

## A Proposal for Taxonomic Re-Evaluation of *Vaccinites* Species from the Santonian Limestones of Southern Istria (Croatia)

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**Key words:** *Vaccinites*, Taxonomy, Cluster analysis, Santonian, Adriatic Carbonate Platform, Istria, Croatia.

### Abstract

Rudists, especially members of the family Hippuritidae, were common dwellers on the Adriatic Carbonate Platform during the Late Cretaceous. Morphological elements (ligamental ridge, teeth, pillars, 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 different species to be defined within the family. Transverse sections of *Vaccinites* specimens from the Santonian limestones in southern Istria show different values of the angle between the teeth and the ligamental ridge, between the ligamental ridge and the E pillar ( $P_2$ ), and of the ratio between the length of the contour and the pillar suture distance. Cluster analyses (Ward's and Unweighted pair-group average methods) using measured elements, allowed the definition of three species groups from seventeen species at the beginning of study.

### 1. INTRODUCTION

Rudists are important macrofossils in the Upper Cretaceous of the Adriatic Carbonate Platform. Among them, hippuritids are common, particularly in the Santonian of southern Istria (MORO, 1997; MORO & ČOSOVIĆ, 2000) where they have been used for detailed biostratigraphy (POLŠAK, 1965; POLŠAK et al., 1982). POLŠAK (1965, 1967) recognised seventeen species (Table 1) based on morphological characteristics (S and E pillars, shell thickness, visceral cavity and ornamentation).

Determination of the species within the family today is based on a combination of morphological elements (ligamental ridge, teeth, and pillars). The sector  $L-P_1-P_2$ , i.e. ligamental ridge and pillars of the lower valve (DECHASEAUX & COOGAN, 1969) are also very important for identification.

The base for taxonomic re-evaluation is SKELTON's (1976) description (Fig. 1) of *Hippurites* and *Vaccinites*, involving evolutionary rotation of the myocardial axis (SKELTON, pers. comm. 1973; in SKELTON, 1976), which was further developed by SIMONPIÉTRI & PHILIP (2000). The difference in angle, as a consequence of ventral expansion, produced a larger body cavity in *Vaccinites* in comparison with *Hippurites*.

*Vaccinites* shows different values of the angle between the teeth and the ligamental ridge, as well as that between the ligamental ridge and the  $P_1$  pillar. Such angles have been based on different criteria for the description and determination of the hippuritids from the Southern Pyrenees (VICENS, 1992), Ostuni area (Italy – LAVIANO & MARESCA, 1992) and Boeotia (Greece – STEUBER, 1999).

According to VICENS (1992), angles between the teeth and the ligamental ridge may be useful for determining the genus and occasionally the group to which a species belongs. Also, beside other angles, the angle between the ligamental ridge and the  $P_1$  pillar (LP2 in VICENS, 1992) could be useful for determining the species groups.

We have chosen the aforementioned two angles (Fig. 1) because they are the most prominent characteristic of the studied individuals, which flourished during a short time span, and in addition they have been found within the same facies (POLŠAK, 1965, 1967), as scattered individuals together with radiolitids in mud supported early Santonian floatstones (MORO, 1997; MORO & ČOSOVIĆ, 2000).

Given the morphological variability of analogous living bivalves (e.g. oysters), among which more than a few species rarely co-occur in the same facies, the apparent high diversity of species recognised by POLŠAK (1967) may be questioned.

Our re-evaluation of *Vaccinites* species is based on biostatistics and on the field and laboratory experiences of the senior author. We are aware that statistical analysis is not a magic tool that will resolve the taxonomy of rudists. When specimens are incorporated in carbonates and it is quite difficult to extract them for determination, their identification at the species-group level using the simplest methods and tools in the field, has to be considered.

