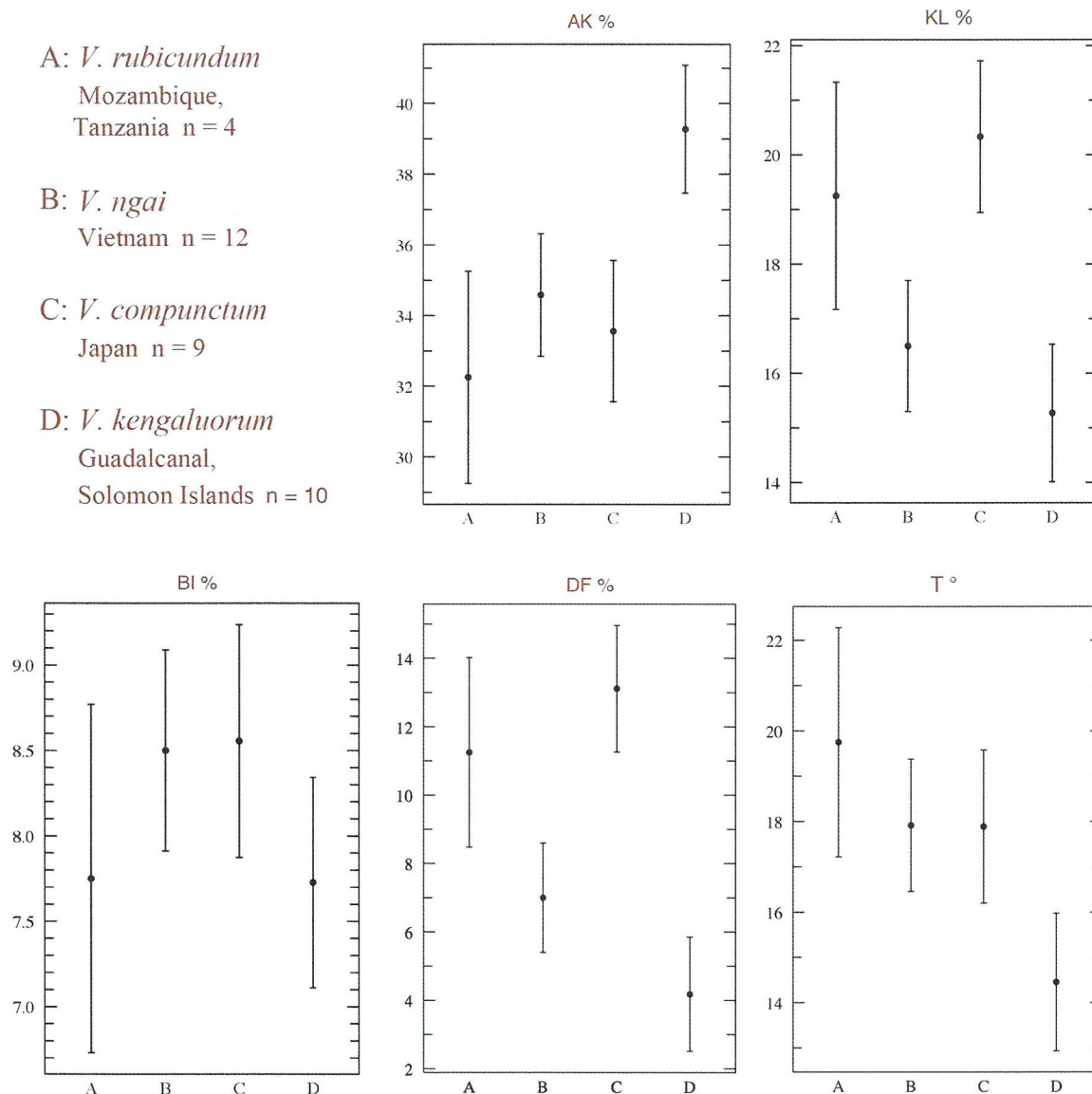


Figure 7. ANOVA data, relative bulge areas in SQ analysis. A = *Vasticardium rubicundum*, B = *V. ngai*, C = *V. compunctum*, D = *V. kengaluorum*. The holotype of *V. ngai* is not included (see Table 1).



**Figure 8.** ANOVA calculation of means and 95 % confidence intervals for AK, KL, BI, DF, and hinge inclinations °T. Species are listed A-D on the x-axis. Data expressed as percentages obtained in a horizontal pivot axis analysis in 10x10 cm squares. The means of each of the metrics AK, KL, and DF are significantly different  $P < 0.0001$ . All F-values  $> 1$ , highest for DF = 20.19. The holotype of *Vasticardium ngai* is not included (see Table 1).

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