

## ***Amphiope caronei* n. sp. (Echinoidea Astriclypeidae) from the Tortonian of Cessaniti, Vibo Valentia Province (Calabria, Italy)**

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### **ABSTRACT**

A new species of *Amphiope* L. Agassiz, 1840 (Echinoidea Astriclypeidae) from the late Miocene (Tortonian) of Vibo Valentia Province, Calabria, Southern Italy, is herein described. This species is distinguished from all the others so far known, by the smaller size of the petalodium, that varies from a minimum of 40.5% to a maximum of 46% (mean 44%) of the test length, thus representing the lowest value in this genus. It is hypothesized that the petalodium reduction could be due to climate and - more generally - environment, resulting from the Mediterranean pre-salinity crisis conditions that characterized these areas during the Tortonian and towards the beginning of the Messinian.

### **KEY WORDS**

*Amphiope*; Astriclypeidae; Tortonian, Miocene; Calabria.

Received 26.02.2018; accepted 18.03.2018; printed 30.03.2018

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### **INTRODUCTION**

This research aims to improve the definition and taxonomy of the genus *Amphiope* L. Agassiz, 1840 (Echinoidea Astriclypeidae), and to properly reconstruct the Proto-Mediterranean diffusion pathways, thus contributing to a reliable palaeogeographic interpretation. In fact, the diffusion and the taxonomy of *Amphiope* is still partly to be clarified because of the lack of accuracy in the description of the species (rarely concerning the structure) that have been left by several ancient authors (see for example, Agassiz, 1841; Agassiz & Desor, 1847; Cotteau, 1877; 1895; Lambert, 1907, 1912; Comaschi Caria, 1955, 1972; Barbera & Tavernier, 1989). Moreover, Philippe (1998) had put into synonymy of *Amphiope bioculata* (Des Moulins, 1837) many of the previously established nominal species, charging to *Amphiope* a very wide morphological variability. This has led several authors to identify as *A. biocu-*

*lata*, many forms that have turned out, or that could result, belonging to other species (see also Kroh, 2005; Pereira, 2010; Garilli et al., 2010).

*Amphiope* is an extinct echinoid genus, belonging to the Astriclypeidae Stefanini, 1912, family, widespread especially in the Proto Western Mediterranean and neighbouring basins during the Miocene (for an overview, see Stara & Rizzo, 2014 and Stara & Borghi, 2017). At the end of the early Miocene, it arrived to Angola, in the South Atlantic, and to North-Western India, in the East (Smith & Kroh, 2011). After Stara & Borghi (2017, with references), the chronological distribution of the species of this genus in the peri-Mediterranean area ranges from the Oligo-Miocene boundary to the Pliocene.

The occurrence of *Amphiope* in the Miocene of Calabria, southern Italy, was previously mentioned by Cotteau (1914) and by Carone & Domning (2007). Carone & Domning (2007) and Marra et al. (2017) have also precisely indicated the stratigra-

phic position of an *Amphiope*-rich level outcropping at Cava Gentile (ex Braunia pro parte), a sand quarry near Cessaniti (Vibo Valentia Province), but none, until now, had described the identifying features of this form of *Amphiope*, classifying them, as proposed by Philippe (1998) as *Amphiope bioculata*. Thanks to a modern approach and using a wide range of measures to study the structure and the morphological and morphometric features of these echinoids, this work propose a new specific systematic classification of these Calabrian's forms. Moreover, once the systematic position has been clarified, finding a link between shape variation and climate change could support, in the future, improved paleoecological interpretations.

### Geological setting

The late Miocene succession of Capo Vaticano-

Monte Poro extends from the coastal area to the inland of the promontory. It has, in the past, been described in detail by Nicotera (1959) and Rao et al. (2007). Since the late Tortonian, the Capo Vaticano-Monte Poro area acted as a structural high, covered by marine coastal deposits (Fig. 1). The succession overlies the granitic basement and consists of two main intervals (Nicotera, 1959). The lower interval, informally identified as “dark argillaceous sands with *Ostreids* and *Cerithids*”, consists of brackish, organic-rich muds with sandy interfingering deposits, and were interpreted as flood tidal deltas (Neri et al., 2005; Gramigna et al., 2008).

The upper interval, informally named “*Clypeaster* sandstones” (“*Arenarie a Clypeaster*” of Ogniben, 1973), consists of grey sands, several tens of meters thick, and contains an abundance of marine faunas composed by echinoids (mainly *Clypeaster*

