Turkish Journal of Earth Sciences (Turkish J. Earth Sci.), Vol. 19, 2010, pp. 613–633. Copyright ©TÜBİTAK
doi:10.3906/yer-0901-12 First published online 22 October 2010

Taxonomy of Rudists from the Campanian Transgressive Sediments of Brašljevica, Donje Orešje and Sv. Martin, Northern Croatia

ALAN MORO, VLASTA ĆOSOVIĆ, JOSIP BENIĆ & JASMINA DOKMANOVIĆ

Department of Geology and Paleontology, Faculty of Science, University of Zagreb, Horvatovac 102A,
10000 Zagreb, Croatia (E-mail: amoro@geol.pmf.hr or vcosovic@geol.pmf.hr)

Received 27 April 2009; revised typescript received 28 August 2009; accepted 15 October 2009

Abstract: Rudists are common fossils in transgressive Upper Cretaceous deposits in three localities placed in northwestern part of Croatia. Their appearances coincide with the beginning of a transgressive sequence through floatstones-thickets. Within the rudist community, *Vaccinites* Fischer 1887, *Hippurites* Lamarck 1801 and *Hippuritella* Douvillé 1908 could be differentiated according to their general or generic morphological elements.

The age of deposits was obtained from the Sr-isotope composition of the rudist shells as well as the micro- and nannofossil community from sediments overlying the rudists-bearing sediments at the Donje Orešje and Brašljevica localities. According to this data the age of the transgressive sediments are determined as Early Campanian.

Morphological elements (ligamental ridge, pillars, inner diameter, length of the contour around the inner margin of the outer shell layer, and the ratio between this length and the distance between the sutures of the pillars) from the transverse shell sections permit possible definition of different species within the family Hippuritidae, Gray 1848. Transverse shell sections of analyzed *Vaccinites, Hippurites* and *Hippuritella* specimens show different values of measured morphological elements as well as their ratios which, subjected to cluster analysis (Ward's and Unweighted pair-group methods), represent grounds for possible taxonomic determination of the species *Vaccinites cornuvaccinum* (Bronn 1831) at all localities; *V. giganteus* (d'Hombres-Firmas 1838) and *V. vesiculosus* (Woodward 1855) at Brašljevica and Donje Orešje; as well as *Hippurites vidali* Matheron 1880 and *Hippuritella lapeirousei* (Goldfuss 1840) at Donje Orešje.

Key Words: Campanian, rudist taxonomy, transgression, hippuritid rudist, strontium isotope stratigraphy, northern Croatia

Brašljevica, Donje Orešje ve Sv. Martin'de (Kuzey Hırvatistan) Kampaniyen Transgresif Tortullarının Rudist Taksonomisi

Özet: Rudistler, Hırvatistan'ın kuzeybatısında yer alan üç lokalitedeki transgresif Üst Kretase çökellerinde yaygın olarak bulunan fosillerdir. İlk ortaya çıkışları, transgresif istifin başlangıcında yer alan yüzertaş katmanlarına karşılık gelir. Rudist topluluğu içersinde, *Vaccinites* Fischer 1887, *Hippurites* Lamarck 1801 ve *Hippuritella* Douvillé 1908, genel veya cinse ait morfolojik parametreler ile birbirlerinden ayrılabilir.

Donje Orešje ve Brašljevica lokalitelerinde çökellerin yaşı, rudist kavkılarının Sr-izotop içeriği ve rudistli tortulları üzerleyen sedimanlarda saptanan mikro ve nannofosil topluluklarından elde edilmiştir. Bu yaş verilerine göre transgresif tortulların yaşı Erken Kampaniyen'dir.

Kavkıların enine kesitlerinde tanımlanan morfolojik parametreler (ligament, piliyeler, iç çap, dış kavkının iç konturunun uzunluğu, bu uzunluk ile piliyelerin süturları arasındaki mesafenin oranı) Hippuritidae, Gray 1848 ailesinde farklı türlerin tanımlanmasını olanaklı kılar. Çalışılan *Vaccinites*, *Hippurites* ve *Hippuritella* türlerinin enine kavkı kesitleri farklı ölçülmüş morfolojik parametre değerleri ve oranlar sunar. Bu değer ve oranlar, *Vaccinites cornuvaccinum* (Bronn 1831)'un tüm lokalitelerde, *V. giganteus* (d'Hombres) ve *V. vesiculosus* (Woodward 1855)'un Brašljevica ve Donje Orešje'de ve *Hippurites vidali* Matheron 1880 ve *Hippuritella lapeirousei* (Goldfuss 1840)'nun Donje Orešje'de olası taksonomik tanımlamaları için bir zemin oluşturan Kümeleme analizi'ne (Ward ve Unweighted grup çifti metodu) tabi tutulmuştur.

Anahtar Sözcükler: Kampaniyen, rudist taksonomisi, transgresyon, hippuritid rudist, stronsiyum izotop stratigrafisi, kuzey Hırvatistan

Introduction

Rudists are common macrofossils in the Upper Cretaceous deposits in the northwestern part of Croatia. They lived as epibenthic suspension feeders (Skelton 1978) and occasionally formed vast biostromal congregations (Moro *et al.* 2002, 2008). Here we present data from transgressive sequences from three localities (Figure 1): Brašljevica (Žumberak Mt.), Donje Orešje (Medvednica Mt.) and Sv. Martin (Kalnik Mt.). Generic identification was based on morphological characteristics of the attached valve such as ligamental ridge, pillars, and position of the teeth (Dechaseaux & Coogan 1969; Steuber 1999). Free valves, with pores and oscules which are also morphological characteristics which permit different genera to be defined (Dechaseaux & Coogan 1969), are not preserved in analyzed specimens.

Representatives of the genus *Vaccinites* show specific values of the angle between the teeth and the ligamental ridge, as well as between the ligamental ridge and the P1 pillar. These angles were used as criteria in description and determination of hippuritids from the Southern Pyrenees (Vicens 1992), the Ostuni area (Laviano & Maresca 1992) and southern Istria (Moro & Ćosović 2004). Beside angles, hippuritids show specific values of the length of the contour around the inner margin. Steuber (1999, 2003) concluded that the mentioned morphological changes might be consequences of evolution.

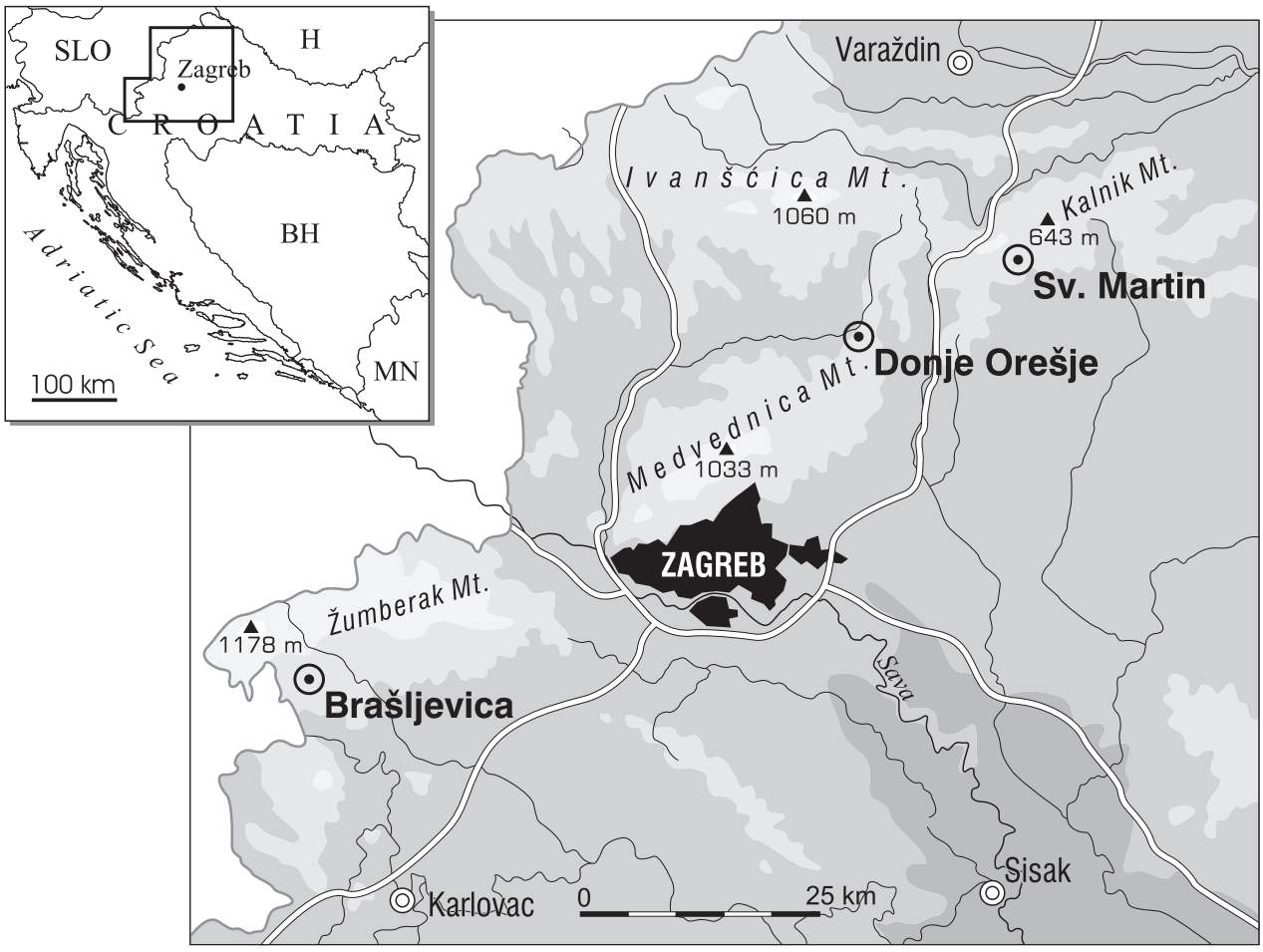

Figure 1. Situation map with investigated sites.

Lineages of species of hippuritid rudists have been proposed by Douvillé (1891) and Toucas (1903). Recent interpretations of lineages involve re-evaluation of the synonymy of several species (Vicens 1992; Simonpiétri *et al.* 1998; Steuber 1999; Simonpiétri & Philip 2000; Moro & Ćosović 2004).

In this work, the following characteristics of attached valves were used for identification of rudist assemblages at the species level: (1) angle between ligamental ridge and P2 pillar (Vicens 1992; Moro & Ćosović 2004) for hippuritids and vaccinitids (L/P2), (2) angle between P1 and P2 pillars for hippuritellids (P1/P2), (3) length of contour around the inner margin of the outer shell layer (U), (4) length of the distance between sutures of the ligamental ridge and pillar P2 (P0-P2) for vaccinitids and hippuritids, (5) distance between sutures of pillars P1 and P2 (P1-P2) for hippuritellids (Steuber 1999), (6) inner diameter (d) (Laviano & Maresca 1992), and area of transverse section (P). We have chosen these because they are the best preserved characteristics of the studied specimens.

All specimens, subjected to biostatistical, morphological, and strontium isotope stratigraphy analysis, were collected by different researchers (Koch 1918; Herak 1966; Polšak *et al.* 1978; Polšak 1979) and represent a part of the fossil collection of the Department of Geology (Zagreb).

The aims of this work is (1) to define the number of species within genera *Vaccinites* Fischer 1887, *Hippurites* Lamarck 1801 and *Hippuritella* Douvillé 1908 based on biostatistical and morphological analysis, (2) to determine the age of Brašljevica and Sv. Martin sediments based on microfossils, and (3) apply strontium isotope stratigraphy (SIS) (Steuber 2003), for more accurate age determination.