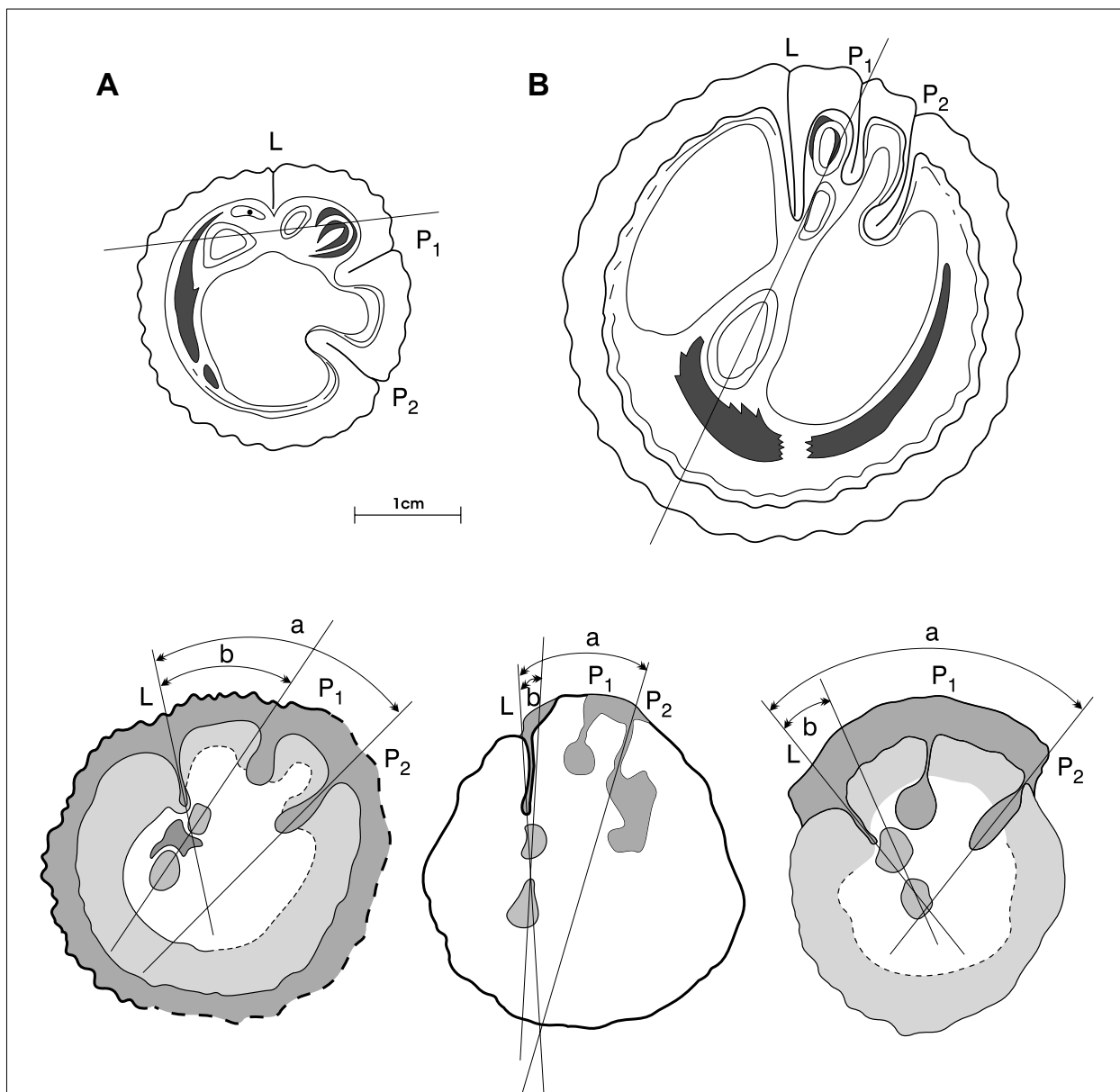


Fig. 1 Upper part of figure: transverse section of *Hippurites* (A) and *Vaccinites* (B) attached valves with rotation of myocardinal axis (from SKELTON, 1976). Lower part of figure: transverse section of *Vaccinites boehmi* (DOUVILLÉ), *V. atheniensis* (KTENAS) and *V. oppeli santoniensis* (KÜHN) from POLŠAK (1967) with L-P<sub>2</sub> (a) and L-T (b) angles. Transverse sections not to scale.

## 2. MATERIAL AND METHODOLOGY

All specimens have preserved ligamental ridges, as well as pillars. Teeth elements in some specimens indeterminate probably due to calcite infilling of the shell interior, which has the same colour as the rest of the shell. Shell layers are poorly preserved. All specimens have been transversely sectioned. Here, we deal with broken specimens; all of them cylindrical in shape with the same diameters along the preserved part of specimens (see POLŠAK, 1967 – pl. 73, fig. 2; pl. 75, fig. 2; pl. 76, figs. 1 and 4; pl. 78, fig. 1; pl. 85, fig. 2). The constant diameters of the *Vaccinites* specimens allowed us to conclude that all specimens considered for this study were adults.

The measured structural elements are obtained from POLŠAK's (1965, 1967) transverse sections of the right valve of *Vaccinites* species (Fig. 1). They include the following:

- angle between the ligamental ridge and the E-pillar (L/P<sub>2</sub> in the further text, a in Fig. 1);
- angle between the ligamental ridge and the teeth (L/T in the further text, b in Fig. 1);
- inner diameter (RV interior, after LAVIANO & MARESCA, 1992);
- length of the contour around the inner margin of the outer shell layer (U in the further text; STEUBER, 1999);