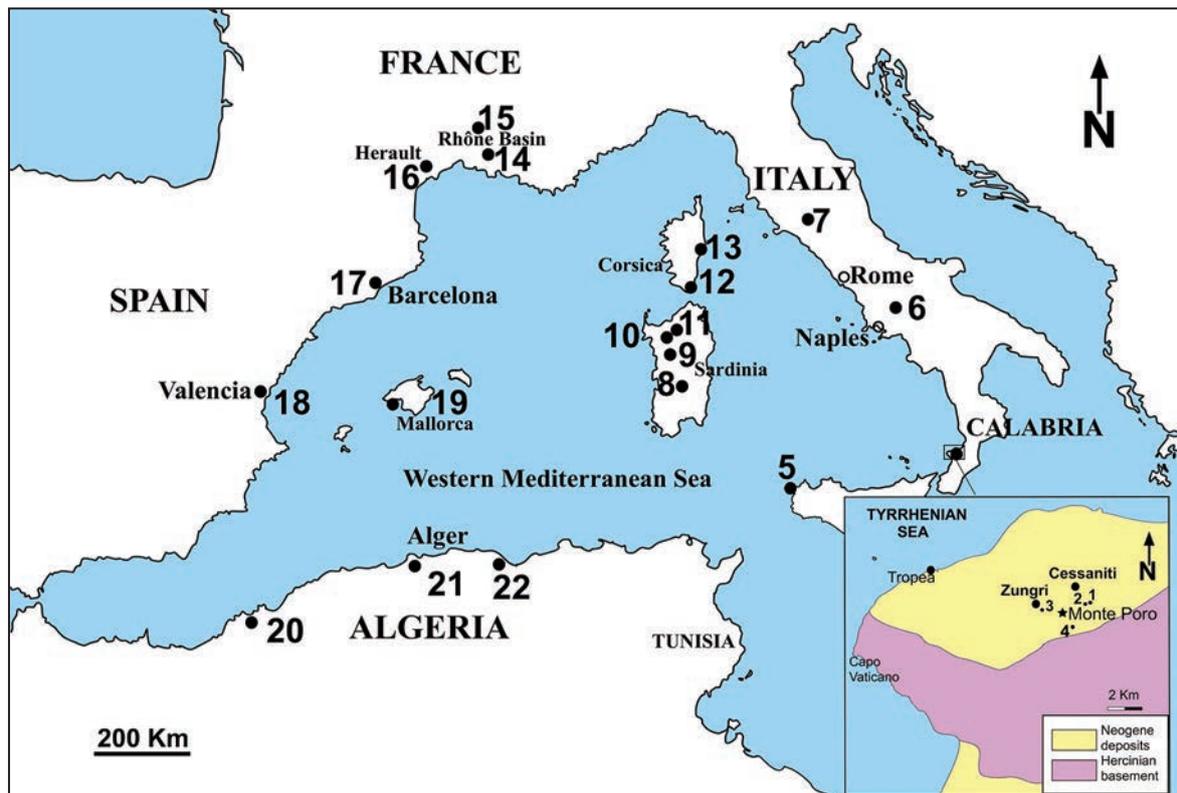


Figure 1: Simplified map of *Amphiope*'s localities cited in, or related to, this study. Italian basins. Calabria: 1 = Cava Gentile; 2 = Cava Franzé; 3 = Papaglionti, loc. Serre; 4 = Zungri. Sicily: 5 = Case Genna (Marsala, Trapani, Tortonian). Campania: 6 = Baselice (Benevento). Latium: 7 = Manciano. Sardinia: 8 = Cuccuru Tuvullau, Nuragus (Cagliari Province); 9 = Bessude and Bonnanaro (Sassari Province); 10 = La Crucca, Bancali and San Giorgio, Western Sassari basin; 11 = Chiaramonti (Sassari Province). France basins. Corsica: 12 = Bonifacio; 13 = Aleria; Rhône Basin: 14 = Cadenet, Vaugines; 15 = Cucuron and Blanqui. Hérault: 16 = Cruzy. Spain basins. 17 = Barcelona; 18 = Valencia; 19 = Mallorca. Algerian basins. 20 = Orano; 21 = Alger; 22 = Tipasa. The Box of Calabria also shows the corresponding geological map (from Marra et al., 2017).

Lamarck, 1801), bivalves, fish, and well preserved mammal remains (see also Seguenza, 1880). The “*Clypeaster* sandstones” grade into the “*Heterostegina* yellow sandstones” (Papazzoni & Sirotti, 1999) and in the overlying hemipelagic “*Orbulina* marls” (“Marne a *Orbulina*”; Rao et al., 2007). According to Marra et al. (2017), the main intervals are separated by a ravinement surface (Fig. 2A-C).

**Amphiope in the Cava Gentile section: palaeoenvironmental reconstruction**

As concluded by Marra et al. (2017), the global transgressive trend documented by the succession of the Upper Tortonian in the Capo Vaticano area, showed different local depositional rate of sediment, probably associated with rapid variations in the depositional rate of the sediment and the available storage (accumulation) space (Fig. 2C). The occurrence of alluvial and soil deposits in the *Clypeaster* sandstones of Cava Gentile, documented by Marra et al. (2017) for the first time, suggested that the late Tortonian transgression was punctuated by minor regression episodes, which caused the abrupt displacements of depositional systems on shallow lagoon and shallow marine environments (Fig. 2). The subsequent increase in the sea level led to the accumulation of sea and land fossils together in certain transgressive horizons. Therefore, the “*Clypeaster* sandstones”, which are well-known and well-studied thanks to the presence of an abundant well-preserved fauna, are ascribed to a shallow-water and wave-dominated marine depositional environment (Carone & Domning, 2007; Gramigna et al., 2008), interspersed by short regressive periods, resulting in changes in the depositional environment (Marra et al., 2017). The marine fauna represented in these sands consists of echinoids (especially well preserved *Clypeaster* and also, to a lesser extent, *Amphiope*, echinolampadids, hypsoclypeids and spatangoids), bivalves and rare gastropods (both of these usually preserved as internal moulds), marine fish and mammals (especially sirenians). The terrestrial fauna is represented by bovinds, proboscideans, and giraffids (Carone & Domning, 2007; Gramigna et al., 2008; Marra et al., 2017).

In this context, the fossil specimens of *Amphiope* lie just above the ravinement surfaces, corresponding to the closest part to the shore line, into metric levels of conglomerates with pebbles up to

3–4 cm (Fig. 3), or sands accompanied by pebbles, with rare fragments of *Clypeaster* and scarce internal moulds of indeterminable bivalves. This interpretation is valid for the section under consideration, but it may differ in thicknesses and facies at the other *Amphiope*-bearing sites. However, the facies in which *Amphiope* remains was ob-

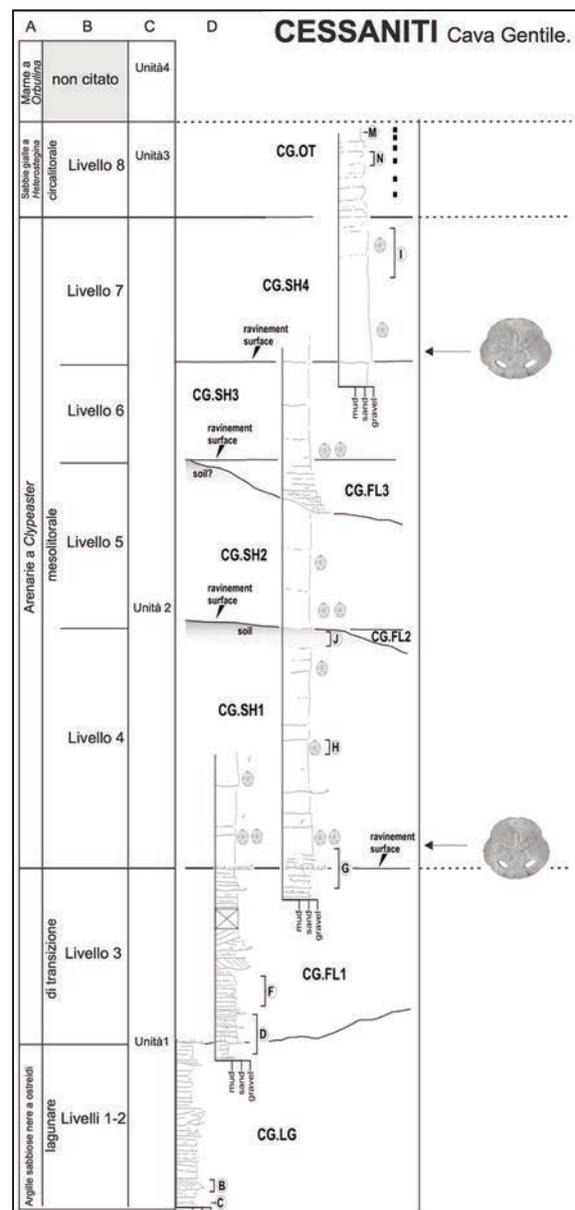


Figure 2. Stratigraphic Columns showing the successions at Quarry Cava Gentile, according to units reported by: (A) Nicotera, 1959; Ogniben, 1973; Rao et al., 2007; (B) Carone & Domning, 2007; (C) Gramigna et al., 2008; (D) Marra et al., 2017.

served (Cava Franzé, Papaglioni and Zungri), differ only slightly from those documented at the Cava Gentile.

The fossils remains of *Amphiope* are generally scattered, and show a random position, rarely they are found in life position or with different inclinations, and sometimes they are overthrown but apparently consistent with the stratification (Fig. 3). Furthermore, the *Amphiope* test remains consistently appear to show the surface indented by sandstone grains and show no evidence of parasites and/or epibionts attacks, nor evidence of post-mortem erosion by transport, but rather they often display a fragmentation of the tests which we interpret as caused by the remixing of the sediment in a wave dominated environment. In this area, the density of *Amphiope* remains is very low, with a maximum of five-six individuals per square meter. The outcrops are only five meters long and as of yet, no mass accumulation cases have been observed.

### Palaeoecology

Variations in the climate occurred from the Oligocene end to the late Miocene (late Tortonian-Middle Messinian); this includes an increase in the average temperature, which reached its peak with the establishment of the Climate Optimum of the late Burdigalian-middle Langhian (Kroh, 2007; Popescu, 2009). The Climate Optimum was followed by a negative trend lasting until the end of the Miocene. In fact, from the Langhian to the Messinian



Figure 3. Conglomerate level with *Amphiope* at the Franzé quarry.