Geological Setting and Stratigraphy of Studied Sites

On all investigated localities, Upper Cretaceous deposits are in transgressive contact either with Upper Jurassic (Brašljevica), or Triassic (Donje Orešje and Sv. Martin) sediments. The Upper Cretaceous deposits at Brašljevica locality (Figure 2), 35 m thick, transgresively overlie Upper Jurassic deposits (Herak 1966, 1968). In vertical succession, Upper Cretaceous breccias with fragments of older rocks within wackestone-packstone matrix pass into wackestone-packstone, rarely grainstone limestones and marly sediments (Herak 1968; Pleničar & Premru 1970; Pleničar *et al.* 1975). Hippuritids which appear in wackestone-packstone limestones are *Vaccinites cornuvaccinum* (Bronn 1831), *V. inaequicostatus* (Münster, *in* Goldfuss 1840) and *V. oppeli* (Douvillé 1892) (Herak 1966). Along with rudists, wackestones-packstones contain foraminifera *Moncharmontia appeninica* (De Castro 1967) and *Scandonea samnitica* De Castro 1971. The nannofossils *Watznaneria barnesae* (Black, *in* Black & Barnes 1959), *Cribrosphaerella ehrenbergi* (Arkhangelsky 1912), *Qadrum gartneri* Prins & Perch-Nielsen, *in* Manivit *et al.* 1977, *Q. gothicum* (Deflandre 1959), *Q. sissinghii* Perch-Nielsen 1986, *Q. trifudum* (Stradner 1961) and *Cretarhabdus angustiforatus* (Black 1971) are in marly limestones. According to the micro- and nannofossils, the age of the sediments are considered as Early–Late Campanian.

Donje Orešje deposits (Figure 2) transgressively overly Upper Triassic limestones (Polšak 1979; Korolija *et al.* 1995). From the base to the top, 45-m-thick succession is made of floatstones with rare rudstones, and marly sediments and pelagic limestones at the top (Pošak 1979). Floatstones, beside corals, contain diverse rudist fauna determined by Polšak (1979). The following species were found: *Vaccinites inaequicostatus* (Münster, *in* Goldfuss 1840), *V. gigianteus* (d'Hombres-Firmas 1838), *V. vredenburgi* (Kühn 1933), *V. oppeli santoniensis* (Kühn 1948), *V. atheniensis* (Ktenas 1907), *V. sulcatus* (Defrance 1821), *V. cornuvaccinum* (Bronn 1831), *V. archiaci* (Douvillé 1892), *Hippurites carinthiachus* Redlich 1900, *H. matheroni* Douvillé 1893, *H. crassicostatus* Douvillé 1893, *H. socialis* Douvillé 1890, *H. striatus* Defrance 1821, *H. heberti* Munier-Chalmas 1888, *Hippuritella nabrasiensis* (Futterer 1893), *Ha. toucasi* (d'Orbigny 1847), *Ha. carezi* (Douvillé 1894), *Ha. praesulcatissima* (Toucas 1903), *Ha. sulcatissimus* (Douvillé 1894), *Ha. variabilis* (Munier- Chalmas, *in* Gaudry 1867) and *Ha. sulcatoides* (Douvillé 1892) (Polšak 1979; Sánchez 1981; Steuber 1999). Microfossils in pelagic limestones and nanofossils in marly sediments (Polšak *et al.* 1978; Polšak 1979; Korolija *et al.* 1995) suggest a Early–Late Campanian age.

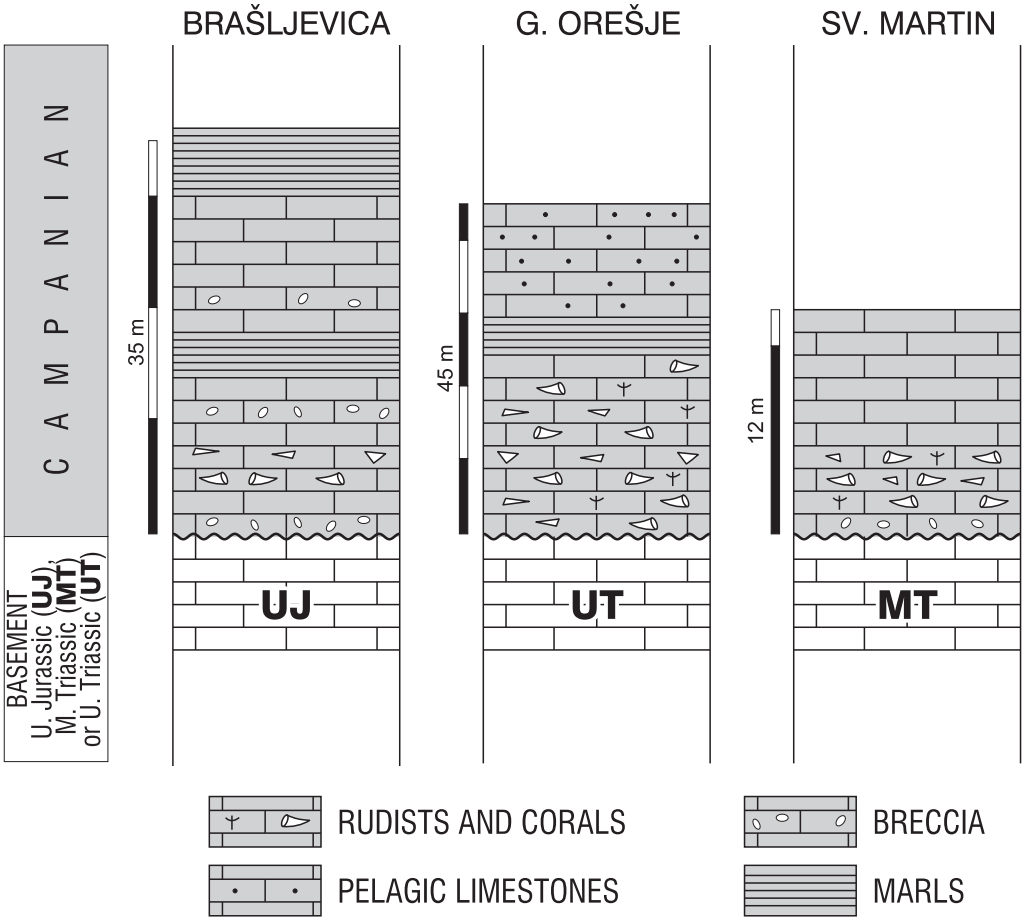

Figure 2. Geological columns of investigated sites. Thickness of beds not to scale. Simplified and modified after Herak (1966, 1968), Pleničar & Premru (1970), Pleničar *et al.* (1975), Polšak (1979), Korolija *et al.* (1995) and Poljak (1942).

Sv. Martin deposits (Figure 2), which are 12 m thick, transgresivelly overlie Middle Triassic limestones (Poljak 1942). They consist of breccias and limestones with corals and rudists *Plagioptychus aguilloni* d'Orbigny 1839, *Vaccinites cornuvaccinum* (Bronn 1831) and *Batolites organisans* Montfort 1808 (Koch 1918). Unfortunately, this outcrop is completely destroyed through quarry excavations (Poljak 1942). The age of sediments was determined as Late Santonian–Early Campanian (Poljak 1942).

Chronostratigraphy

Two splits of samples of the outer shell layer of the hippuritid rudists were taken for geochemical and strontium isotope analysis, and for each locality, three samples of different rudist shells were submitted for analysis.

The samples of strontium isotope ratios were determined at Bochum University under supervision of Prof. D. Buhl (Table 1). Strontium isotope ratios of samples are adjusted to a ratio of 0.709175 of USGS EN-1 to derive numerical ages from the 'Look-Up' table (Version 4: 08/03) provided by Horwath & McArthur (1997) and McArthur *et al.* (2001).

The sample splits were analyzed by ICP-AES for elemental composition using the procedure suggested by Steuber & Rauch (2005) under supervision of Dr. S. Miko (Table 2). The samples

Table 1. Analytical results for strontium isotope stratigraphy of rudists from studied localities. Standards NIST NBS 987 0.710247 (McArthur value) and 0.710238 (Mean Bochum value); USGS EN-1 0,709175 (McArthur value) and 0.709157 (Mean Bochum value). Column 3: $^{87}Sr/^{86}Sr$ normalized to NBS 987 values bracketing the samples and corrected for deviation from value stated by McArthur. Column 4: $^{87}Sr/^{86}Sr$ normalized to USGS-EN-1 values bracketing the samples and corrected for deviation from value stated by McArthur. Column 5: $^{87}Sr/^{86}Sr$ normalized to NBS 987 mean value Bochum and corrected for deviation of the mean value from NBS 987 value stated by McArthur. Column 6: $^{87}Sr/^{86}Sr$ normalized to USGS-EN-1 mean value Bochum and corrected for deviation of the mean value from USGS EN-1 value stated by McArthur. Standard used to derive numerical age in bold.

Sample	$^{87}Sr/^{86}Sr$ measured	± 2 σ mean	Column 3	**Column 4**	Column 5	Column 6
D. Orešje1	0.707502	0.000007	0.707506	**0.707514**	0.707511	0.707520
D. Orešje2	0.707500	0.000007	0.707504	**0.707512**	0.707509	0.707518
D. Orešje3	0.707496	0.000007	0.707500	**0.707508**	0.707505	0.707514
Brašljevica1	0.707542	0.000010	0.707546	**0.707554**	0.707551	0.707560
Brašljevica2	0.707492	0.000007	0.707496	**0.707504**	0.707501	0.707510
Brašljevica3	0.707539	0.000007	0.707543	**0.707551**	0.707548	0.707557
Sv. Martin1	0.707494	0.000007	0.707498	**0.707506**	0.707503	0.707512
Sv. Martin2	0.707487	0.000007	0.707491	**0.707499**	0.707496	0.707505
Sv. Martin3	0.707549	0.000007	0.707553	**0.707561**	0.707558	0.707567

Table 2. Geochemical analysis of hippuritid shells from studied localities with numerical ages (bold) derived from the 'Look-Up' table (Version 4: 08/03) provided by Horwath & McArthur (1997) and McArthur *et al.* (2001).

Sample	Mg (mg/kg)	Sr (mg/kg)	Mn (mg/kg)	Ba (mg/kg)	Fe (mg/kg)	$^{87}Sr/^{86}Sr$	**Age (Ma)**
D. Orešje1	3081	1062	42	1091	631	0.707514	**80.85**
D. Orešje2	2993	1087	31	1595	1369	0.707512	**81.05**
D. Orešje3	3402	937	36	932	1697	0.707508	**81.35**
Brašljevica1	1272	876	28	965	103	0.707554	**77.95**
Brašljevica2	3067	412	34	656	181	0.707504	**81.65**
Brašljevica3	1504	494	36	363	44	0.707551	**78.10**
Sv. Martin1	2155	782	<80	679	890	0.707506	**81.50**
Sv. Martin2	2915	627	<50	227	225	0.707499	**82.00**
Sv. Martin3	1125	575	<40	70	725	0.707561	**77.60**

were dissolved in 1 ml (1.25 N) HCl solution in teflon 10 ml tubes and diluted with 5 ml of redistilled water. All bottles and tubes used for sample processing were washed in 10% HNO_3 solution in advance. Individual aliquots of the powder were diluted 250–780 times. The resulting solutions were analyzed for Mg, Ba, Sr, Mn and Fe by the Inductively Coupled Plasma–Atomic Emission Spectrometry (JY 50P, Jobin Yvon, France) facility of Croatian Geological Survey, Zagreb. The intensity to solution concentration calibrations was used and the instrumental error for the analyzed elements was ±3%.

In four of nine samples which were analyzed for $^{87}Sr/^{86}Sr$ values, Mn and Fe concentrations are below 50 and 300 μg/g, respectively. Sr concentrations range from 1087 to 412 μg/g and Mg concentrations range from 1125–3402 μg/g.

According to the results of SIS (Tables 1 & 2), specimens of hippuritids from all localities indicate an age which corresponds to the upper part of the Lower Campanian (Figure 9).