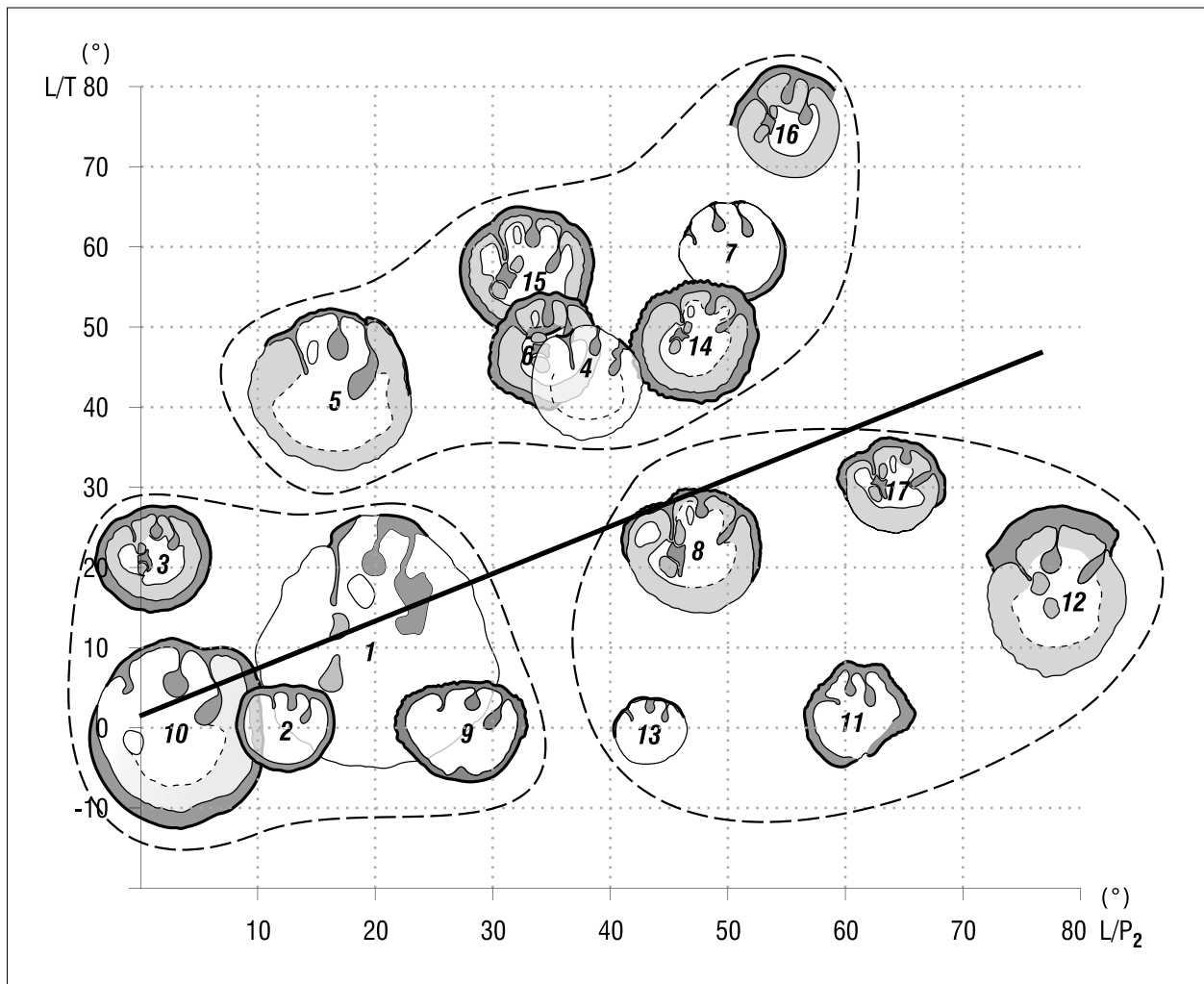


Fig. 2 Reduced major axis showing the relationship between  $L/P_2$  versus  $L/T$  angles in *Vaccinites* species from southern Istria (after POLŠAK, 1965, 1967). The size of the transverse sections of the right valves of *Vaccinites* species are reduced with respect to their original size. Numbers attached to the transverse sections correspond to numbers given to species in Table 1. Dotted line encircles statistically determined groups.

– the ratio between the length of  $U$  and the distance between the sutures for  $P_0$ – $P_2$  ( $U/P_0$ – $P_2$  in the further text; STEUBER, 1999).

The angle  $L/P_2$  is formed by straight lines which follow the general extension line of the ligamental ridge, i.e. which passes through the end of the ligament and the point where it intersects the inner diameter of the shell, and that which passes through the end of the pillar and the point where the  $P_2$  pillar intersects the inner diameter of the shell (Fig. 1).

For measurement of the Ligament–Teeth ( $L/T$ ) angle, the straight lines that follow the general extension of the ligamental ridge (as for  $L/P_2$  angles), and that which passes through the centre of both teeth, was considered (Fig. 1). The measurements are displayed in Table 1.

Statistical analyses (35 specimens for  $L/P_2$  and  $L/T$  and 17 for  $U$  and  $U/P_0$ – $P_2$ ) were calculated using the PAST software program (HAMMER et al., 2003). To avoid any possible dependency between variables, and

to achieve the line of best fit, we plotted Reduced Major Axis (RMA) (Fig. 2). Unlike standard approaches, this model is invariant to the selection of which variable is portrayed on which axis, and to differences in variable type (MACLEOD, 2004).

The data were also subjected to cluster analysis. Cluster analysis is one of the most widely used and commonly understood multivariate analytical techniques in the palaeontological literature. It segregates entities (species, specimens, measurements) into “naturally occurring groups” and quantifies the between-group relationships (PARKER & ARNOLD, 1999). Hierarchical cluster analyses were calculated using the Ward Method with Euclidean distance and Unweighted Pair-Group Average Method with Euclidean distance.