Salinity Crisis, there had been a continuous decrease in the average temperature and an increase in seasonality (Popescu, 2009). Consequently, there had been a shift towards the south of the tropical-subtropical climate that had previously characterized the entire basin of the Western Proto-Mediterranean Sea, its peri-Mediterranean basins (Lauriat-Rage et al., 1993; Kroh, 2007; Popescu, 2009), and its related terrestrial environments (Kürschner et al., 2008).

According to Carone & Domning (2007) the reduced size of Sirenia that populated the marine environment along the Calabro-Peloritan Arc during the late Tortonian-early Messinian was due to deteriorated ecological conditions. Another evidence of the climatic cooling after the Miocene Climate Optimum is given by Popescu (2009), who observed the climate change by comparison of the northern mangrove populations, which first retreated from the French coast, then from the Spanish ones, and survived only along the North African coasts in the late Miocene.

According to Stara et al. (2015) and Stara & Borghi (2017), climate cooling seem associated in *Amphiope* with a progressive decrease in the size of the lunules, documented e.g., in some populations of the Serravallian-Tortonian of Herault, France (Stara & Borghi, 2017); Late Tortonian of Calabria (this work); Tortonian of Valencia, Spain (Stara et al., 2015) and Pliocene of Tipasa, Algeria (Aymé & Roman, 1954).

Finally, Gramigna et al. (2012) also observed that in the late Tortonian-early Messinian age, the marginal areas of Calabria (e.g., the Capo Vaticano-Monte Poro area, where the *Amphiope* population under study dwelled), were characterized by the development of siliciclastic-carbonate temperate ramps and that the absence of non-skeletal grains (ooids and green algae), the scanty presence of Porites coral reefs, and the rare occurrence of primary marine cementation, confirm that these ramps were poorly lithified in a warm-tempered environment.

## MATERIAL AND METHODS

### Study area

The fossils found in Calabria were collected

from four localities (Figure 1): Cava Gentile quarry; Cava Franzé quarry (both in the Cessaniti Municipality); “Zungri” outcrop, at the periphery of the Zungri village; Serre locality outcrop, near Papaglionti village (Zungri Municipality). The Zungri and Papaglionti outcrops are quite small, only a few square meters, and the vegetation surrounding them did not allow us to detect, to any certainty, a stratigraphic section. The Cava Gentile and the Cava Franzé localities, on the other hand, were two large excavations with separate accesses, located in the same hill. According to Gramigna et al. (2012), the stratigraphic sequence throughout the Cessaniti-Monte Poro area is homogeneous, albeit with different thicknesses. For this, as was done by Gramigna et al (2008), Carone & Doming (2007), and Marra et al. (2017), the most complete and best exposed section of Cava Gentile (Fig. 2) is here taken as reference for the whole area. The specimens collected in Cava Franzé come from two levels corresponding to those of Cava Gentile.

### Material

Twenty-six whole specimens and various fragments of *Amphiope*, collected in June 2013, are here examined: six, plus some fragments, from Papaglionti, five from Cava Gentile, thirteen from the Cava Franzé and one, plus some fragments, from Zungri. The data from these specimens was compared with those of other species of *Amphiope*, as reported in the graphs; other measures and statistics were taken from illustrations reported in the literature. Additional data on French, Algerian, and Italian related species, used for comparisons, were taken from Stara & Borghi (2017).

### Methods

To highlight the sutures lines, the specimens have been humidificated by a mixture of water and hydrochloric acid (ca. 2%) and finally the washed surfaces were moistened with vaseline based cream. The internal structure was studied by sectioning the test subject and in some cases by X-ray analysis. To simplify the comparison, we divided the *Amphiope* species into two informal groups, as proposed by Stara et al. (2015). The

first, called the “*A. bioculata*” group, were characterised by roundish to broad elliptical lunules with major/minor diameter ratios ( $SI \leq 1.6$ ), and the “*A. nuragica*” group, consistent of mainly narrow lunules and ratios of  $SI > 1.6$ . Since all the specimens examined on behalf of this paper belong to the *A. nuragica* group, we have thus analysed only the differences among the species included in these particular species. To make the comparative diagrams, we used the statistic program of Hammer Ø., 2014. PAST 3.2. Numbering in plate drawings is based upon the Lovén (1874) system, and interambulacra are shaded in grey. Systematic palaeontology follows Kroh & Smith (2010), Smith & Kroh (2011), Stara & Borghi (2017), and Kroh & Mooi (2018). Geographic coordinates are provided in WGS84.

ABBREVIATIONS AND ACRONYMS. Morphological abbreviations as in Figure 4 and Table 1 (pro parte): TL = test length; TW = test width; TH = test height; L1-L2 = lunule length and width, respectively; L3 = distance between posterior petal-tip and lunule, L4 = distance between apical system and posterior margin, L5-L6 = length and width of the frontal petal, respectively; L7-L8 = length and width of the anterior paired petals, respectively; L9-L10 = length and width of the posterior petals, respectively; L11 = distance between posterior border of the periproct and posterior margin test; L12 = distance between the posterior border of the peristome and the border of the periproct, L13 = front-rear diameter of the ambulacral basicoronal circlet. PL = petalodium length;  $\emptyset pc$  = periproct diameter;  $\emptyset ps$  = peristome diameter. To describe the lunules shape and dimension into a numeric value, we use a SI (Shape Index) corresponding to the ratio  $L2/L1$  and a WI (Width Index) =  $(L1 \times L2)$  corresponding the area inscribing the lunule, as done by Stara & Borghi (2017).

Institutions abbreviation: MP.CM.UNINA (Museo di Paleontologia, Centro Museale Università Federico II, Napoli, Italy); MURI (Museo di Ricadi, Vibo Valentia Province, Italy); MAC (Museo di Storia Naturale Aquilegia, Masullas, Oristano province, Italy); MNHN-F (Muséum National d’Histoire Naturelle of Paris, France).