Although the analyzed specimens show relatively poor preservation potential for calculation of mean $^{87}Sr/^{86}Sr$ (Steuber 2003), generally there is good

agreement between SIS and biostratigraphical data, based on micro- and nannofossils (Brašljevica and Donje Orešje). As for the Sv. Martin locality, SIS data generally confirmed a similar age of transgressive sediments with the other two localities which is quite important due to the lack of microfossils.

Biostatistics of Rudists

All specimens were transversely sectioned closest to the unbroken part of the shell, and therefore probably were cut through vertically different parts of the attached valve. Such prepared shells show the preserved ligamental ridge as well as pillars, while tooth elements are in half of the specimens indeterminable.

For the biostatistical analysis specimens are grouped by localities and by hipuritid genera (*Vaccinites*, *Hippurites* and *Hippuritella*), using criteria described by Dechaseaux & Coogan (1969) and Steuber (1999). Brašljevica specimens are *Vaccinites*, Donje Orešje sediments contain representatives of three genera, *Vaccinites*, *Hippurites* and *Hippuritella,* and at Sv. Martin sediments individuals of *Vaccinites* only occur.

Statistical analyses were calculated using the PAST software program (Hammer *et al*. 2003).The data were subjected to cluster analysis, which is one of the most widely used and commonly understood multivariate analytical techniques in the palaeontological literature (Parker & Arnold 1999). The list of measurements considered for 'cluster analysis' is presented in Tables 3–7. Hierarchical cluster analysis was calculated using the 'Ward and Unweighted Pair-Group Average' methods, both with Euclidean distance. When individuals were grouped into clusters, their morphological characteristics were compared for possible similarities or dissimilarities between groups.

The Brašljevica assemblage contained 38 specimens of *Vaccinites*. Hierarchical cluster analysis produced five cluster groups (Figure 3; Table 3).

The total of 101 specimens of *Vaccinites*, 30 specimens of *Hippurites* and 29 specimen of *Hippuritella* are contained in the Donje Orešje sediments. *Vaccinites* individuals are grouped in 25 cluster groups (Figure 4, Table 4), *Hippurites* individuals into three (Figure 5, Table 5), and *Hippuritella* in six cluster groups (Figure 6, Table 6).

The Sv. Martin collection of rudists contains 13 *Vaccinites* individuals, grouped into three cluster groups (Figure 7, Table 7).

Morphological Observations

Cluster groups obtained from multivariate analysis have been correlated to the morphological characteristics of each specimen. Combination of observable (descriptive) morphological similarities and statistically calculated 'distances' allowed determination of morphologically different rudists groups ('species').

Within the *Vaccinites* community, there are three different morphological groups. The first morphological group is characterized by ligamental ridge and pillars located close together. The ligamental ridge is straight or slightly curved anteriorly, and its termination is generally truncated. P1 have subparallel flanks with slightly wider bases towards the ligamental ridge and oval head. P2 has a long, kidney-shaped peduncle with a pinched or penductulated base, curved slightly anteriorly. One cluster group of specimens from Brašljevica (Figure 3, cluster 4), two from Donje Orešje (Figure 4, clusters 24 and 25) and all cluster groups form Sv. Martin (Figure 7), could be considered as representative of *Vaccinites cornuvaccinum* (Bronn 1831). It is worth noting that this species is a possible synonym for *V. archiaci* (Douvillé 1892), despite the hypothesis proposed by Douvillé (1897) and Toucas (1904) and noted by Vicens (1992) that between *V. cornuvaccinum* and *V. archiaci* there is no phylogenetic relationship. Comparison of average values for measured morphological elements reveal that individuals from Donje Orešje are smaller, while Brašljevica and Sv. Martin individuals show similar average values (Table 8).

The second morphological group is present at Brašljevica rudist community with three cluster groups (Figure 3, clusters 1–3) and at Donje Orešje with twentyone cluster groups (Figure 4, clusters 1–21). It is characterized with ligamental ridge and pillars similarly distanced within ¼ of the shell

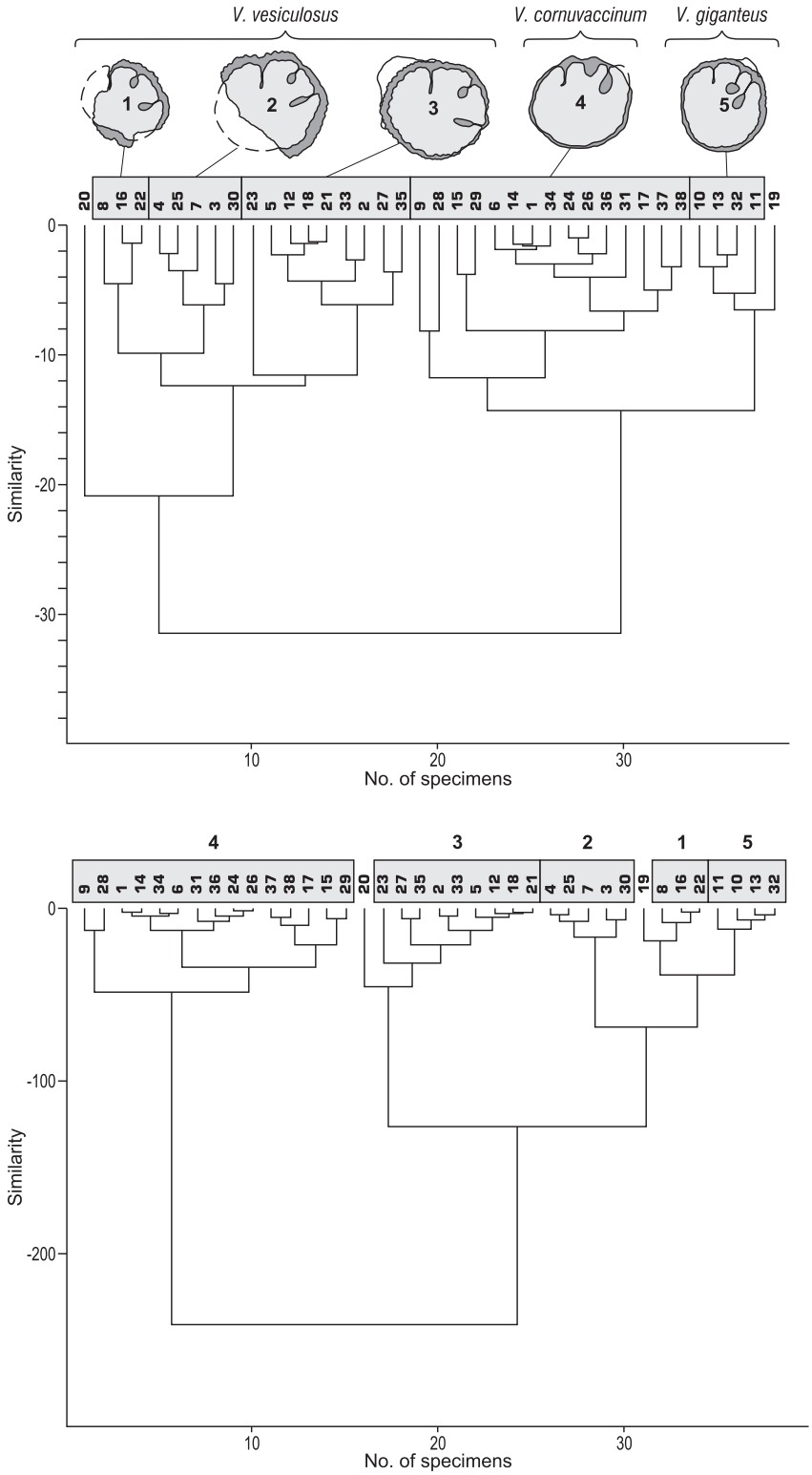

Figure 3. Hierarchical cluster analysis (Pair-Group and Ward's methods) including all parameters for *Vaccinites* specimens from Brašljevica locality. Numbers in transverse sections correspond to the statistically determined groups.

Table 3. Measured parameters for *Vacinites* specimens from Brašljevica locality.

Specimen	L/P2 (°)	P (cm^2)	U (cm)	U/P0-P2 (cm)	d (cm)
1	15	34.19	30.0	7.50	6.60
2	85	32.15	30.0	3.75	6.40
3	66	35.77	28.0	6.22	6.75
4	78	33.17	30.0	5.45	6.50
5	100	29.21	30.0	4.29	6.10
6	14	37.92	28.5	7.13	6.95
7	82	40.13	36.0	4.50	7.15
8	68	25.50	25.0	5.00	5.70
9	18	17.71	22.0	7.86	4.75
10	40	29.21	31.0	7.75	6.10
11	36	21.64	21.0	6.00	5.25
12	94	30.18	28.0	4.00	6.20
13	33	27.33	27.0	6.75	5.90
14	17	35.24	29.0	9.67	6.70
15	0	42.99	31.0	15.50	7.40
16	60	22.05	26.0	5.20	5.30
17	12	55.39	37.0	7.40	8.40
18	95	27.32	29.0	4.14	5.90
19	47	34.19	31.0	6.20	6.60
20	129	28.26	26.5	3.31	6.00
21	97	29.21	28.0	4.00	6.10
22	57	22.05	26.0	5.78	5.30
23	87	11.94	18.0	3.60	3.90
24	11	37.37	29.0	9.67	6.90
25	81	36.29	32.0	4.57	6.80
26	10	39.02	30.0	10.00	7.05
27	98	38.47	33.0	4.13	7.00
28	0	20.02	24.0	8.00	5.05
29	0	46.54	34.0	22.67	7.70
30	71	42.99	33.0	6.00	7.40
31	10	37.37	35.0	14.00	6.90
32	34	27.79	32.0	8.00	5.95
33	91	33.17	30.0	4.29	6.50
34	17	37.37	31.0	7.75	6.90
35	106	39.02	34.0	3.78	7.05
36	9	33.68	30.0	8.57	6.55
37	6	46.54	36.0	9.23	7.70
38	12	44.16	34.0	6.80	7.50

interior. The ligamental ridge is straight or slightly inflected anteriory. P1 is straight with a round or oval head and a strongly pinched or pedunculate base. P2 is straight, with a pedunculated, elliptical head. On the basis of these morphological characteristics, individuals within cluster groups presumably belong to *Vaccinites vesiculosus* (Woodward 1855).

The third morphological group, present with one cluster group at Brašljevica (Figure 3, cluster 5) and Donje Orešje with two (Figure 4, clusters 22 and 23), have a long ligamental ridge, which could thins at its centre, with rounded termination. P1 and P2 are pedunculate, with sub-parallel stalks, closely spaced and inclined around 45° against ligamental ridge. P1 is well rounded, and P2 is more ellipsoidal in shape. Individuals with these morphological characteristics show similarities with species *Vaccinites giganteus* (d'Hombres-Firmas 1838) and *V. vredenburgi* (Kühn 1933). The former species has been taxonomically problematical for some time (Laviano & Guarneri 1989; Steuber 1999). Interestingly, all studied specimens show no-visible truncation of the ligamental ridge. Also, there is an absence of kidney-like form of P2, which is typical for Greek specimens (Steuber 1999). Therefore, it could be concluded that specimens of this morphological group belong to *Vaccinites giganteus*. Average values for this species show that individuals from Donje Orešje are significantly larger than those from Brašljevica (Table 8).

Hippurites specimens are present only at Donje Orešje locality (Figure 5). Morphologically, specimens from all three groups have a similar appearance. In transverse section, the ligamental ridge is short and triangular with a wide base. The flanks of P1 are parallel or sub-parallel, and sometimes slightly pinched. P2 reaches almost double the length of P1 with parallel or slightly pinched flanks. Similar characteristics are found in *Hippurites vidali* Matheron 1880 and *Hippurites canaliculatus* Rolland du Roquan 1841. Both species belong to the same lineage, they have similar development of the pillars (Vicens 1992), which differ in distal end of the ligamental ridge (always truncated in *H. canaliculatus*; Vicens 1992). According to the morphological characteristics, it is possible to presume that all specimens belong to *Hippurites vidali* Matheron 1880.