Ward’s and Unweighted pair-group methods join two entities with the highest mutual similarity at each iteration. At each step, a potential new cluster that yields the lowest total Euclidean distance is formed. This continues until a single cluster remains. Recognition of “significant” clusters within a dendrogram are based on

		No. of specs.	L/P <sub>2</sub> min/max	L/T min/max	L/P <sub>2</sub> (°)	L/T (°)	d (cm)	Π (cm <sup>2</sup> )	U (cm)	U/P0–P2 (cm)
1	<i>V. atheniensis</i>	3	18/22	6/8	20	7	4.1	52.8	84.6	6.0
2	<i>V. cornuvaccinum</i>	1			11		2.7	22.9	24.2	8.96
3	<i>V. taburni</i>	3		19/21		20	3.2	32.2	29.0	10
4	<i>V. giganteus</i>	2	37/37	41/47	37	44	3.1	30.2	36.1	8.804
5	<i>V. giganteus medulinus</i>	1			19	42	3.0	28.3	42.427	10.606
6	<i>V. salopeki</i>	5	30/40	42/48	35	45	2.7	22.9	32.2	7.318
7	<i>V. vredenburgi</i>	5	47/53	53/61	50	57	2.6	21.2	31.0	7.75
8	<i>V. inaequicostatus</i>	2	34/61	22/22	48	22	4.5	63.6	36.9	7.096
9	<i>V. cf. gosaviensis</i>	1			27		4.8	72.3	32.2	6.851
10	<i>V. kuehni</i>	1			2		4.3	58.0	43.75	8.75
11	<i>V. cf. kuehni</i>	1			62		2.8	24.6	27.0	6.923
12	<i>V. oppeli santonensis</i>	2	77/77	15/15	77	15	4.5	63.6	46.5	5.81
13	<i>V. sulcatus</i>	1			43		2.3	16.6	20.1	6.931
14	<i>V. boehmi</i>	2	40/57	46/46	48	46	2.7	22.9	31.0	6.326
15	<i>V. extremus</i>	1			33	57	3.7	42.9	37.9	6.851
16	<i>V. anici</i>	1			55	74	2.9	26.4	33.5	6.836
17	<i>V. gosaviensis</i>	3	52/70	30/30	64	30	2.7	22.9	26.0	5.098

Table 1 The list of *Vaccinites* species from the Santonian limestones with measured parameters.

the shortest distance between paired *Vaccinites* specimens.

### 3. BIOSTATISTICAL RESULTS

Hierarchical cluster analysis (Ward's method in Fig. 3) on the ligament–E pillar (L/P<sub>2</sub>), ligament–teeth (L/T), inner diameters, lengths of the contour (U) and the ratio between U and suture distance P0–P2, produced three main cluster groups.

The species *V. atheniensis* (1) (known as adult growth stage of *V. chaperi*; STEUBER, 1999), *V. cornuvaccinum* (2), *V. taburni* (3), *V. cf. gosaviensis* (9) and *V. kuehni* (10) represent the first cluster. The cluster combines species with L/P<sub>2</sub> angles from 2–27°, L/T up to 20°, U between 24.2 and 84.6 cm, and U/P0–P2 varying from 6.0 to 10 cm. The second cluster (Fig. 3) contains five species, *V. inaequicostatus* (8), *V. cf. kuehni* (11), *V. oppeli santonensis* (12), *V. sulcatus* (13) and *V. gosaviensis* (17). The species gathered together are defined by the following characteristics: L/P<sub>2</sub> varying from 43 to 77°, L/T from 15 to 30°, U between 20.1–46.5 cm, and U/P0–P2 between 5.1 and 7.1 cm. The third cluster (Fig. 3) is composed of the following species *V. giganteus* (4), *V. giganteus medulinus* (5), *V. salopeki* (6), *V. vredenburgi* (7), *V. boehmi* (14), *V. extremus* (15) and *V. anici* (16). The cluster includes species with the L/P<sub>2</sub> angles between 19–55°, L/T values between 42 and 74°, the U between 31–42.4 cm, and the U/P0–P2 ranging from 6.3 to 10.6 cm.

The applied Unweighted pair–group method (Fig. 4) reveals the identical grouping of species.

The results emerging from the cluster analysis of the measured angles (L/P<sub>2</sub> and L/T angles, Fig. 5), identify three cluster groups: the first cluster (*V. giganteus* (4), *V. giganteus medulinus* (5), *V. salopeki* (6), *V. vredenburgi* (7), *V. boehmi* (14), *V. extremus* (15) and *V. anici* (16)), with an average L/P<sub>2</sub> value of 39.57° and an average value of L/T of 52.14°. The second cluster (*V. atheniensis* (1), *V. cornuvaccinum* (2), *V. taburni* (3), *V. cf. gosaviensis* (9) and *V. kuehni* (10)), combines species with the lowermost values of the angles, the average L/P<sub>2</sub> value of 12° and of L/T of 5.4°. The third cluster, (*V. inaequicostatus* (8), *V. cf. kuehni* (11), *V. oppeli santonensis* (12), *V. sulcatus* (13) and *V. gosaviensis* (17)), is characterized by the largest disproportion of measured angles, the average value of L/P<sub>2</sub> around 59° and of L/T around 13°.

The Unweighted paired–group method of measured angles (Fig. 6) has resulted in the same grouping of species.

A particular difference in grouping of the seventeen species between linear graph (Fig. 2) and multivariate statistic analysis (Figs. 3–6) exists. The species with indefinite values of L/T or L/P<sub>2</sub> angles (for statistics we put value 0) are involved in this discrepancy.

### 4. MORPHOLOGICAL OBSERVATIONS

The determined groups of *Vaccinites* show certain degrees of morphological similarities.