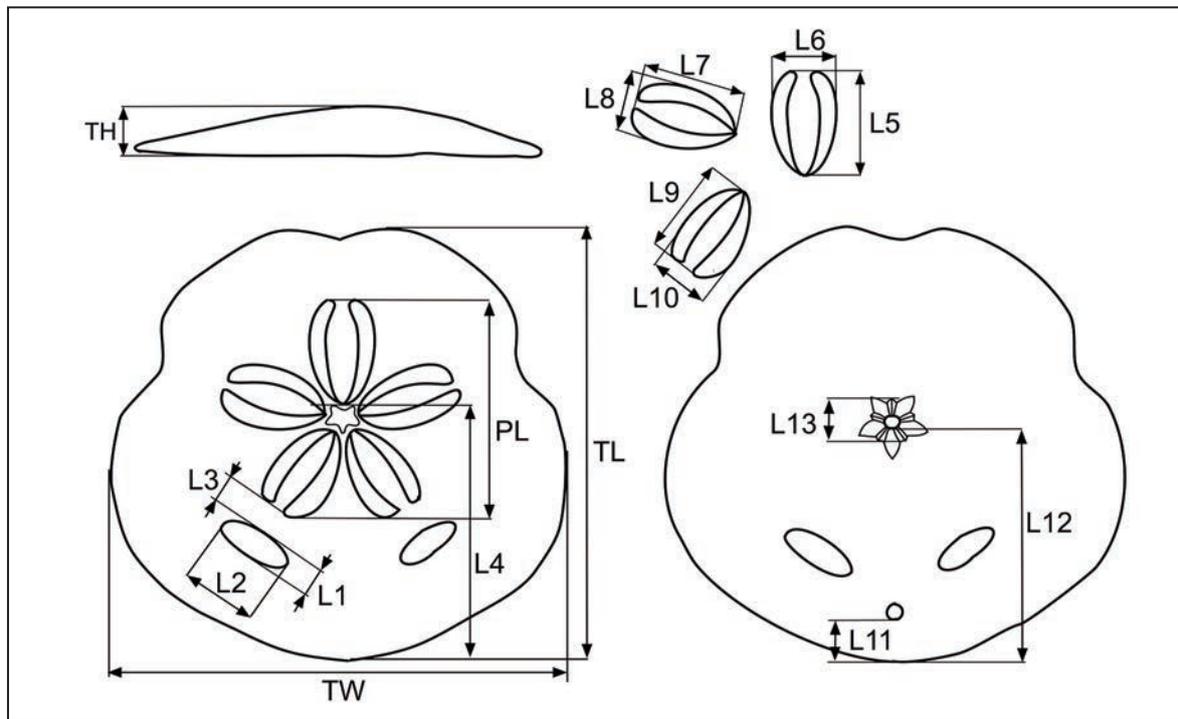


Figure 4. Biometric parameters utilised in the studied samples.

## RESULTS

Compared with all those known so far, the specimens under study shows very small lunules (mean  $WI = 80$ ), but also the smallest petalodium within this genus (see Figure 5): in fact, the petalodium length range from 40.5% of TL to 46% of TL, contrary to a range known for this genus that spans from 44% to 62% of TL (Stara & Borghi, 2017). The total number of specimens (Twenty-six whole specimens and various fragments) allows us to consider this sample valid for a correct specific systematic classification. In this group of specimens, two morphotypes are distinguishable, by a slightly different robustness of the structure and by a slightly different plates schemes on the oral face within the interambulacrum 5, as detailed in the discussion and systematic chapter. However, since the X-rays analysis performed on these two forms does not show substantial differences (Figs. 12, 13), we decided to include both morphotypes in a single species. By comparison, these specimens are different from all forms so far known in the *A. nuragica* group and represents a new species, for which the name *Amphiope caronei* n. sp. is here proposed.

## DISCUSSION

*Amphiope* is a genus adapted to a tropical climate (Nebelsick & Kroh, 2002; Smith & Kroh, 2011; Stara et al., 2012; Mancosu & Nebelsick, 2013, Stara & Borghi, 2014; Stara & Sanciu, 2014; Mancosu & Nebelsick, 2015). Consequently, the temperate environment type, inhabited by the studied populations (Gramigna et al., 2012), was not ideal for them and substantial evidence suggests that they had undergone adaptation processes. As noted by Stara & Borghi (2014), important changes in the structure of *Amphiope* have occurred during the Oligo-Miocene. Together with a reduction of the overall structure (thickness of internal reinforcement and extension of visceral spaces), there has been a decrease in the number of plates, in particular in the interambulacrum 5; this varied from 16–20 plates in *Amphiope nuragica* (Comaschi Caria, 1955), from the Chattian-Aquitainian of Cuccuru Tuvullau (Sardinia, Italy), to 10–11 in *Amphiope deyderi* Lambert, 1912, from the Serravallian of Vaugines (Vaucluse, France).

However, while these structural changes did not appear clearly to be directly related to the va-

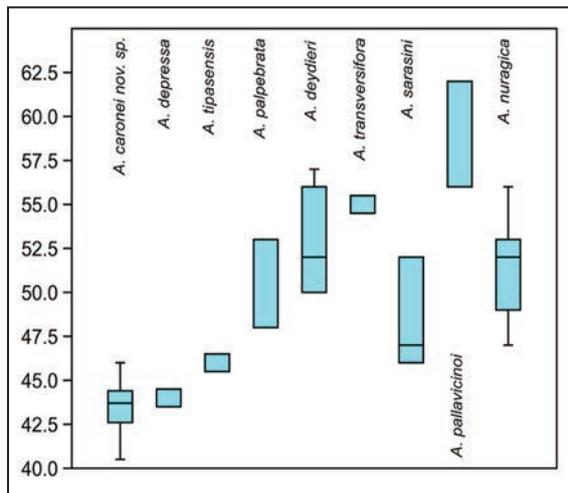


Figure 5. PL comparison between *Amphiope caronei* n. sp. and the others species included in the informal *nuragica* group (except *A. hollandei*).

riation of environmental conditions, other changes seem correlated to the climate-ecological changes. In fact, the *Amphiope* populations considered in this study, share some peculiarities with other contemporary populations of *Amphiope* in the Proto-Mediterranean regions, during the period starting from the middle-late Miocene up to the Pliocene: *Amphiope* sp. from La Crucca, Sassari Province, Sardinia, Italy (in Stara et al., 2012; Langhian-early Serravallian in age, after Carboni & Kotsakis, 1983); *Amphiope sarasini* Lambert, 1907 from the Rhône Basin, SE France (Serravallian-Tortonian); *Amphiope* sp. from Valencia (in Stara et al., 2015), Spain (Tortonian); *A. depressa* Pomel, 1887, from Orano Region, NW Algeria (prob. Tortonian); *A. tipasensis* (Roman in Aymé & Roman, 1954) from Tipasa Province, Northern Algeria (Pliocene) (in Stara & Borghi, 2017). For a complete review of the function and dimension of the lunules, we refer to the reader the work of Mancosu & Nebelsick (2015), in which the different theses published over the time by previous authors on this topic are compared. However, after our observations, these peculiarities appear to be linked to the deterioration of the climatic and ecological conditions occurring in the Proto-Mediterranean Basin toward the late Miocene.

#### Lunule and petalodium size

The characteristics of the different *Amphiope*

morphotypes that lived in the peri-Mediterranean Basin, provided to us by previous studies, allow us to bring some observations. The size of the lunules has considerably increased during the Middle Miocene Climate Optimum, then slowly diminished, reaching its minimum during the Serravallian-Tortonian and the Pliocene.

Some examples of morphotypes with large lunules are the *Amphiope* sp. 2 from Bancali and *A. montezemoloi* from San Giorgio, Sardinia, both from the late Burdigalian-Early Langhian (Stara & Borghi, 2014; Mancosu & Nebelsick, 2015), “*A. montezemoloi*” from Middle Miocene of La Sequita, Tarragona, Barcelona Region, Spain (Lambert, 1928) and “*A. montezemoloi*” from the Burdigalian of Sidi Aïch, Vallée de la Soummam, Algeria (specimens MNHN-F R67289a-b). It should also be noted that at times, the test size had increased simultaneously to the growth of the lunules, as is *Amphiope* sp. 2 from the upper Burdigalian of Bancali (in Stara & Borghi, 2014; Mancosu & Nebelsick, 2015), in which the test subject rose to 170 mm of TL., the maximum size known in this genus.

Concerning the specimens from Calabria, a significant decrease in the petalodium size accompanies the decrease in size of the lunules. This suggest (but further studies need) a structural adjustment resulting from the deterioration of the ecological conditions, even if we do not know the mechanisms that may have modulated these characters.