Specimens of *Hippuritella* also occur only at Donje Orešje (Figure 6, Table 6). From morphological observations of statistically determined groups we recognize one morphological type (Figure 6, clusters 1–6) which is characterized by P1 and P2 similar in size or P1 slightly smaller. Both have broad bases and flanks that converge towards the interior of the shell. P1 is generally shorter than P2, with a wider base. P2 have parallel to sub-parallel flanks and could double the length in comparison with P1. These morphological features correspond to *Hippuritella lapeirousei* (Goldfuss

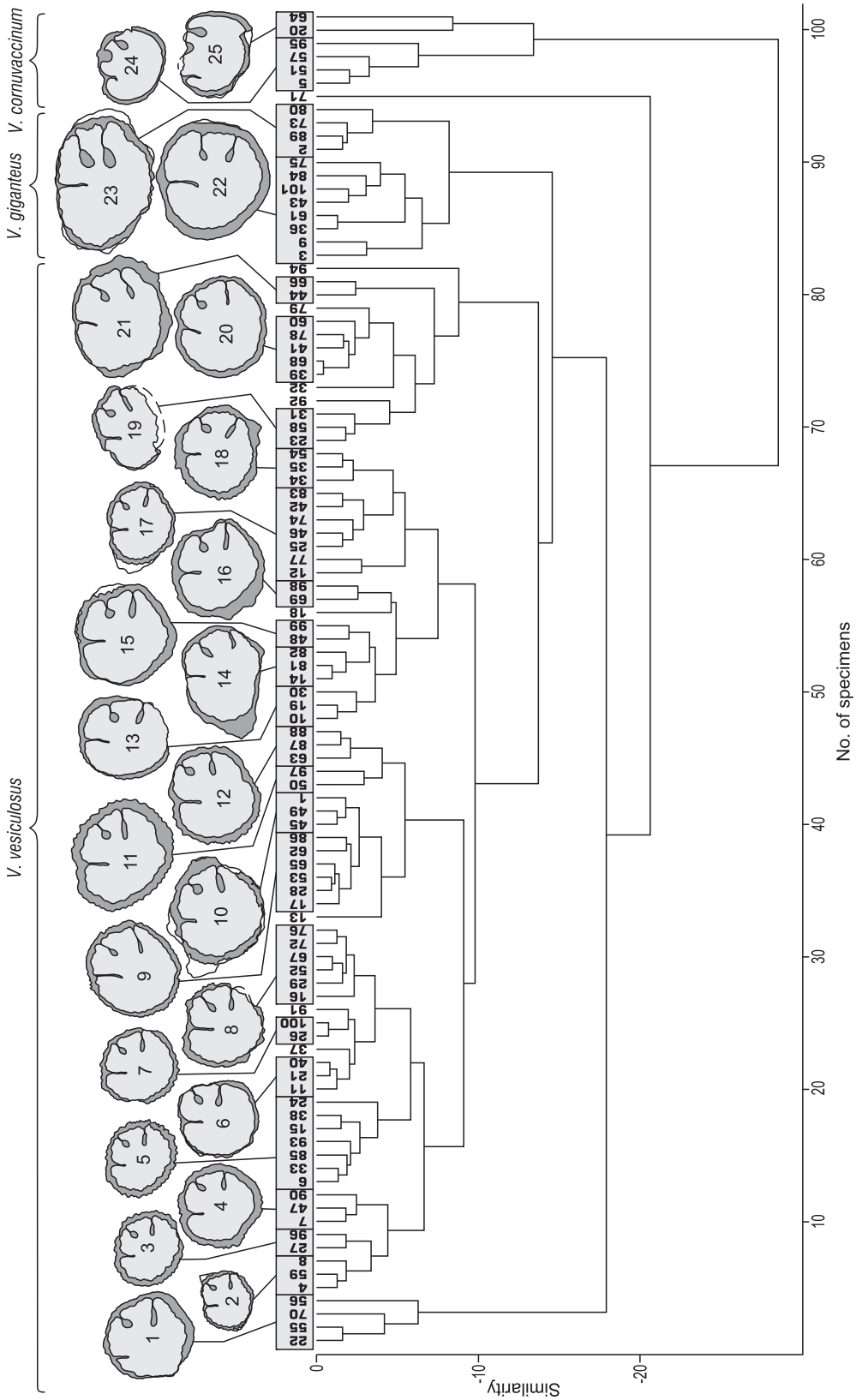

Figure 4. Hierarchical cluster analysis (Pair-Group and Ward's methods) including all parameters for *Vaccinites* specimens from Donje Orešje locality. Numbers in transverse sections correspond to the statistically determined groups.

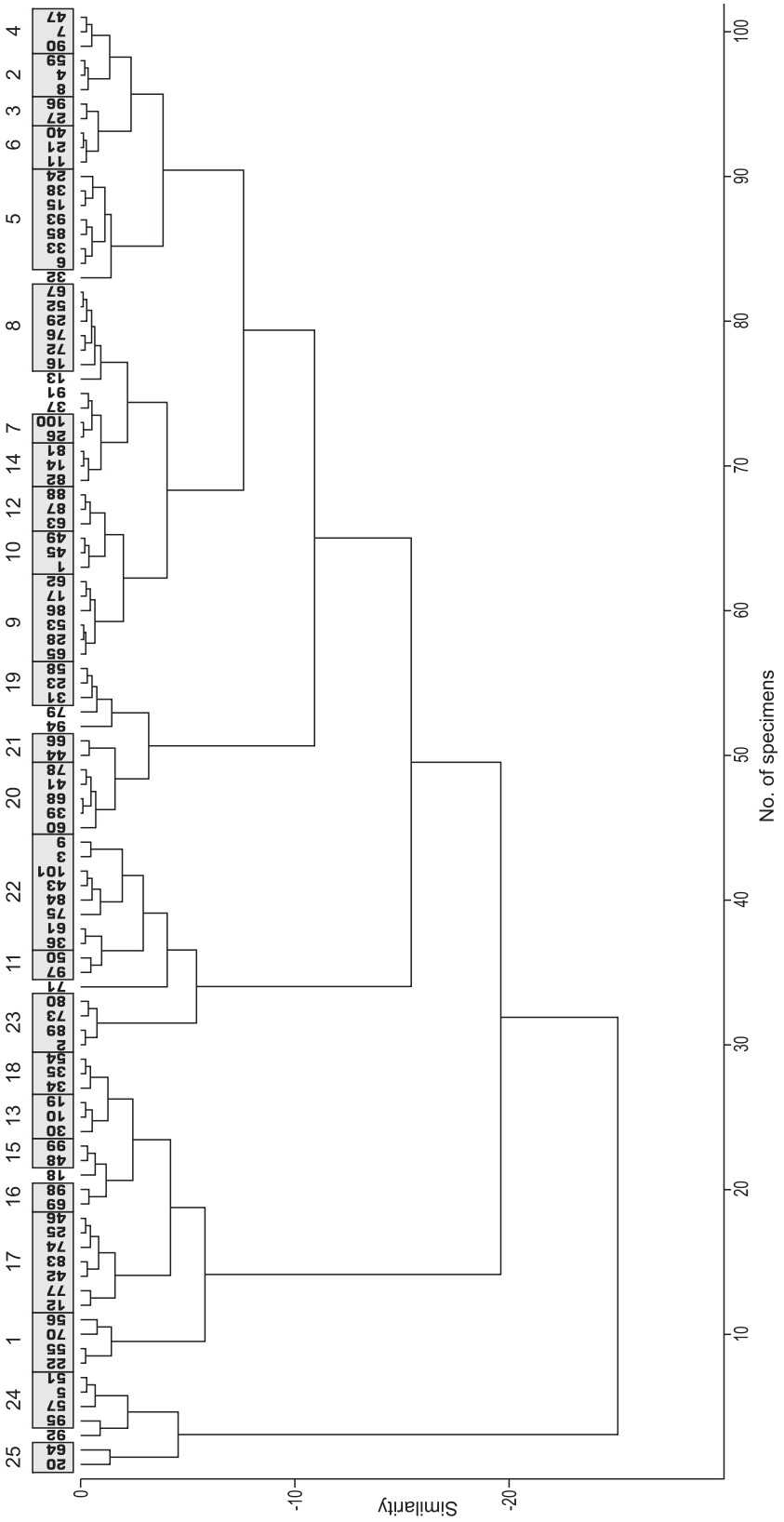

Figure 4. Continued.

Table 4. Measured parameters for *Vacinites* specimens from Donje Orešje locality.

Specimen	L/P2 (°)	P (cm²)	U (cm)	U/P0-P2 (cm)	d (cm)
1	80	35.24	31.0	4.43	6.70
2	99	44.16	35.0	3.89	7.50
3	81	56.05	45.0	5.63	8.45
4	93	14.51	19.2	3.76	4.30
5	31	20.42	21.0	5.25	5.10
6	76	15.19	21.5	5.24	4.40
7	84	10.75	14.0	4.67	3.70
8	96	14.85	21.0	3.68	4.35
9	85	60.79	48.0	5.65	8.80
10	100	27.33	30.0	4.29	5.90
11	86	20.42	25.0	5.55	5.10
12	112	19.23	21.0	4.04	4.95
13	82	26.77	34.0	5.67	5.85
14	91	28.26	27.5	3.93	6.00
15	81	18.85	23.0	4.60	4.90
16	79	28.26	26.0	4.00	6.00
17	88	34.19	31.0	5.17	6.60
18	93	38.46	30.0	4.00	7.00
19	98	27.79	28.0	4.31	5.95
20	15	24.18	24.0	6.00	5.55
21	87	22.05	25.0	5.00	5.30
22	116	25.50	26.0	3.71	5.70
23	55	24.18	27.0	6.75	5.55
24	78	15.19	29.0	7.25	4.40
25	106	20.42	24.0	4.36	5.10
26	89	24.18	27.0	4.91	5.55
27	90	16.25	22.0	4.40	4.55
28	86	33.68	33.0	4.71	6.55
29	80	23.75	26.0	5.20	5.50
30	97	26.41	24.0	3.69	5.80
31	59	22.89	26.0	5.78	5.40
32	72	24.62	26.0	5.20	5.60
33	78	16.61	20.0	4.44	4.60
34	110	25.50	26.0	4.33	5.70
35	107	29.21	26.0	4.00	6.10
36	78	47.76	38.0	4.75	7.80
37	90	20.42	27.0	4.50	5.10
38	80	15.89	23.0	4.60	4.50
39	66	34.19	30.0	4.62	6.60
40	87	23.75	24.5	4.45	5.50
41	64	30.18	30.0	6.00	6.20
42	100	22.05	24.0	4.80	5.30
43	88	49.61	35.0	5.00	7.95
44	62	42.98	37.0	5.69	7.40
45	83	31.65	30.0	4.62	6.35
46	105	18.85	21.0	3.82	4.90
47	84	11.04	18.0	5.14	3.75
48	93	32.66	32.0	4.57	6.45
49	81	32.66	31.0	6.20	6.45
50	78	43.57	31.0	5.17	7.45
51	29	16.97	23.0	5.75	4.65
52	84	25.50	25.0	4.55	5.70
53	86	33.17	31.0	4.43	6.50
54	105	26.41	27.0	3.86	5.80
55	119	27.33	27.0	3.60	5.90
56	132	31.65	28.0	4.67	6.35
57	33	13.19	21.0	8.40	4.10
58	56	26.41	30.0	5.45	5.80
59	94	12.56	17.5	4.38	4.00
60	67	28.26	30.0	5.00	6.00
61	77	49.61	40.0	4.71	7.95
62	88	37.37	31.0	5.64	6.90
63	72	37.37	31.0	5.17	6.90
64	0	33.68	30.0	6.00	6.55
65	84	34.19	31.0	4.43	6.60
66	65	39.57	34.0	5.67	7.10
67	82	24.62	25.0	4.55	5.60
68	66	33.17	30.0	5.00	6.50
69	103	36.83	32.0	4.57	6.85
70	122	32.15	32.5	4.06	6.40
71	55	57.39	39.0	5.57	8.55
72	83	27.33	28.0	4.67	5.90
73	99	47.76	36.0	4.50	7.80
74	102	16.61	22.0	5.50	4.60
75	88	55.39	36.5	4.06	8.40
76	84	24.62	28.0	4.67	5.60
77	112	13.85	18.0	4.00	4.20
78	62	32.15	28.0	4.67	6.40
79	63	28.26	24.5	7.00	6.00
80	102	52.14	38.0	4.22	8.15
81	92	28.26	25.5	3.92	6.00
82	90	31.15	28.5	5.18	6.30
83	98	19.63	22.0	4.40	5.00
84	90	47.15	41.0	7.45	7.75
85	73	15.19	21.0	5.25	4.40
86	84	37.92	32.0	5.82	6.95
87	76	34.19	30.0	5.00	6.60
88	73	33.17	31.0	4.43	6.50
89	101	44.16	38.0	4.22	7.50
90	89	10.17	15.5	3.88	3.60
91	93	23.75	25.0	4.17	5.50
92	48	28.26	31.0	6.89	6.00
93	74	18.85	23.0	4.60	4.90
94	58	16.61	18.0	5.14	4.60
95	44	20.42	21.0	6.00	5.10
96	86	16.61	22.0	4.89	4.60
97	73	41.83	35.0	5.38	7.30
98	102	34.19	27.0	4.15	6.60
99	97	30.66	32.0	4.57	6.25
100	90	25.50	27.0	5.40	5.70
101	88	45.34	36.0	4.80	7.60