Group I (Fig. 2, Table 2) contains forms with an elongated ligamental ridge, which are truncated at the tip. P<sub>1</sub> is pinched with an oval head. P<sub>2</sub> is pinched at its base and is longer than P<sub>1</sub>. P<sub>1</sub> and P<sub>2</sub> could be located

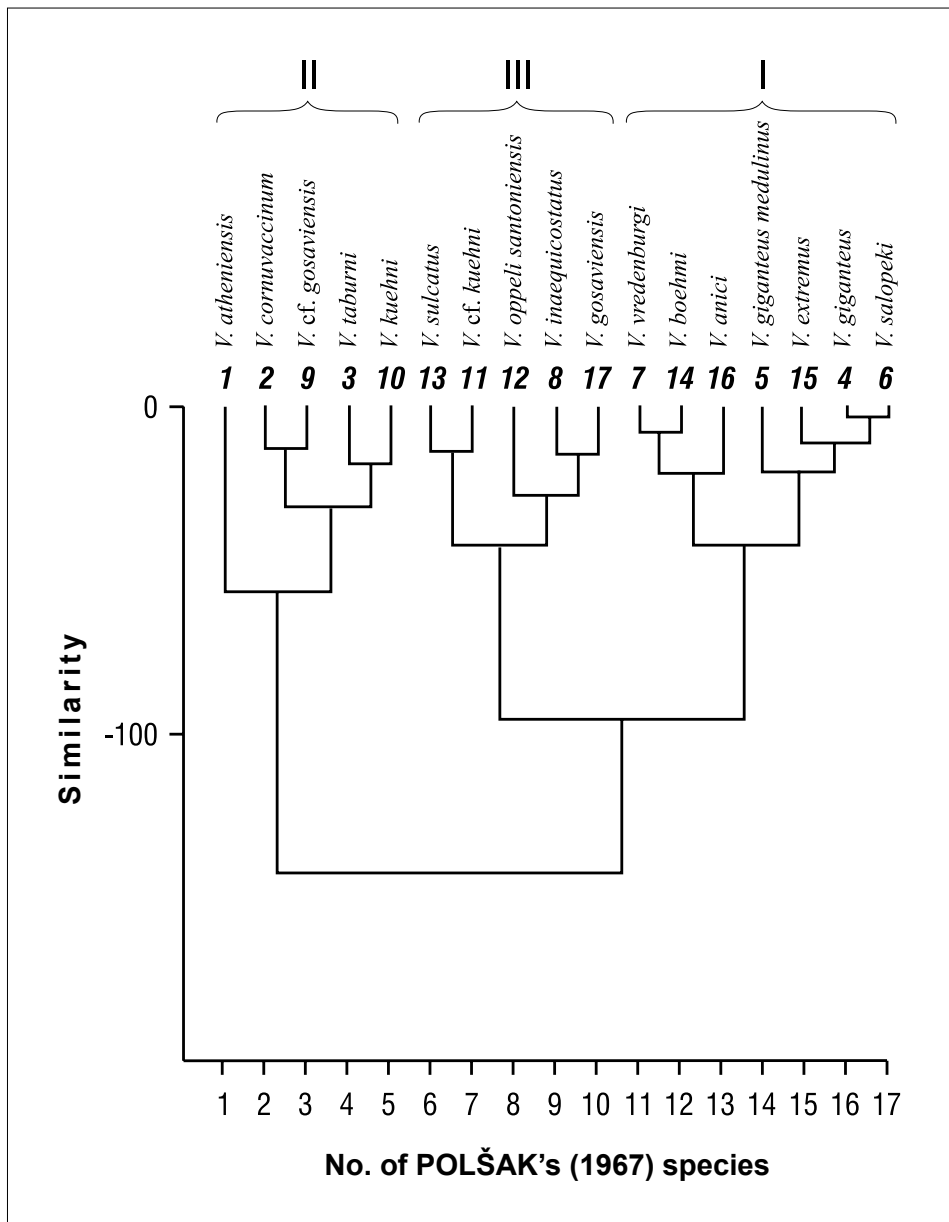


Fig. 3 Hierarchical cluster analysis (Ward's method) including all parameters for *Vaccinites* species from Santonian of southern Istria. Numbers I, II and III correspond to statistically determined groups.

	Group I	Group II	Group III
L/P <sub>2</sub> (°)	19–55	2–27	43–77
mean L/P <sub>2</sub> (°)	39.57	12	58.8
L/T (°)	42–74	7–20	15–30
mean L/T (°)	52.14	3.85	13.4
U	31–42.4	24.2–84.6	20.1–46.5
U/P0–P2	6.3–10.6	6.0–10	5.098–7.096
mean U	34.9	42.75	31.3
mean U/P0–P2	7.78	8.112	6.37
	<i>V. giganteus</i>	<i>V. cornuvaccinum</i>	<i>V. inaequicostatus</i>
	<i>V. gig. medulinus</i>	<i>V. taburni</i>	<i>V. o. santoniensis</i>
	<i>V. salopeki</i>	<i>V. cf. gosaviensis</i>	<i>V. cf. kuehni</i>
	<i>V. vredenburgi</i>	<i>V. kuehni</i>	<i>V. sulcatus</i>
	<i>V. extremus</i>	<i>V. atheniensis</i>	<i>V. gosaviensis</i>
	<i>V. boehmi</i>		
	<i>V. anici</i>		
Total no. of sp.	7	5	5

Table 2 Main characteristics of species groups recognized through statistical analyses.