#### Variation in plate number and shape

Observations and analysis carried out by Stara & Borghi (2014) while studying variations in the plating pathways in *Amphiope*, found that the number of plates lowered along the geologic times. The number of plates, which was 16–20 in *A. nuragica* (Chattian-Aquitainian in age), both in the interambulacrum 5, and in the ambulacra I and V, was found much lower in *A. lovisatoi* (Late Burdigalian in age). In fact, in this species, the plate numbers was only 13–14 (in the interambulacrum 5) and 15–16 (in the ambulacra I and V).

A substantial numerical change was also observed in the oral interambulacrum 5 plate scheme of these two species: a drop in the number of plates from 3–4 to 2–3 in column “a” and from 4 to 3 in column “b”, respectively.

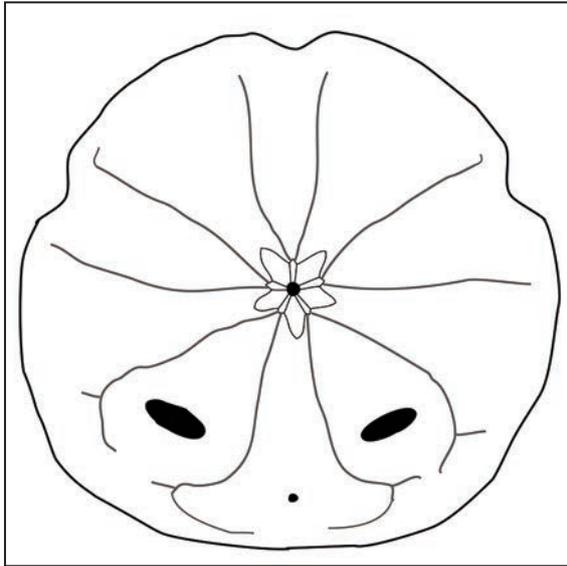


Figure 6. Food grooves schema in *Amphiope* specimen from Gentile Quarry.

Also, in the specimens collected from Calabria there were a low number of plates: 13–14 in the interambulacrum 5 and 15/17 per column in the ambulacra I and V, together with a simplification in the plating scheme of the oral part of the interambulacrum 5, with only 2 plates in column “a” and 2–3 in column “b”. In particular, in some specimens from Papaglianti (Figs. 14–17), the first ambulacral post-basicoronal plates (I.2.b and V.2.a), that occlude the interambulacrum 5, appear to complete their development late during growth.

At the same time, however, the plates of the interambulacrum 5 have already reached their maximum size and their number does not increase, at least in the considered sample.

## SYSTEMATIC PALAEOLOGY

Family ASTRICLYPEIDAE Stefanini, 1912

Genera included: *Amphiope* L. Agassiz, 1840; *Paraamphiope* Stara et Sanciù, 2014; *Sculpsitechinus* Stara et Sanciù, 2014; *Echinodiscus* Leske, 1778; *Astriclypeus* Verrill, 1867

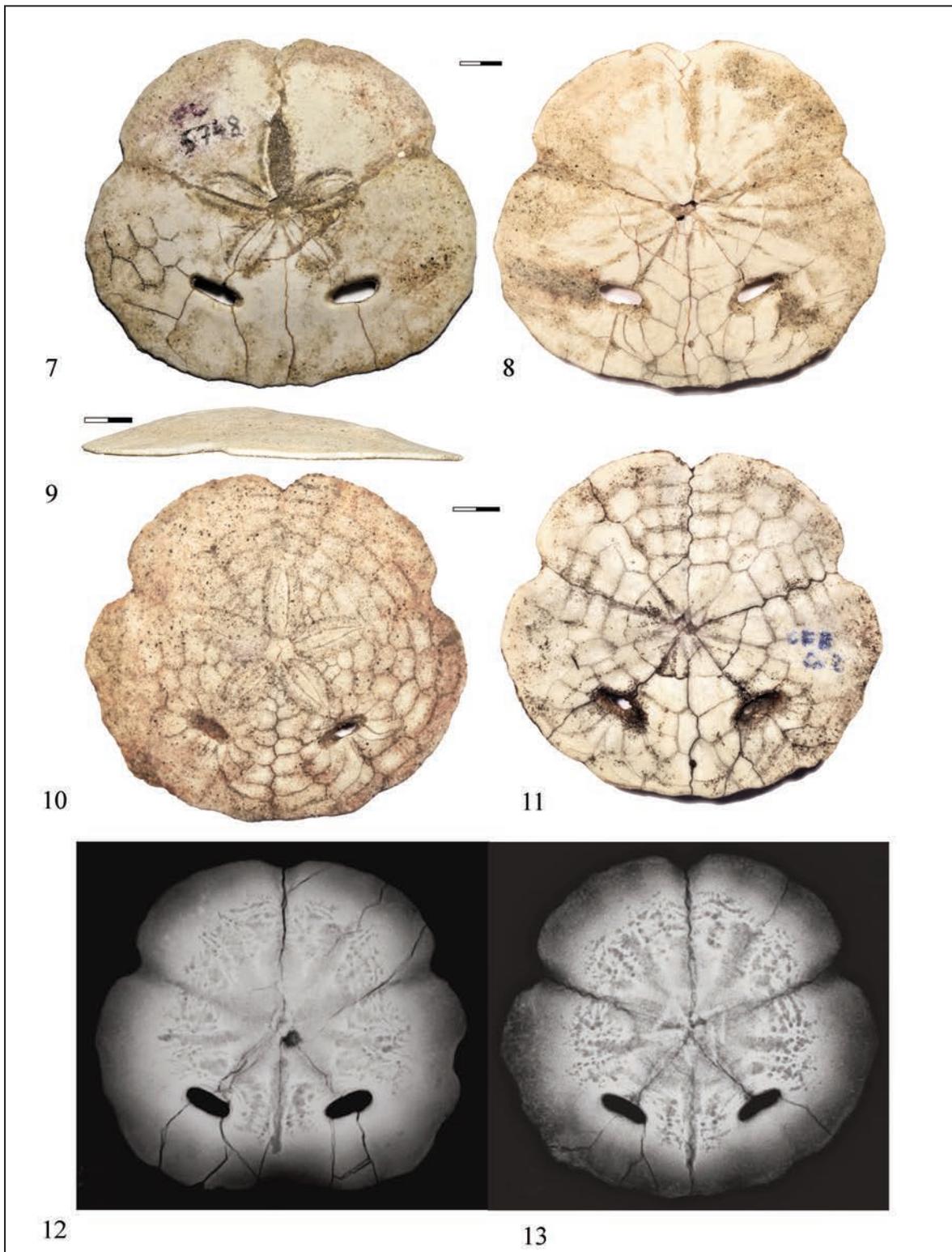
Genus *Amphiope* L. Agassiz, 1840

Type species. *Scutella bioculata* Des Moulins,

1837, by subsequent designation of Lambert (1907, p. 49).

EMENDED DIAGNOSIS. Partially modified from Smith & Kroh (2011) and Stara & Borghi (2017).