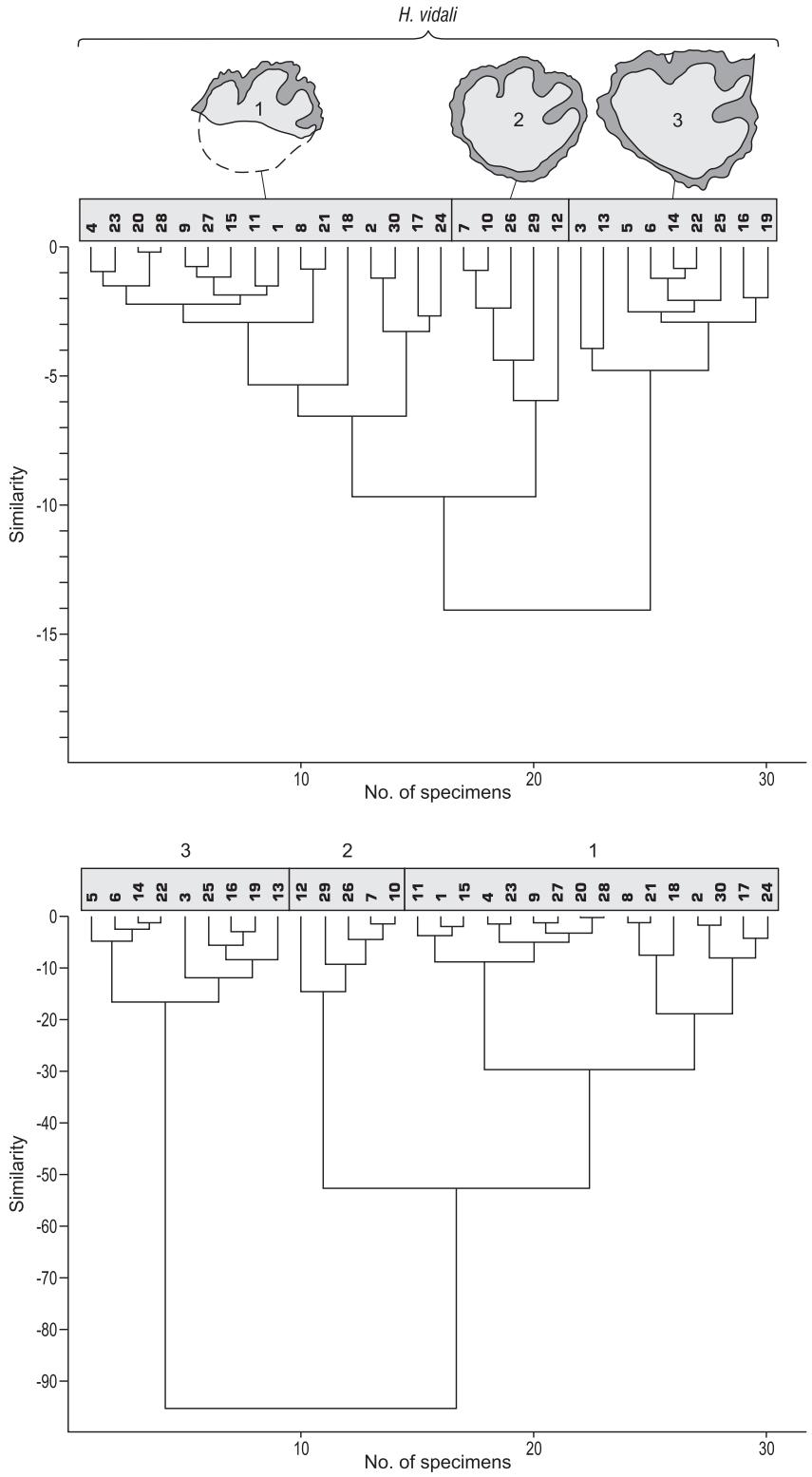

Figure 5. Hierarchical cluster analysis (Pair-Group and Ward's methods) including all parameters for *Hippurites* specimens from Donje Orešje locality. Numbers in transverse sections correspond to the statistically determined groups.

Table 5. Measured parameters for *Hippurites* specimens from Donje Orešje locality.

Specimen	L/P2 (°)	P (cm²)	U (cm)	U/P0-P2 (cm)	d (cm)
1	53	9.07	13.0	4.69	3.40
2	68	3.79	8.8	4.40	2.20
3	96	6.60	11.0	3.67	2.90
4	59	5.31	12.0	6.00	2.60
5	82	3.46	9.0	4.74	2.10
6	83	6.15	11.0	4.40	2.80
7	45	7.06	12.5	5.00	3.00
8	62	7.54	14.0	4.67	3.10
9	56	7.06	14.0	5.60	3.00
10	45	8.29	14.0	4.67	3.25
11	53	5.94	12.0	4.00	2.75
12	30	6.83	12.0	6.00	2.95
13	92	10.17	18.0	3.60	3.60
14	86	6.15	11.2	3.73	2.80
15	55	9.07	15.0	5.00	3.40
16	83	8.55	15.0	3.75	3.30
17	74	5.31	11.0	3.67	2.60
18	62	16.61	18.0	5.14	4.60
19	87	10.17	15.5	3.88	3.60
20	57	6.60	11.0	4.40	2.90
21	62	9.07	15.0	5.00	3.40
22	85	5.31	12.5	4.17	2.60
23	60	6.60	13.0	5.20	2.90
24	71	9.07	14.5	3.63	3.40
25	89	7.06	12.0	3.43	3.00
26	40	8.55	14.0	5.60	3.30
27	57	8.04	13.5	4.82	3.20
28	57	6.15	11.0	4.40	2.80
29	40	2.83	7.0	2.19	1.90
30	70	3.46	8.0	2.86	2.10

Table 6. Measured parameters for *Hippuritella* specimens from Donje Orešje locality.

Specimen	P1/P2 (°)	P (cm²)	U (cm)	U/P1-P2 (cm)	d (cm)
1	40	4.52	9.0	6.00	2.40
2	46	4.52	8.5	5.67	2.40
3	53	8.81	13.0	6.50	3.55
4	52	5.10	9.5	4.75	2.55
5	46	9.07	12.0	8.00	3.40
6	46	9.62	12.0	5.45	3.50
7	45	11.94	13.0	6.50	3.90
8	43	12.56	14.0	7.00	4.00
9	45	8.55	12.0	6.00	3.30
10	48	5.72	9.0	6.00	2.70
11	27	5.72	10.0	10.00	2.70
12	47	5.72	10.0	6.67	2.70
13	34	8.55	13.0	8.67	3.30
14	45	11.34	14.0	7.00	3.80
15	24	7.07	10.0	9.09	3.00
16	58	5.72	9.0	4.50	2.70
17	43	1.33	7.0	7.00	1.30
18	44	2.54	6.5	4.33	1.80
19	58	2.27	7.0	7.00	1.70
20	16	7.07	12.0	6.00	3.00
21	43	3.46	8.0	8.00	2.10
22	37	11.04	14.0	5.60	3.75
23	35	4.52	9.0	6.00	2.40
24	36	12.56	16.0	3.20	4.00
25	40	1.77	6.5	3.25	1.50
26	42	15.54	21.0	4.67	4.45
27	54	15.89	17.0	4.25	4.50
28	46	11.94	15.0	3.00	3.90
29	42	7.54	11.5	3.83	3.10

1840), which is synonymous with *Hippuritella nabrasiensis* (Futterer 1893) (Alceo Tarlao, personal communication 2008), and *Hippuritella variabilis* (Munier-Chalmas, *in* Gaudry 1867).

In spite of difference in ligamental ridge development (Vicens 1992) both species belong to the same lineage. While *Hipuritella variabilis* has relatively well-pronounced triangular shaped ligamental ridge, in *Ha. lapeirousei* ligamental ridge is reduced to a small inflexion in outer layer (Vicens 1992). Based on these morphological features, it could be presumed that all specimens belong to *Hippuritella lapeirousei* (Goldfuss 1840).

Species from Donje Orešje *V. vesiculosus*, *H. vidali* and *Ha. lapeirousei* have the widest range of transverse section size (Figures 4–6, Table 8). These wide ranges could be due to sectioning of the vertically different parts of the shell, or the rudist population is characterized with different growth stages of individuals. Because most of the fossil material is broken (rudist shells are sampled from hard rock, limestones), and therefore transverse sections are made closest to the unbroken part of the shell, this hypothesis could not be tested.