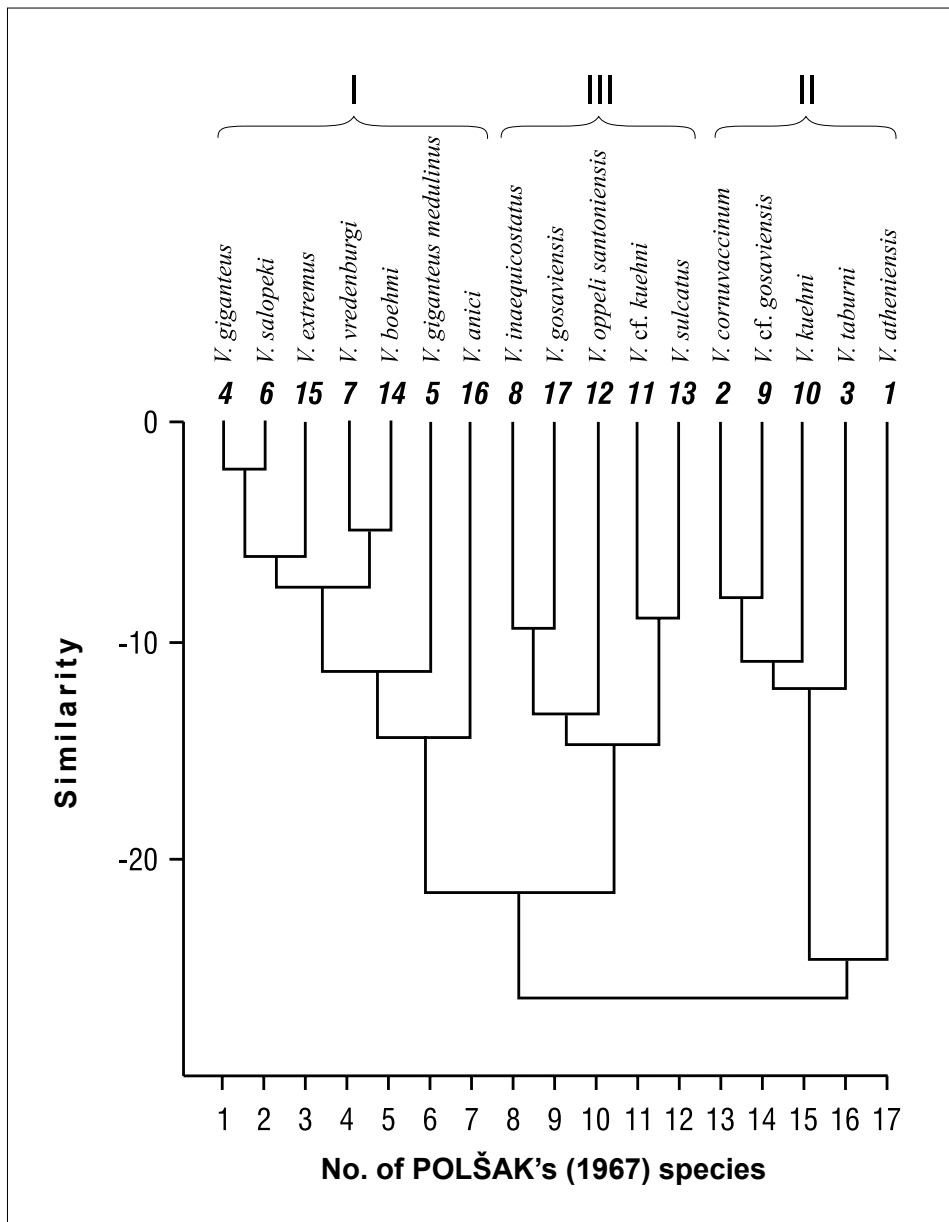


Fig. 4 Hierarchical cluster analysis (pair-group method) including all parameters for *Vaccinites* species from Santonian of southern Istria. Numbers I, II and III correspond to statistically determined groups.

close to each other. The teeth and their array are curved towards the anterior. A distinction between species included in this group, *V. vredenburgi* and *V. giganteus*, has been problematical for a while (LAVIANO & GUARNIERI, 1989; STEUBER, 1999).

The Group II (Fig. 2, Table 2) contain one of the oldest known hippuritid species, *Vaccinites cornuvaccinum* which is also the type species of the genus *Vaccinites* (BRONN, 1831; FISCHER, 1887; DECHA-SEAUX & COOGAN, 1969; STEUBER, 1999). Separating species, which are members of this group, *V. cornuvaccinum* from *V. taburni* has frequently been a problem, as well as another member of this group, *V. atheniensis*, which probably represents an adult growth stage of *V. chaperi* (STEUBER, 1999). Also, *V. cornuvaccinum* and *V. chaperi* are considered to be

of the same stratigraphic age, as well as coenozone, on the Adriatic Carbonate Platform (SLIŠKOVIĆ, 1968; POLŠAK et al., 1982; STEUBER, 1999). The ligamental ridge is slightly curved toward the anterior, especially at the end.  $P_1$  varies from parallel sided to considerably pinched at its base with an oval head.  $P_2$  is pedunculated with an oval head which can be slightly curved in an anterior direction.  $P_1$  and  $P_2$  can be fused at their junction with the inner diameter of the shell. The teeth are almost in line with the ligament ridge.