- Test low with sharp margin.
- Internal support well developed, consisting of pillars and walls crossed by cavities.
- Peripheral ballast system may be very dense and crossed by micro-canals, towards the ambitus.
- Apical disc monobasal, sub-central, with four gonopores.
- Petals well developed; short (PL range from 40.5 to 61% TL) and closed distally; generally, all five petals similar in length, sometimes the anterior slightly longer or the posterior slightly shorter.
- Lunules rounded, largely ovate transverse (rarely ovate axial), narrow ovate or slit-like transverse, present in the posterior ambulacra.
- Oral side flat or slightly concave.
- Oral interambulacra narrower than the ambulacra, even at their widest point. Oral interambulacra 1, 4 and 5 always with only the first postbasicoronal plate 5.b.2 in contact with the first pair of ambulacral plates; the interambulacral zones are separated by a couple of enlarged first postbasicoronal ambulacral plates. Interambulacra 2 and 3 may have only the plate 5.2.b, or both plates 5.2.b and 5.2.a, in contact with the two adjacent ambulacral postbasicoronals.
- Basicoronal circlet pentastellate with interambulacral plates forming the points.
- Peristome small, subcentral.
- Periproct circular, small, opening between the first, the second, or the third pair of postbasicoronal interambulacral plates. Two to five postbasicoronal plates present in the interambulacrum 5 adorally.
- Food grooves simple (more complex in *A. sarasini*), bifurcating at the edge of the basicoronal plate; they do not reach the margin. Posterior pair of food grooves running around the lunules.
- Ambulacra a little wider than interambulacra at ambitus.
- Tuberculation dense, made of very small, perforate and crenulate tubercles, larger on the oral face than aborally.



Figures 7–9, MP.CM.UNINA5748 from Papaglioni: aboral, oral, and lateral views, respectively. Figures 10–11: MP.CM.UNINA 5749 from Cava Franzé. Figures 12–13: radiographs of MP.CM.UNINA5748 and MP.CM.UNINA5749, respectively.

DISTRIBUTION. Oligo-Miocene of Sardinia; Miocene of Europe, Northern and Western Africa, Middle East and Northern India; Pliocene of Algeria.

Species included (from Stara & Borghi, 2017):

- Amphiope bioculata* - (Des Moulins, 1837), Langhian-Serravallian, Hérault (France)  
*A. elliptica* - Desor, 1847, late Aquitanian, Bouche du Rhône (France)  
*A. hollandei* - Cotteau, 1877, Burdigalian, Corsica (France)  
*A. depressa* - Pomel, 1887, middle Miocene, Algeria  
*A. palpebrata* - Pomel, 1887, Miocene, Algeria  
*A. lovisatoi* - Cotteau, 1895, late Burdigalian, Sardinia (Italy)  
*A. neuparthi* - de Loriol, 1905, ?Burdigalian, Luanda (Angola)  
*A. lorioli* - Lambert, 1907, Tortonian, Hérault (France)  
*A. sarasini* - Lambert, 1907, Serravallian-Tortonian, Hérault (France)  
*A. transversifora* - Lambert, 1910, Langhian, Drôme (France)  
*A. montezemoloi* - Lovisato, 1911, late Burdigalian-early Langhian, Sardinia (Italy)  
*A. ludovici* - Lambert, 1912, Tortonian, Vaucluse (France)  
*A. deydieri* - Lambert, 1912, Serravallian, Vaucluse (France)  
*A. pallavicinoi* - Lovisato, 1914, late Burdigalian, Sardinia (Italy)  
*A. tipasensis* - (Roman, in Aymé & Roman, 1954), Pliocene, Algeria  
*A. nuragica* - (Comaschi Caria, 1955), late Chattian-early Aquitanian, Sardinia (Italy)  
*A. romani* - Stara & Borghi, 2017, Serravallian - Tortonian, Touraine (France)  
*A. caronei* n. sp. - Tortonian, Vibo Valentia Province, Calabria (Italy)

Other species were described in the literature, but they need re-discussion by modern approach (from Smith & Kroh, 2011; Stara & Sancieru, 2014; Stara & Borghi, 2017).

The informal *A. nuragica* group includes: *A. hollandei*, *A. depressa*, *A. palpebrata*, *A. sarasini*, *A. transversifora*, *A. deydieri*, *A. pallavicinoi*, *A. tipasensis*, *A. nuragica* and *A. caronei* n. sp.

*Amphiope caronei* n. sp. Figs. 7–19, Table 1

- Amphiope bioculata* - Cottreau, 1914: 31  
*A. biauriculata* - Carone & Domning, 2007: 60  
*A. sp.* - Stara et al., 2015: 396

TYPE MATERIAL. Holotype: a complete specimen housed in MP.CM.UNINA 5748. Main data in Table 1; Paratypes: MP.CM.UNINA 5749–55; MURI GPT 105(ces)E4, MURI GPT 117(ces)E4, MURI GPT 113(pap)E1; MAC PL 1728.

TYPE AREA. Monte Poro: includes Cava Gentile and Cava Franzé quarries (38°39'02.42"N, 16°02'01.57"E); Papaglioni, Serre locality near Zungri (36°39'29.39"N, 16°01'06.85"E) and Zungri village outcrops. Vibo Valentia Province, Calabria (Italy).

TYPE STRATUM. Conglomerate made up of mostly granodioritic pebbles together with *Amphiope* fossils remains in the Unit 2, Gramigna et al., 2008; Levels 4 and 7, Carone & Domning, 2007; or CG.SH1 and CG.SH4, after Marra et al., 2017, at the Cava Gentile, all into the informal "Arenarie a *Clypeaster* formation", Nicotera, 1959.

EXAMINED MATERIAL. The studied sample from the type area consists of 24 whole tests (code: MP.CM.UNINA 5748-54; MURI GPT 105–112(ces)E4, 116-117(ces)E4, 118(ces)E7, 113–115(pap)E1; MAC PL 1728, MAC PL-1475–7 and two test fragments (MP.CM.UNINA 5755).

ETYMOLOGY. In honour of the Italian palaeontologist Giuseppe Carone, founder of the MURI, "Paleontological Ricadi Museum" (Vibo Valentia Province), Italy.

DIAGNOSIS. Species of *Amphiope* with small petalodium (minimum PL = 40.5% TL, mean PL = 44% TL) and with small (mean WI=80), narrow and slit-like transverse lunules.

DESCRIPTION. Medium sized individuals (maximum value in our sample, TL = 94 mm), usually a bit wider than long (mean TW = 107% TL); narrower anteriorly, with large inflections in the margin, at the end of the ambulacra II, III and IV; rounded rear. Depressed shape (mean TH = 11% TL), with rounded margins (1.8–2 mm). Apex middle-sized (8% TL) and centrally positioned.

Internal structure: in the radiograph, the central hollow vary from sub-pentagonal to star-shaped (Figs. 12, 13), the antero-posterior length equals the length of the petalodium. The internal support system is well-articulated and light around the central hollow, but it becomes very dense toward the ambitus.

From the central hollow, five cavities branch off along the interambulacra; the widest is located along the interambulacrum 2, while the longer leads to the periproct, along the interambulacrum 5.

The Aristotle lantern is wide; a reconstruction shows that it measures, in antero-posterior direction, about 22% TL.

Oral face flat, with slight inflections along the ambulacra.