Nevertheless, we correlate ratio U/P0-P2 with length of the contour U for possible grouping of the

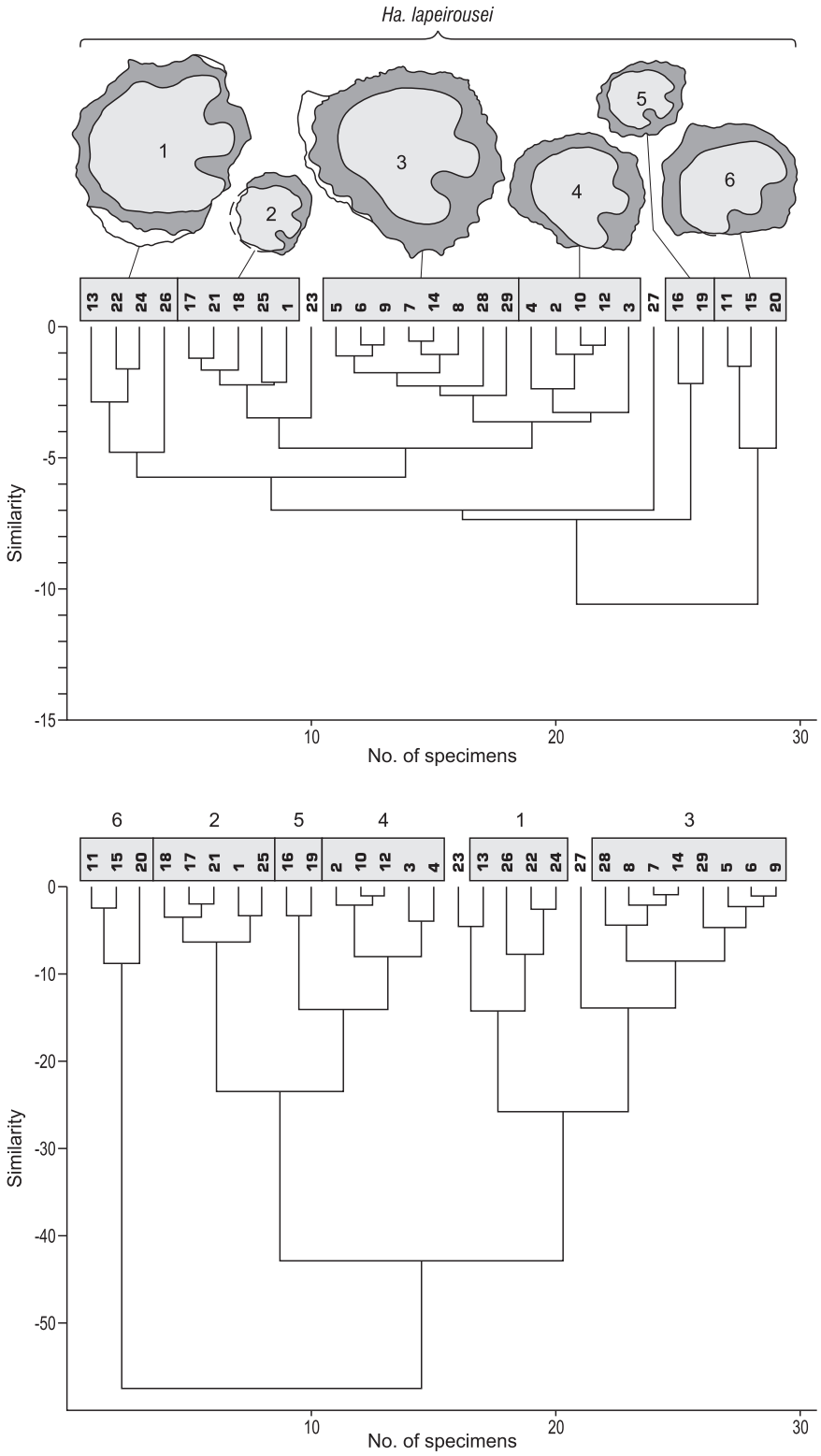

Figure 6. Hierarchical cluster analysis (Pair-Group and Ward's methods) including all parameters for *Hippuritella* specimens from Donje Orešje locality. Numbers in transverse sections correspond to the statistically determined groups.

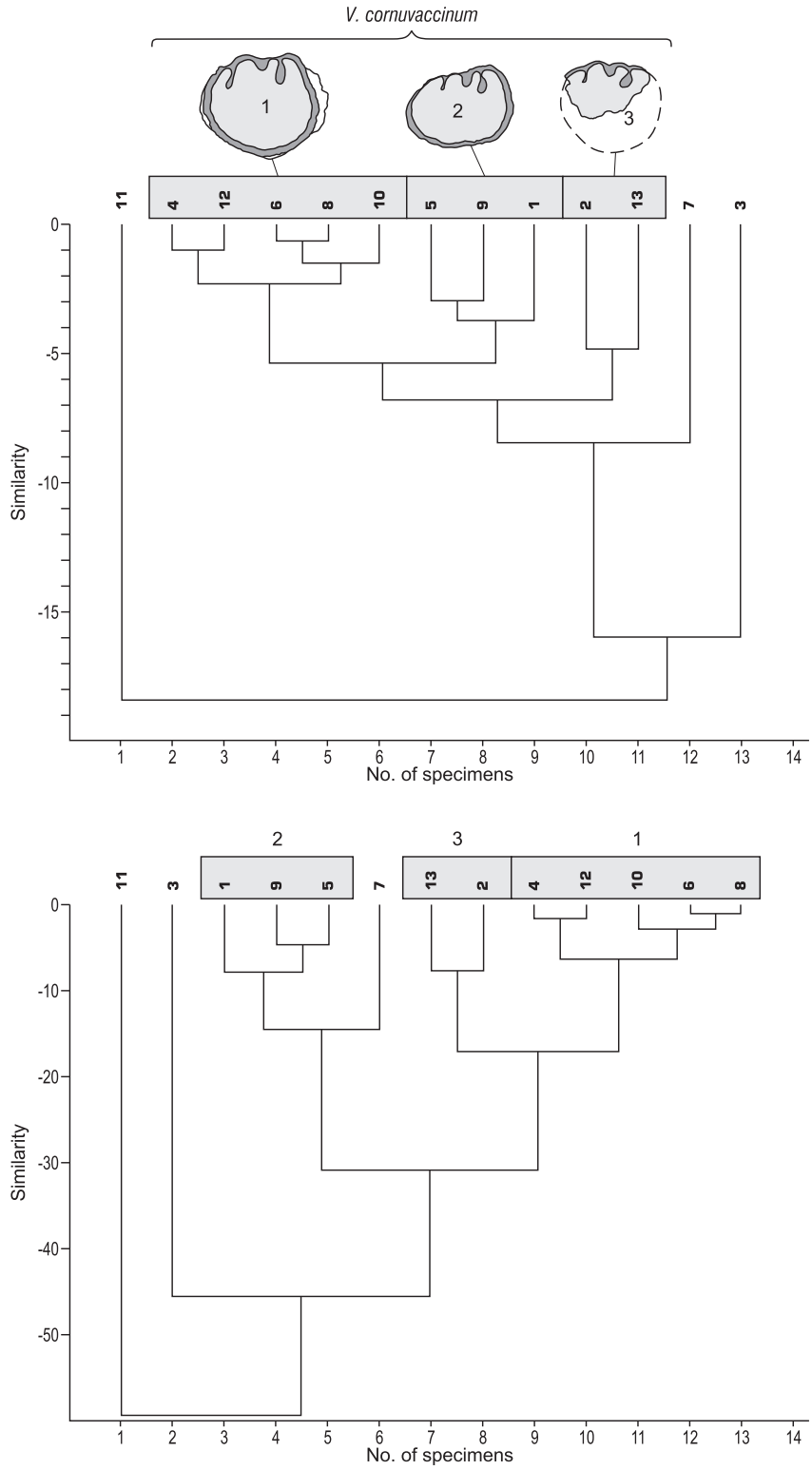

Figure 7. Hierarchical cluster analysis (Pair-Group and Ward's methods) including all parameters for *Vaccinites* specimens from Sv. Martin locality. Numbers in transverse sections correspond to the statistically determined groups.

Table 7. Measured parameters for *Vacinites* specimens from Sv. Martin locality.

Specimen	L/P2 (°)	P (cm^2)	U (cm)	U/P0-P2 (cm)	d (cm)
1	6.0	24.62	31	10.33	5.60
2	14.0	39.57	30	8.57	7.10
3	39.0	38.46	31	7.75	7.00
4	0.0	39.57	32	8.00	7.10
5	0.0	26.86	26	9.29	5.85
6	0.0	36.29	29	9.67	6.80
7	16.0	26.86	24	6.00	5.85
8	0.0	37.37	30	9.37	6.90
9	3.5	32.15	28	9.33	6.40
10	0.0	37.37	31	12.40	6.90
11	0.0	70.10	48	8.00	9.45
12	0.0	41.83	32	8.00	7.30
13	7.0	47.76	31	8.86	7.80

vaccinitid species. This comparison is generally used for determination of possible ontogenetic variations within one individual rudist shell, where three pillars move closer together with increasing length of the mantle margin. This trend is more pronounced in species with primarily closely distanced pillars and less distinct in species which pillars are distributed around the posteriodorsal quarter of the shell (Steuber 1999).

Graphs for vaccinitid specimens from Brašljevica and Donje Orešje localities shows that *Vaccinites cornuvaccinum* with closely distanced pillars are grouped in upper part, while specimens of *V. vesiculosus* and *V. giganteus* with more distances pillars, are grouped in the lower part of plotted measurements.

Trend of plotted measurements (Figure 8) has lower angle in comparison with similar analyses (Steuber 1999) probably due to same age of deposits

Table 8. Rudist species from investigated localities with average values and maximum and minimum values of measured morphological elements form transverse sections of rudist shells. In first column measured values for *Ha. lapeirousei* is P1/P2 (*).

Species/ Locality	L /P2(*P1/P2) (^{0}) $L/P2\ (*P1/P2)_{max-min}$ (^{0})	P (cm^2) $P_{max-min}$ (cm^2)	U (cm) $U_{max-min}$ (cm)	U/P0(P1*)-P2 (cm) $U/P0(P1*)\text{-}P2_{max-min}$ (cm)	d (cm) $d_{max-min}$ (cm)
V.cornuvaccinum	10.06	37.70	30.70	10.11	6.87
Brašljevica	18–0	55.39–17.71	37–22	22.67–6.80	8.40–4.75
V.cornuvaccinum	25.33	21.47	23.33	6.23	5.17
Donje Orešje	44–0	33.68–13.19	30–21	8.40–5.25	6.55–4.10
V.cornuvaccinum	3.05	36.33	30	9.38	6.77
Sv. Martin	14–0	47.76–24.62	32–26	12.40–8.0	7.80–5.60
V.vesiculosus	83.29	31.09	29.17	4.62	6.25
Brašljevica	106–57	42.99–11.94	36–18	6.22–3.60	7.40–3.90
V.vesiculosus	87.16	26.19	26.59	4.74	5.70
Donje Orešje	132–55	43.57–10.17	37–14	7.25–3.60	7.45–3.60
V.gigianteus	35.75	26.49	27.75	7.12	5.80
Brašljevica	40–33	29.21–21.64	32–21	8.0–6.0	6.10–5.25
V.giganteus	89.66	49.99	38.87	4.90	7.97
Donje Orešje	102–77	60.79–44.16	48–35	7.45–3.89	8.80–7.50
H. vidali	65.30	7.19	12.61	4.41	2.98
Donje Orešje	96–30	16.61–2.83	18.0–7.0	6.0–2.19	4.60–1.90
Ha. lapeirousei	42.44	7.46	11.20	6.06	2.98
Donje Orešje *	58–16	15.54–1.33	21–6.50	10.0–3.0	4.45–1.30

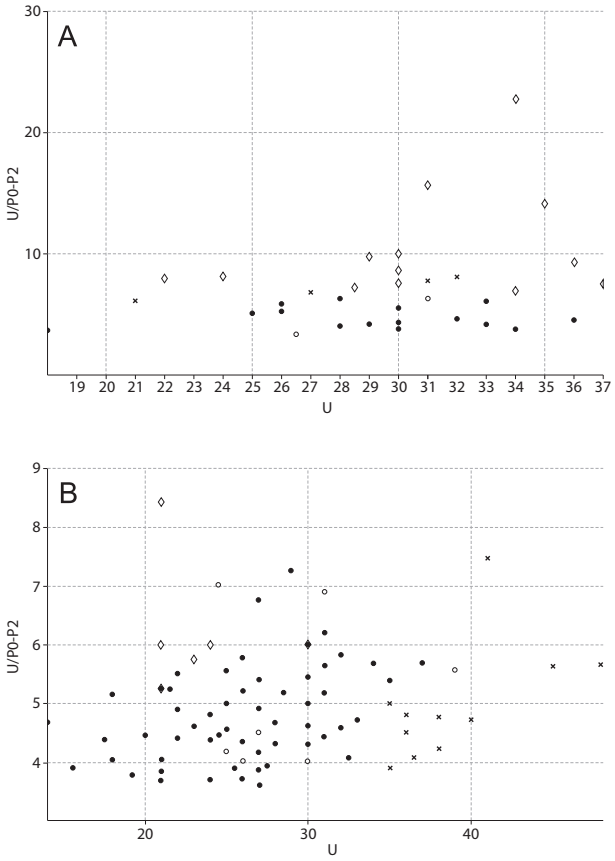

Figure 8. Plots of U and U/P0-P2 measurements of *Vaccinites cornuvaccinum* (diamonds), *V. vesiculosus* (dots), *V. giganteus* (crosses) and statistically ungrouped (white dots) from Brašljevica (A) and Donje Orešje (B) localities.

with vaccinitids and transverse sections of different vaccinitid specimens.