Specimens of the Group III (Fig. 2, Table 2) are characterised by a straight ligamental ridge, slightly curved towards the anterior.  $P_1$  has a round or oval head more or less pinched at its base and generally shorter than  $P_2$ .  $P_2$  is straight, and pinched at the base with an elliptical head. Teeth are both beside and in prolongation of the ligamental ridge.

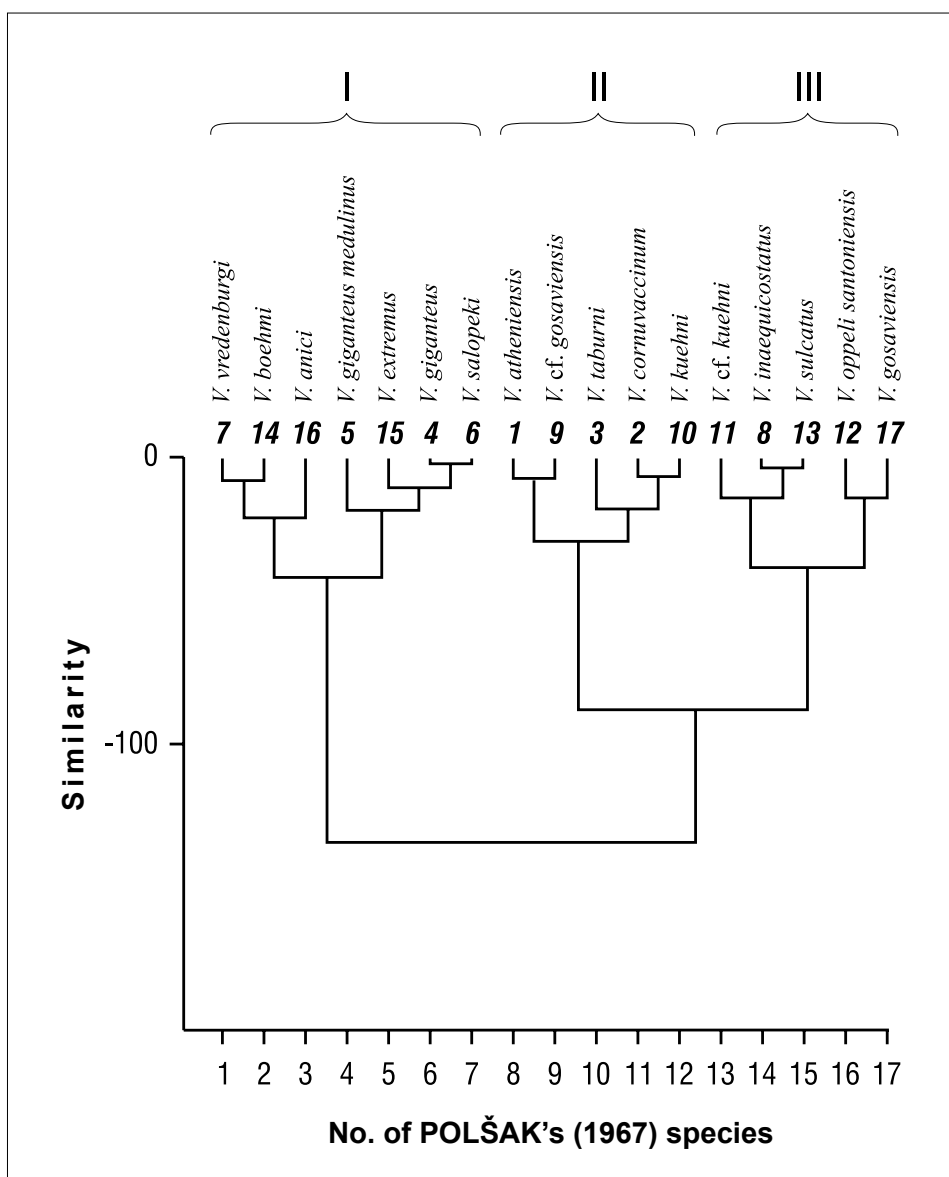


Fig. 5 Hierarchical cluster analysis (Ward's method) taking into account  $L/P_2$  and  $L/T$  measurements for *Vaccinites* species (POLŠAK, 1965, 1967). Numbers I, II and III correspond to statistically determined groups.

## 5. CONCLUSION

The aim of this work has been to check the possibility of taxonomic re-evaluation of *Vaccinites* species using cluster analysis (Ward's and Unweighted pair-group average methods). Cluster analyses of the measured elements indicates a relationship between the position of the teeth, ligamental ridge, E pillar, the length of U contour and the P0–P2 suture distance in the Santonian *Vaccinites* species from southern Istria. The cluster analysis, based upon field and laboratory observations, results in the recognition of three groups.

The first group, *V. giganteus*, *V. giganteus medulinus*, *V. salopeki*, *V. vredenburgi*, *V. boehmi*, *V. extremus* and *V. anici*, shows angle values between 19 and 55° ( $L/P_2$ ), 42–74° ( $L/T$ ), U values from 31–42.4 cm and  $U/P_0-P_2$  from 6.3–10.6 cm. The dental array is curved in an anterior direction.