Petalodium small (range from 40.5 to 46 % TL, mean PL = 44% TL); petals closed, sub-equal, the posterior paired petals slightly shorter (mean L5 and L7=21% TL; mean L9=18% TL); all of equivalent width. Ratio between the width of the por-

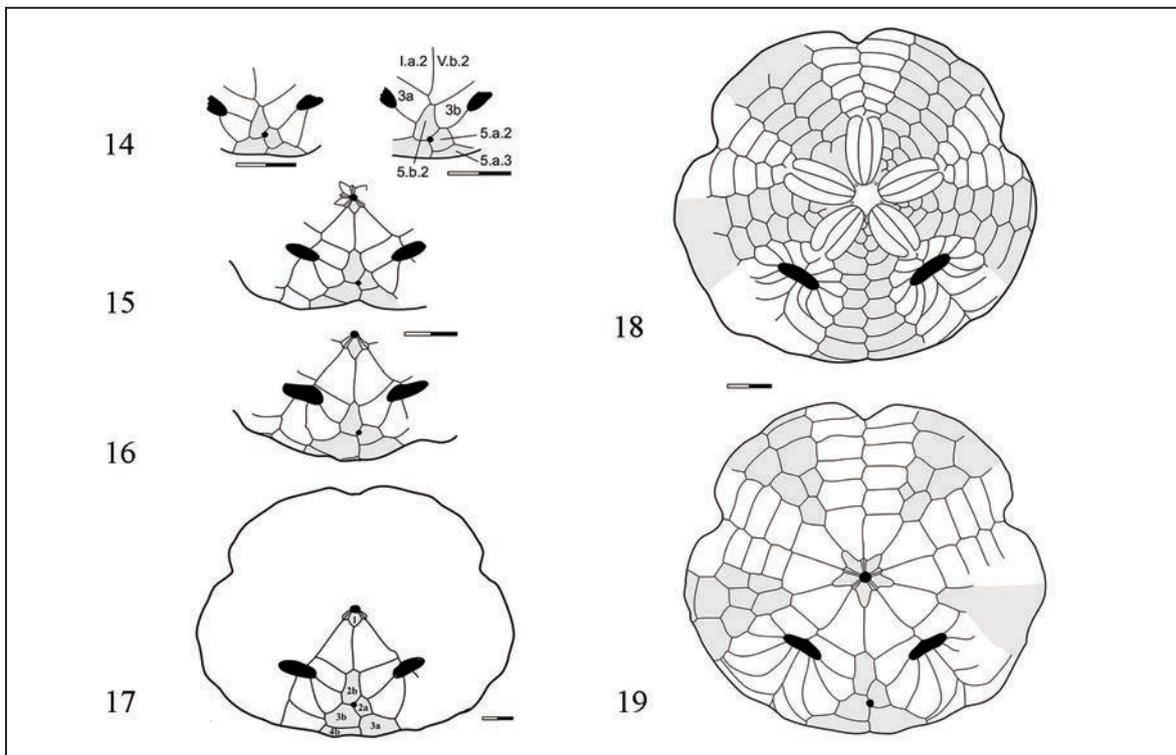
iferous and interporiferous areas highly variable (Figs. 7–10).

Lunules always small (mean WI = 80), long and narrow (mean SI = 2.9), like linear slits. Lunules open at about one third of the distance petal - posterior margin; the distance between the tip of posterior petals and the corresponding lunules (L3= 6% TL) is occupied always by two plates per column.

In the oral interambulacrum 5, column "a" is made of 2 post-basicoronal plates, column "b" of 2–3 plates. The basicoronal interambulacral plate 5.1 is short (about 6-8% TL). On the whole, there are 13–14 plates per column in the interambulacrum 5, 13–14 in the ambulacra III and 15–16/17 in the ambulacra I and V.

Stoma small (1.8–3.4% TL), rounded, with prominences in correspondence of the interambulacra, central (mean L12=48% TL).

Periproct small (mean 2.5% TL), rounded, next to the rear margin (mean L11 = 9% TL), open between plates 5.b.2-5.a.2-5.b.3. (seven specimens), 5.a.2-



Figures 14–17. Partial plating schemes in specimens from Papaglionti outcrop: Figures 14–16. Relationship of / modifications between plates 5.b.2 and the first post-basicoronal plates 1.b.2 and V.a.2 during growth; Figure 17, MP.CM.UNINA5748, showing the Lovén's numbering and periproct position in interambulacrum 5. Figures 18, 19, aboral and oral plating schemes, respectively, of MP.CM.UNINA5749 from Franzé Quarry.

5.b.3 (six specimens) or 5.a.2-5.b.3-5.a.3 (three specimens).

Food-grooves generally not well visible; only a single specimen collected from Cava Gentile and some fragments from Cava Franzé, not indented by sand grains, enabled to draw the food grooves scheme, shown in Figure 5.

Tuberculation poorly evident, due to the indentation of the granules of sandstone on the test surfaces and by the fossilisation processes.

**OCCURRENCE.** Cava Gentile and Cava Franzé quarries near Cessaniti, Papaglionti and Zungri (Vibo Valentia Province, Calabria), late Tortonian.

**REMARKS.** All the samples examined belong to the informal *A. nuragica* group, and then comparison will be limited to the species belonging to this group.

*Amphiope caronei* n. sp. differs from: *A. hollandei*, *A. sarasini*, *A. transversifora*, *A. deyderi*, *A. palpebrata*, and *A. nuragica*, mainly by the smaller petalodium (mean 44% TL against 54%, 49%, 55%, 53%, 52%, 53% TL, respectively) (see also Fig. 5, pro parte).

Additionally, *A. caronei* n. sp. differs from these species by other characters, shown in figure 20 (WI comparison) and figure 21 (SI comparison, pro parte). Data taken from Stara et al. (2015) and Stara & Borghi (2017).

*Amphiope hollandei* and *A. deyderi* have also

the widest test (TW=120% and 122% TL, respectively, against an average of 107% TL in *A. caronei* n. sp.). *Amphiope hollandei* also has the lunules with SI = 7 against 2.9 of *A. caronei* n. sp., while *A. deyderi* has WI=135 against 80 of *A. caronei* n. sp.

*Amphiope transversifora* differs from *A. caronei*, also in having a higher WI (148 versus 80) and a lower number of plates, both in the interambulacrum 5 (12–13 against 13–14), than in the ambulacrum I and V (13–14 against 15–17).

*Amphiope caronei* n. sp. differs from *A. palpebrata* also by a different internal structure; in fact, *A. palpebrata* has a much lighter system of internal supports, with wider central cavity, which extends almost to the margin.

Different results are provided by the comparison with *Amphiope depressa* Pomel, 1887 and *A. tipasensis* from Algeria. The first species is known only by the original illustration (Pomel, 1887: plate XII, figures 1a-c), but the author himself stated that in reality, the illustrated specimen had a part of the posterior margin missing; moreover, in the drawing the plating scheme was not reported, consequently it is not completely comparable with other species. According to the available data we can say that *A. depressa* differs from *A. caronei* n. sp. in having (o by) smaller lunules (WI = 46 versus 80), and with a lower SI (1.8 against 2.9). *Amphiope tipasensis* has lunules similar to those of *A. caronei* n. sp., but

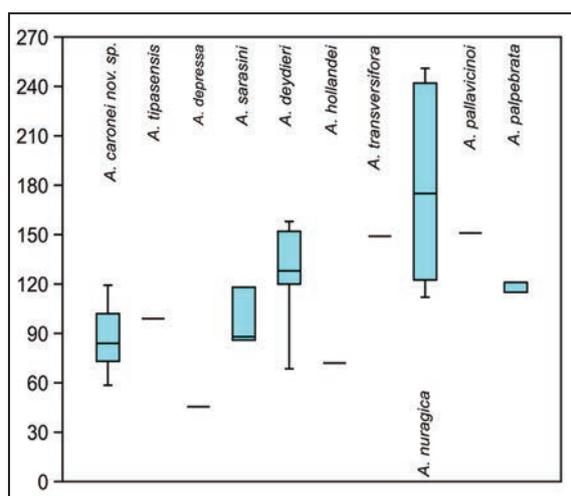


Figure 20. WI comparison between *Amphiope caronei* n. sp. and all other species included in the informal *A. nuragica* group.