The relatively constant values of U/P0-P2 (Table 3) in *V. giganteus* specimens from Brašljevica locality produce more horizontal distribution of data (Figure 8A). This could be due to widely spaced pillars, and consequently less changes in their arrangement during shell growth (Steuber 1999).

Also, there are few measurements of *V. vesiculosus* as well as one of *V. giganteus* from Donje Orešje locality which are present in upper part of the graph as result of higher values of U/P0-P2 (Figure 8B). Presumably more conically shaped specimens within fossil material, with relatively bigger length of contour in comparison with length of P0-P2 (Table 4), resulted in few vertically distributed measurements (Figure 8).

Discussion

Biostatistical results, gathered at possibly the species level through morphological observations, reveal that significant characteristics for each species make them quite simple for determination (Figure 9). While the most prominent characteristic for biostatistics is the L/P2 and P1/P2 angles, for morphology it is the arrangement of the ligamental ridge and pillars within the shell interior.

V. cornuvaccinum have the lowest angle ranges in comparison with the other two vaccinitid species. Morphologically, the most prominent characteristics are the subparallel orientation of the ligament ridge and pillars, as well as short and thick P1.

V. vesiculosus characterizes the average angle around 90 degrees (Figure 9, Table 8), almost equally spaced ligamental ridge and pillars within ¼ of the shell, a P2 double longer than P1, and all converging towards the centre of the shell.

V. gigianteus, with L/P2 angles lower or similar to *V. vesiculosus* (Table 8), differs from *V. vesiculosus* with longer stalks of the pillars, which have better rounded heads respectively (Figure 9). P1 is closer to P2 than to the ligamental ridge. Pillars also could be mutually parallel.

H. vidali, have L/P2 averaging 65°, the ligamental ridge and pillars are equally spaced, a wide triangular base of the ligamental ridge and a cornuvaccinum-like shape of P1. P2 is also thick, rarely slightly pinched.

The difference between specimens of species *Ha. lapeirousei* is in the shape of the transverse section, which could be ellipsoidal with similar size of the pillars or more rounded with generally shorter P1 than P2 (Figure 9).

Also, above determined rudist species have well known biostratigraphic ranges: *Vaccinites cornuvaccinum* from Coniacian–Campanian (Polšak 1979; Polšak *et al.* 1982; Šribar & Pleničar 1991; Steuber 1999), *V. vesiculosus* from Campanian–Maastrictian (Polšak *et al.* 1982; Platel *et al.* 1994; Philip & Platel 1996; Steuber 1999), *V. gigianteus* from Coniacian–Campanian (Sánchez 1981; Polšak 1979; Laviano & Guarneri 1989; Steuber 1999; Pleničar 2005), *Hippurites vidali* from Campanian

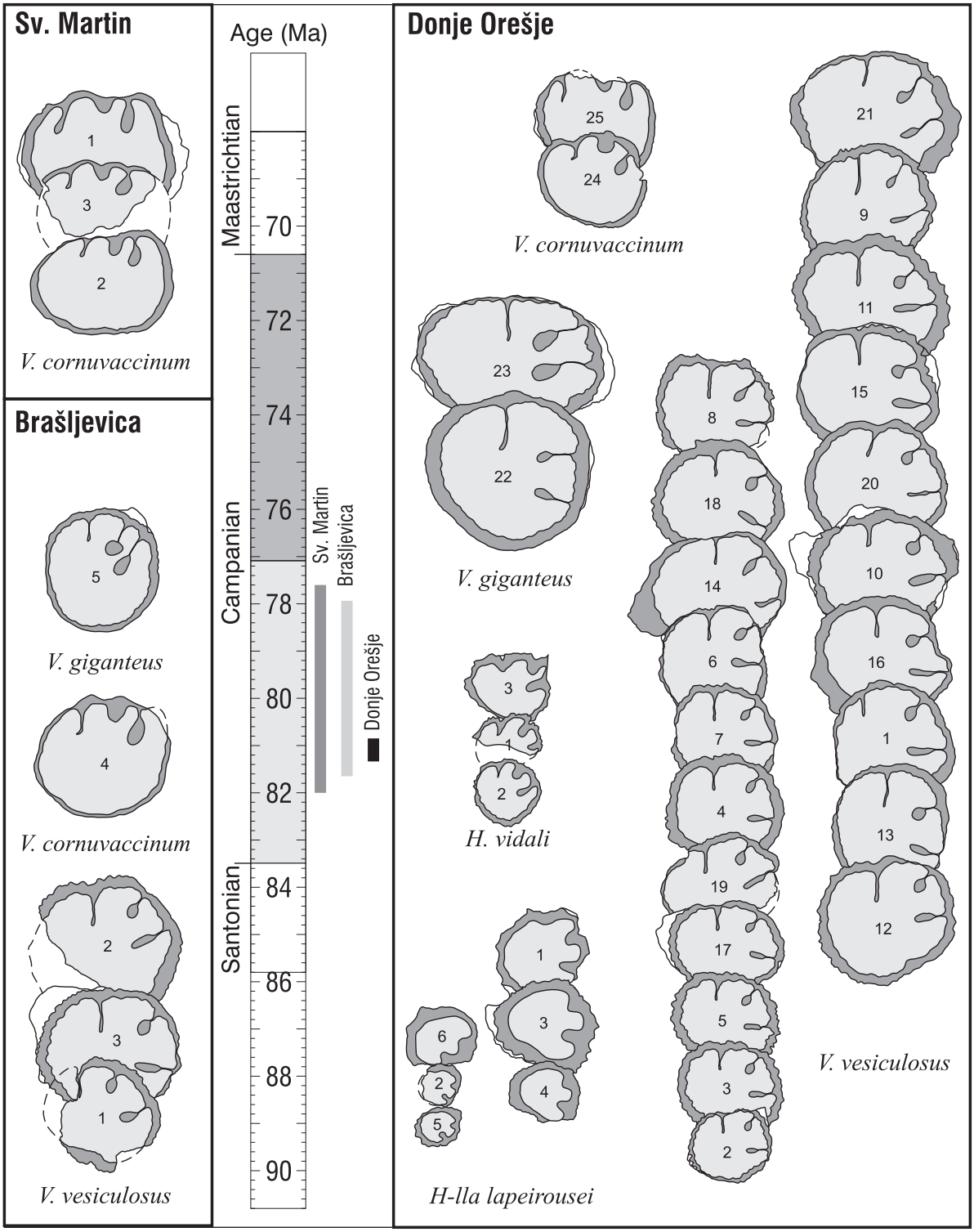

Figure 9. Transverse sections of hippuritid right valves from investigated locality grouped in different species. Stratigraphic age according to the strontium isotope stratigraphy. Time scale after Gradstein *et al.* (2004). Numbers on transverse sections correspond to the statistically determined groups. Upper and Lower Campanian are marked by different shades of gray.

(Sánchez 1981; Vicens 1992) and *Hippuritella lapeirousei* from Upper Santonian–Maastrictian (Polšak 1979; Sánchez 1981; Vicens 1992; Steuber 2003; Pleničar 2005). Above listed biostratigraphical rages of determined rudists have good agreement with biostratigraphy of micro- and nannofossils (Lower–Upper Campanian), as well as with SIS data which correspond to the upper part of the Lower Campanian.

Conclusion

According to the statistical analysis and morphological observations of rudist communities and the fossil content and strontium isotope stratigraphy of three investigated sites in NW Croatia with transgressive Upper Cretaceous deposits it is possible to conclude the following:

(1) On basis of the micro- and nannofossils and strontium isotope analysis of rudist shells, the studied sediments are aged as upper part of Lower Campanian.

(2) Rudist communities, are also present and when subjected to Cluster analysis, together with morphological observations, result in recognition of following rudist species: *Vaccinites cornuvaccinum* is determined at all localities, *V. giganteus* and *V. vesiculosus* at Brašljevica and Donje Orešje, while *Hippurites vidali* and *Hippuritella lapeirousei* are present at Donje Orešje.

Acknowledgements

The authors would like to thank reviewers Jean Philip and Enric Vicens for giving valuable advices and suggestions, especially to E.V. for exact notations which improved the manuscript. We also thank R. Košćal for the computer preparation of figures and Dr. Carrie E. Schweitzer (Department of Geology, Kent State University) for English language. This work was supported by a grant from the Ministry of Science, Education and Sport of the Republic of Croatia, projects 0019-1101152-1167 and 0019-1101152-1169.

References

Arkhangelsky, A.D. 1912. *Upper Cretaceous Deposits of the East European Russia. Materials on Geology of Russia*. Imperator Akademii Nauk, St. Petersburg **25** [in Russian].

Black, M. 1971. Coccoliths of the Speeton clay and Sutterby marl. *Proccedings of Yorkshire Geological Society* **38**, 381–424.

Black, M. & Barnes, B. 1959. The structure of coccoliths from the English Chalk. *Geological Magazine* **96**, 321–328.

Bronn, H.G. 1831. Hippurites. *In:* Ersch, J.S. & Gruber J.G. (eds), *Allgemeine Encyclopedie der Wissenschaften und Künste, Zweite Section, Achter Theil*. Brockhaus, Leipzig, 371–376.

De Castro, P. 1967. *Moncharmontia apenninica*, nuovo nome per *Neoendothyra appeninica* De Castro, 1966. *Bolletino della Società dei Naturalisti in Napoli* **76**, 475–476.

De Castro, P. 1971. Osservazioni su Raadshooveniaa Van Den Bold e i suoi rapporti col nuovo genere *Scandonea* (Foraminiferida, Miliolacea). *Bolletino della Società dei Naturalisti in Napoli* **80**, 1–78.

Dechaseaux, C. & Coogan, A.H. 1969. Family Hippuritidae Gray 1848. *In*: Moore, R.C. (ed), *Treatise on Invertebrate Paleontology*. The Geological Society of America. University of Kansas, Lawrence, N799–N803.

Defrance, J.L.M. 1821. Hippurites. *In:* Defrance, J.L.M. (ed), *Dictionaire des Sciences naturelles,* **21**. Levrault, Paris, 195–197.

Deflandre, G. 1959. Sur les nannofossiles calcaires et leur systematique. *Revue de Micropaleontologie* **2,** 127–152.

Douvillé, H. 1890. Communication sur les Hippurites. *Bulletin de la Société géologique de France, Série* 3, **18**, 324–325.

Douvillé, H. 1891. Etudes sur les rudistes. Révision des principales éspèces d'Hippurittes. *Mémoires de la Société géologique de France, Paléontologie 6* **1**, 1–31.

Douvillé, H. 1892. Etudes sur les rudistes. Révision des principales éspèces d'Hippurittes. *Mémoires de la Société géologique de France, Paléontologie 6* **2**, 33–56.

Douvillé, H. 1893. Etudes sur les rudistes. Révision des principales éspèces d'Hippurittes. *Mémoires de la Société géologique de France, Paléontologie 6* **3**, 57–94.

Douvillé, H. 1894. Etudes sur les rudistes. Révision des principales éspèces d'Hippurittes. *Mémoires de la Société géologique de France, Paléontologie 6* **4**, 95–138.

Douvillé, H. 1897. Études sur les Rudistes: Distribution régionale des Hippurites. Les Hippurites de la Province Orientale. *Memories de la Société Géologique de France, Paléontologie 6* **6**, 187–230.

Douvillé, H. 1908. Sur le développement des hippurites. *Bulletin de la Société géologique de France, Série 4* **8**, 268–269.