The second group includes the species *Vaccinites cornuvaccinum*, *V. chaperi* (= *V. atheniensis*), *V. taburni*, *V. cf. gosaviensis* and *V. kuehni*. The characteristics of this group are:  $L/P_2$  values 2–27°,  $L/T$  values 7–20°, U values 24.2–84.6 cm and  $U/P_0-P_2$  values 6.0–10 cm. The teeth are almost in the line with the ligament ridge.

The third group, *V. inaequicostatus*, *V. cf. kuehni*, *V. oppeli santoniensis*, *V. sulcatus* and *V. gosaviensis*, has angle values from 43 to 77° for  $L/P_2$ , 30° or less for  $L/T$  (between 15 and 30°), U values from 20.1–46.5 cm, and  $U/P_0-P_2$  from 5.1–7.1 cm. The teeth are beside and in prolongation of the ligamental ridge.

## Acknowledgements

We wish to thank Professors Jean PHILIP and Peter W. SKELTON, as well as Dr. Ricardo CESTARI for reviewing the paper and giving valuable advice which

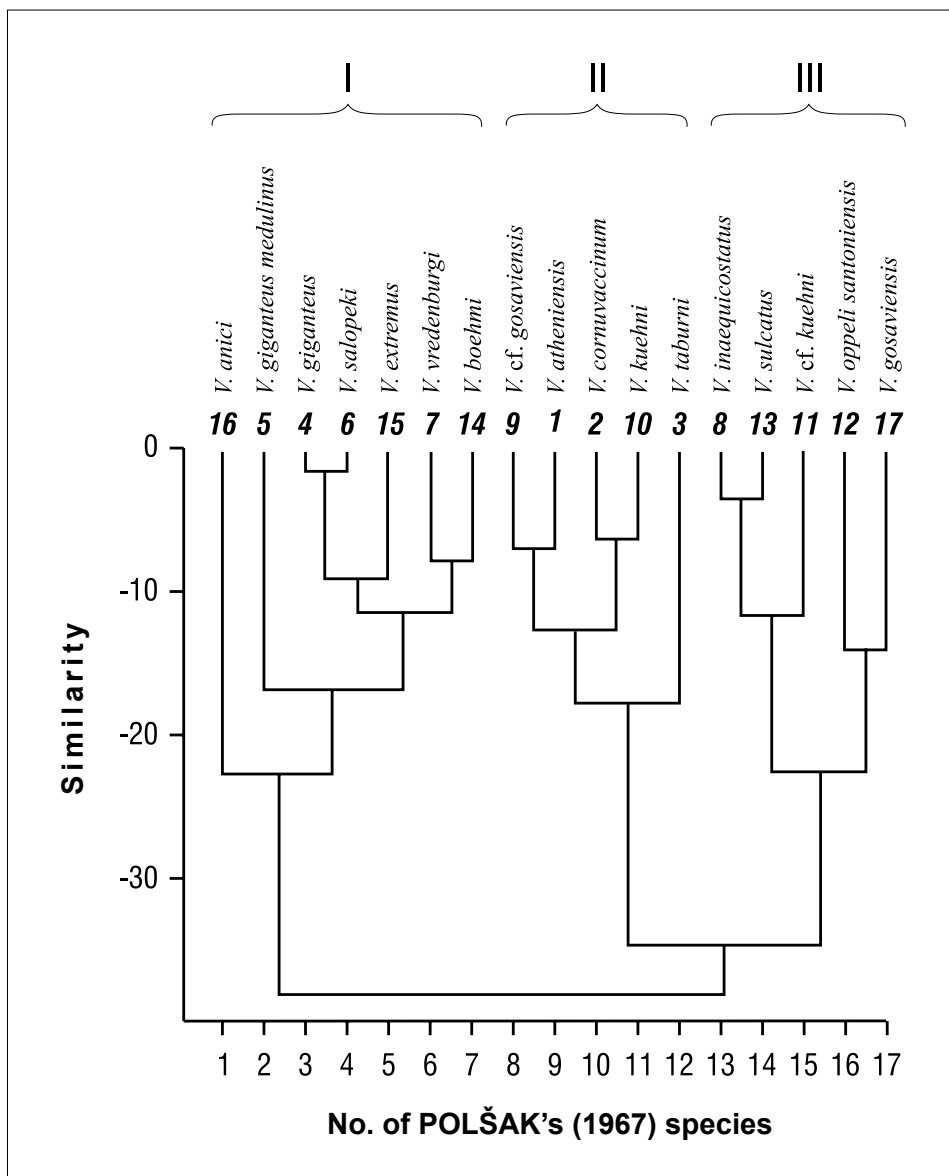


Fig. 6 Hierarchical cluster analysis (pair-group method) considering  $L/P_2$  and  $L/T$  measurements for *Vaccinites* species (POLŠAK, 1965, 1967). Numbers I, II and III correspond to statistically determined groups.

improved the manuscript, and especially P.W. SKELTON for language improvement. We also thank R. KOŠČAL for computer preparation of figures. This work has been supported by a grant from the Ministry of Science, Education and Sport of the Republic of Croatia, projects 0119402 and 119315.

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Manuscript received March 12, 2003.

Revised manuscript accepted November 08, 2004.