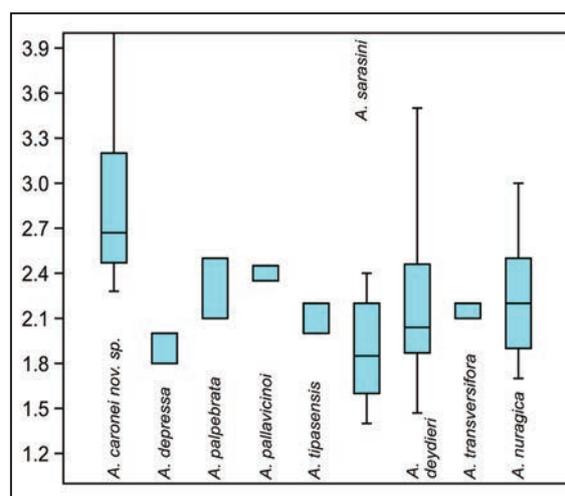


Figure 21. SI comparison between *Amphiope caronei* n. sp. and the other species included in the informal *A. nuragica* group (except *A. hollandei*).

	TL	H%	TW%	PL%	L1%	L2%	S1	WI	L4%	L11%	L12%	pos Pc
VV6 CFA1	66	8.9	121	46	5.6	19	3.4	106	54	11	50	2a-3b
CFACa6	90	11.6	105.5	42	-	-	-	-	-	-	-	
CFACa7	87	10.3	104.5	44	5.9	14.6	2.5	86	54	6.6	47	2a-3b-3a
CFb1	80	8	95.5	40.5	6	15	2.5	90	49	7	45	2a-3b
CFb2 (VVCfb4)	87	-	103	43	6	14	2.4	84	-	11	-	2a-3b-3a
VV3 CFB	80	12.5	103	45	4	16	4	64	51	6.8	-	2a-3b
VV4 CFB2	79		98	44	6	17	2.8	102	55.5		49	—
VV5 CFB3	67	11.9	115	43	5.6	15	2.7	84	54	9.5	48	2a-3b
CFB Ca1	80	10	105	44	5.6	13.5	2.8	76	53	8.6	50	-
CFBCa2	77	10.4	110	43	4.4	13.3	3	58.5	53	8.6	45	2a-3b
CFBCa3	81	9.9	104	45	6.4	16.3	2.5	104	-	8.5	47	-
CFBCa4	75	10.6	108	44	6.4	14.6	2.3	93	50	8.6	50	-
CFBCa5	78	10.9	108	45	5.3	13.8	2.6	73	-	10	49	-
PL1672 Pa	90	11.1	109	44	3.9	15	3.8	58.5	48	11.6	50	2b-2a-3b
VV7 Pa	89	11.2	115	43.5	3.6	17	4.7	61	55.5	8.5	51	2b-2a
VV16 Pa	94	11.2	105	-	4.6	13	2.8	60	-	10	-	2b-2a-3b
PL1728 Pa	76	14.5	112	42.5	5.6	14.5	2.6	81	56	10.8	48	2b-2a-3b
VV19CaUP1	74	11.5	109	44	7.1	16.8	2.4	119	54.5	6.7	49	-
VV18CaUP2	93	11.8	111	44	5.3	15.2	2.9	81	57	11.2	49	2a-3b
VV8 Zu	80	12.5	114	44	5	16.5	3.2	82.5	52	7.3	48	—
VV17CaCGMa2	81	8.6	106	44.5	5	16.3	3.3	81.5		8.8	48	-
CG1	82	11	112	42	4	14.8	3.7	59		9.6	48	2b-2a-3b
CG2	85	12.3	106	46	5.2	12.4	2.4	64.5	52	7	46	2b-2a-3b
CG3	89	11.8	96	46	4.6	11.3	2.4	52	55	8		2b-2a-3b
CG4	87	11.8	108	45.5	6.4	16.7	2.6	106	57	11.2		2b-2a-3b
range	66-94	8-14.5	95.5-121	40.5-46	2-7.1	11.3-19	2.3-4.7	52-119	48-57	6.6-11.6	45-50	
mean		11	107	44	4.9	15	2.9	80	53	9	48	

Table 1. Biometric measures taken in the studied sample.

it differs by the number of plates in the interambulacrum 5 that is: 3 against 2 in column “a”, 4 against 2-3 in column “b”. *Amphiope sarasini* has a larger PL and a higher test (TH=14% against 11% TL). Finally, the group of species formed by *A. tipasensis*, *A. sarasini* and *A. sp. 1* from Valencia (Stara et al., 2015), shares a high number of plates in the oral intrambulacrum 5, with the periproct far from the posterior margin. In fact, *A. sarasini* has L11=12–13% TL; *Amphiope sp. 1* from Valencia has L11 up to 20% TL; *A. tipasensis*, has L11=12.5% TL, against an average of 9% TL in *A. caronei* n. sp.

Pomel (1885-87), in the original description of *A. depressa*, cited five genital pores, instead of four, which seem characteristic of this genus, but observed in only one specimen.

Since it was not possible to trace the types of Pomel collection (originally, it was not indicated their institutional repository, or the type locality, Cotteau

et al., 1889, were also not able to locate them), it is not possible to verify this morphological particular.

## CONCLUSIONS

The aim of this work was to define the systematic position and the geographic diffusion of the Cessaniti *Amphiope* populations. This knowledge could result to be very useful to improve the paleogeographic reconstruction of peri-Mediterranean regions during the Oligo-Miocene. So far, no known species of *Amphiope* seem to have a wide diffusion, and also *A. caronei* n. sp. seems to have only a loco-regional diffusion. However, research in progress could highlight new sites and the taxonomy based on modern approach could help to improve the true relationships between the large number of forms previously called *Amphiope “bioculata”* by Philippe (1998).

Studies on *Amphiope* taxonomy in regions such as Morocco, Algeria, Libya, Egypt, Turkey were scanty and need to be updated. Only when the old finds are redefined by modern approach, we'll be able to know the real diffusion areas of the various species belonging to this genus.

Finally, the wide variation in the petalodium size in both fossil and Recent astriclypeids, in particular in the genera closely related to *Amphiope*, such as *Sculpsitechinus*, *Paraamphiope* and *Echinodiscus* (for an overview see Stara & Sanciù, 2014 and Fatemi et al., 2016), opens up an investigation on the correlation between the size of this respiratory organ, typical of the scutelliforms, and the ecological conditions influencing the percentage of dissolved oxygen in seawater.

#### ACKNOWLEDGEMENTS

We warmly thank Pino Carone, Paolo Cutuli, and all Members of the Gruppo Paleontologico di Tropea for the support given us in the field researches and for having made available several specimens of the Museo di Ricadi (V.V.).

Special thanks go to Maria Rosaria Ghiara, Director, and to Maria Carmela del Re, Curator of the MP.CM.UNINA of Naples and Luigi Sanciù, Director of the MAC of Masullas, for having made available several specimens used in this study.

A heartfelt thanks goes to Enrico Borghi (Società Reggiana di Scienze Naturali) and to Antonella Cinzia Marra, from the MIFT of the University of Messina (I) for the careful re-reading criticism of the paper. We are grateful also to Mariano Serafini, for having made available excellent Papaglionti specimens, and to Valter Marini, who shared with the authors the field researches and knowledge in the preparation of the samples. We warmly thank also Mario Lai (3-S, Laboratori Immagini, Capoterra (Cagliari) and his assistants, for making optimum radiographic photos utilised in this study.

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