Fischer, P. 1887. *Manuel de conchyliologie et de paléontologie conchyliologique ou historie naturelle des mollusques vivants et fossiles*. F. Savy, Paris, 1–1369.

Futterer, C. 1893. Hippurites von Nabresina, *Sonderabdruck aus der Zeitschrift der Deutschen geologischen Gesellschaft* **45**, 3, p. 486.

Gaudry, A. 1867. *Animaux fossiles et géologie de l'Attique*. F. Savy, Paris, 1–476.

Goldfuss, A. 1840. *Petrefacta Gemaniae*. **2**, Part 7, 225–317.

Gradstein, F.M., Ogg, J.G., Smith, A.G., Agterberg, F.P., Bleeker, W., Cooper, R.A., Davydov, V., Gibbard, P., Hinnov, L., House, M.R., Lourens, L., Luterbacher, H. P., Mc Arthur, J., Melchin, M.J., Robb, L.J., Shergold, J., Villeneuve, M., Wardlaw, B.R., Ali, J., Brinkhuis, H., Hilgen, F.J., Hooker, J., Howarth, R.J., Knoll, A.H., Laskar, J., Monechi, S., Powell, J., Plumb, K.A., Raffi, I., Röhl, U., Sanfilippo, A., Schmitz, B., Shackleton, N.J., Shields, G.A., Strauss, H., Van Dam, J., Veizerm, J., Van Kolfschoten, Th. & Wilson, D. 2004. *A Geologic Time Scale 2004*. Cambridge University Press, Cambridge, p. 611.

Gray, J.E. 1848. On the arrangement of the Brachiopoda. *Annals and Magazine of Natural History, Series 2*, **2**, 435–440.

Hammer, O., Harper, D.A.T. & Ryan, P.D. 2003. *PAST-Paleontological statistics, Ver. 1.15*. http://folk.uio.no/ohammer/past.

Herak, M. 1966. Geological investigation of Žumberak Mt. limestones. *Ljetopis JAZU* **71**, 263–265 [in Croatian].

Herak, M. 1968. New results of investigations of the basic stratigraphic units at Žumberak area. *Geološki vjesnik* **21**, 111–116 [in Croatian].

Hombres-Firmas, L.A.d' 1838. *Recueil de mémoires et d'observations de psysique, de météorologie, d'agriculture et d'historie naturelle*. Ballivet et Fabre, Nismes, 1–278.

Horwath, R.J. & McArthur, J.M. 1997. A robust LOWESS fit to the marine Sr-isotope curve for 0–206 Ma, with look-up table for derivation of numerical age. *Journal of Geology* **105**, 441–456.

Koch, F. 1918. Die oberen Kreideschiscicten das Kalnik-Gebirges in Kroatien. *Glasnik Hrvatskog Prirodoslovnog Društva* **31**, 67–79.

Korolija, B., Fuček, L., Oštrić, N. & Velić, I. 1995. Upper Triassic and Senonian sediments at Donje Orešje. *In*: Šikić, K. (ed), *Geological Guidebook of Medvednica Mt.* Croatian Geological Institute, INA, Zagreb, 173–179 [in Croatian].

Ktenas, A. 1907. Sur l'age des terrains calcaires des environs d'Athènes. *Comptes rendus des Séances de l'Académie des Sciences* **144**, 697–699.

Kühn, O. 1933. Rudistae from eastern Persia. *Records of the Geological Survey of India* **66**, 151–179.

Kühn, O. 1948. Stratigraphie und Paläogeographie der Rudisten. IV. Rudisten aus Griechehland. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Abhandlungen* **B–89**, 167–194.

Lamarck, J.B. 1801. *Système des animaux sans vertebras ou tableau général des classes, des ordres et de genres des animaux*. Volume **1**, Deterville, Paris, p. 432.

Laviano, A. & Guarneri, G. 1989. *Vaccinites vredenburgi* Kühn, 1932, from the Upper Cretaceous of Apulia (southern Italy). *Bolletino della Società Paleontologica Italiana* **28**, 78–86.

Laviano, A. & Maresca, M.G. 1992. Paleontological characters of the species *Vaccinites vesiculosus* (Woodward). *Geologia Romana* **26**, 49–59.

Manivit, H., Perch-Nielsen, K., Prins, B. & Verbeek, J.W. 1977. Mid Cretaceous Calcareous Nannofossil Biostratigraphy. *Proceedings of the Koninklijke Nederlandse Academie van Wetenschappen. Series B: Physical Sciences* **80**, 169–181.

Matheron, P. 1880. *Recherches paléontologiques dans le Midi da la France.* Volume **6**, Marseille.

McArthur, J.M., Horwath R.J. & Bailey T.R. 2001. Strontium isotope stratigraphy: LOWESS Version 3. Best-fit line to the marine Sr-isotope curve for 0 to 509 Ma and accompanying look-up table for deriving numerical age. *Journal of Geology* **109**, 155–169.

Montfort, D. de 1808. *Conchyologie systématique et classification méthodique des coquilles*. F. Schoell, Paris **1**, 332–334.

Moro, A. & Ćosović, V. 2004. A Proposal for taxonomic Re-Evaluation of *Vaccinites* Species from Santonian Limestones of Southern Istria (Croatia). *Geologia Croatica* **57**, 139–147.

Moro, A., Mezga, A., Ćosović, V., Tunis, G. & Tarlao, A. 2008. Rudists and dinosaur footprints – mutual relationship within mud-supported Upper Cenomanian peritidal limestones of Istria, Croatia. *Bollettino della Societa Geologica Italiana* **127**, 423–428.

Moro, A., Skelton, P.W. & Ćosović, V. 2002. Palaeoenvironmental setting of rudists in the Upper Cretaceous (Turonian–Maastrichtian) Adriatic Carbonate Platform (Croatia), based on sequence stratigraphy. *Cretaceous Research* **23**, 489–508.

Munier-Chalmas, H. 1888. Communication relative aux rudistes. *Bulletin de la Société géologique de France, Série 3*, **13**, 71–75.

Orbigny, A.d'. 1839. Note sur le genre *Caprina*. *Revue zoologique de la Société Cuviérienne Paris* **2**, 168–169.

Orbigny, A.d'. 1847. Sur les brachiopodes ou palliobranches. *Complets rendus hebdomadaires des Séances de l'Académie des Sciences* **25**, 266–269.

Parker, C.W. & Arnold A.J. 1999. Quantitative methods of data analysis in foraminiferal ecology. *In:* Sen Gupta, B.K. (ed), *Modern Foraminifera*. Kluwer Academic Publishers, Dorderecht, 71–89.

Perch-Nielsen, K. 1986. New Mesosoic and Paleogene calcareous nannofossils. *Eclogae Geologiace Helvetiae* **79**, 835–847.

Philip, J. & Platel, J.-P. 1996. Stratigraphy and rudist biozonation of the Campanian and the Maastrichtian of eastern Oman. *Revista mexicana de Ciencias geológicas* **12**, 257–266.

Platel, J.-P., Philip, J., Bourdillon-De Grissac, C., Babinot, J.F., Roger, J. & Mercadier, C. 1994. Modalités de la transgression campanienne sur le massif du Haushi-Huqf (Oman). Stratigraphie, contexte géodinamique et paléoenvironnements. *Bulletin de la Société géologique de France* **165**, 147–161.

Pleničar, M. 2005. *Upper Cretaceous Rudists in Slovenia.* Opera/Academia scientarium et atrium Slovenica, Classis IV, Historia naturalis **39**, 1–255.

Pleničar, M. & Premru, U. 1970. Basic geological map of SFRY, Explanatory notes for sheet Novo Mesto L 33–79, Savezni geološki zavod Beograd, Beograd [in Slovenian].

Pleničar, M., Premru, U. & Herak, M. 1975. *Basic Geological Map of SFRY, Sheet Novo Mesto. L 33–79, 1:100 000*. Savezni geološki zavod Beograd, Beograd.

Polšak, A. 1979. Stratigraphy and Paleogeography of the Senonian Biolititihic complex at Donje Orešje, Mt. Medvednica, North Croatia, *Acta Geologica IX/6* **42**, 195–231.

Polšak, A., Bauer, V. & Sliškovič, T. 1982. Stratigraphie du Crétacé Supérieur de la Plate-forme Carbonatée dans les Dinarides Externes. *Cretaceous Research* **3**, 125–133.

Polšak, A., Devidé-Nedêla, D., Turnšek, D., Gušić, I. & Benić, J. 1978. Biostratigraphy of Upper Cretaceous reef, subreef and basin deposits of Donje Orešje (Mt. Medvednica, northern Croatia). *Geološki vjesnik* **30**, 189–197 [in Croatian with English abstract].

Poljak, J. 1942. Contribution to geological knowledge of Kalnička gora Mt. *Vjesnik Hrvatskog Državnog Geološkog Zavoda i Hrvatskog Državnog Geološkog Muzeja* **1**, 52–92 [in Croatian].

Redlich, K.A. 1900. Die Kreide des Görtschitz- und Gurkthales. *Jahrbuch der Kaiserlich-Königlichen Geologischen Reichsanstalt* **49**, 663–678.

Rolland Du Roquan, O. 1841. *Description des coquilles fossils de la famille des rudistes qui se trouvent dans le terrain crétacé des Corbiéres*. L.Pomiés-Gardel, Carcassonne, 1–70.

Sánchez, M.V. 1981. Hippuritidae y Radiolitidae (Bivalvia). Catalogo de especies. *Universidad Autonoma de Barcelona, Publicaciones de Geologia* **15**, 1–228.

Simonpiétri, G. & Philip, J. 2000. Relations ontogénese- philogénese chez les rudistes: l'example des Hippuritidae Gray, 1848 (Ontogeny-philogeny relationship in rudists: the example of Hippuritidae Gray 1848 – in French). *Sceinces de la Terre et planets* **330**, 717–724.

Simonpiétri, G., Philip, J. & Platel, J.-P. 1998. Etude statistique des espéces du genre Vaccinites /Hippuritacea, Hippuritidae) du Campanien du Sultanat d'Oman. *In*: Masse, J.-P. & Skelton, P.W. (eds), *Quatrième Congrès International sur les Rudistes,* Geobios, Memorie Spéciale **22**, 313–329.

Skelton, P.W. 1978. The evolution of functional design in rudists (Hippuritacea) and its taxonomic implications. *Philosophical Transactions of the Royal Society of London* **B284**, 305–318.

Steuber, T. 1999. *Cretaceous Rudists of Beotia, Central Greece*. Special Paper in Paleontology **61**.

Steuber, T. 2003. Strontium isotope stratigraphy of Cretaceous hippuritid rudist bivalves: rates of morphological and heterochronic evolution. *Palaeogeography, Palaeoclimatology, Palaeoecology* **200**, 221–243.

Steuber, T. & Rauch, M. 2005. Evolution of the Mg/Ca ratio of Cretaceous seawater: implications from the composition of biological low-Mg calcite. *Marine Geology* **217**, 199–213.

Stradner, H. 1961. Vorkommen von Nannofossilien im Mesozoikum und Altlertiär. *Erdoel-2* **77**, 77–88.

Šribar, L. & Pleničar, M. 1991. Upper cretaceous assemblage zones in southwestern Slovenia. *Geologija* **33**, 171–205.

Toucas, A. 1903. Études sur la classification et l'évolution des Hippurites. Premiére partie. *Memories de la Société Géologique de France, Paléontologie 30* **11**, 1–64.

Toucas, A. 1904. Études sur la classification et l'évolution des Hippurites. Deuxième partie. *Memories de la Société Géologique de France, Paléontologie 30* **12**, 65–128

Vicens, E. 1992. Intraspecific variability in Hippuritidae in the Southern Pyrenees, Spain: Taxonomic implications. *Geologia Romana* **28**, 119–161.

Woodward, S.P. 1855. On the structure and affinities of the Hippuritidae. *Quarterly Journal of the Geological Society, London* **11**, 40–61.