

First record of the sand dollar *Amphiope* Agassiz, 1840 (Echinoidea: Astriclypeidae) from the Miocene of Sicily

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ABSTRACT - The first Sicilian record of the sand dollar *Amphiope* is reported on the basis of the occurrence of the species *A. bioculata* (des Moulins, 1837), recovered from a previously unreported sandy deposit cropping out near Case Genna (western Sicily). The best preserved tests are described and compared with similar congeners. Taphonomic and palaeoecological observations on the *A. bioculata*-thaphocenoses, and granulometric characterizations indicate that the sand dollar-bearing deposit formed in very shallow, nearshore environments subjected to bottom current. This deposit, if considered as a subunit of the deltaic upper Tortonian-lower Messinian "Molassa" of the Terravecchia Formation, would have a late Miocene age (upper Tortonian). In this case the Mediterranean distribution of *A. bioculata*, previously known from the Aquitanian to the lower Tortonian, should be extended to the upper part of the latter stage.

RIASSUNTO - [Prima segnalazione di *Amphiope* Agassiz, 1840 (Echinoidea: Astriclypeidae) nel Miocene della Sicilia] - Si descrive una tafocenosi dominata da *Amphiope* bioculata (des Moulins, 1837), un echinoide irregolare a teca depressa del gruppo noto come "sand dollars". Tale ritrovamento costituisce la prima segnalazione siciliana del genere *Amphiope* Agassiz, 1840 la cui distribuzione stratigrafica è relativa all'intervallo Oligo-Miocene; esso rappresenta, inoltre, la prima circostanziata presenza di un'associazione dominata da *Amphiope* nel settore centrale dell'area mediterranea. *A. bioculata*, descritta e comparata con alcune specie congeneriche, proviene da un deposito sabbioso, precedentemente sconosciuto alla letteratura geo-paleontologica, esposto nelle immediate vicinanze di Case Genna (Marsala, Trapani, Sicilia occidentale). Con uno spessore complessivo di circa 6 m, il deposito è costituito da sabbie gialle passanti superiormente a sabbie bianco-giallastre, localmente cementate, contenenti frammenti di pectinidi, ostréidi e valve disarticolate di spondili. Tali sabbie, frequentemente bioturbate, sovrastano i sedimenti batiali della Formazione delle Marne di San Cipirello (Langhiano superiore-Tortoniano inferiore). Tuttavia non è stato possibile osservare il contatto tra le due litologie. Nell'area studiata, alla Formazione delle Marne di San Cipirello, si sovrappongono i depositi terrigeni deltizi della "Molassa" della Formazione di Terravecchia (Tortoniano superiore-Messiniano inferiore). Superiormente, il deposito sabbioso ad *Amphiope* è interessato da una superficie di erosione sulla quale giacciono delle calcareniti biancastre con molluschi continentali. L'età di tali calcareniti è presumibilmente riferibile al Quaternario superiore. Gli echinoidi, osservati sempre in posizione fisiologica, risultano più abbondanti nella porzione inferiore del deposito sabbioso. Essi sono spesso interessati da fratture radiali; in esemplari completi è visibile la classica implosione da carico dell'area centrale del lato orale. Le analisi granulometriche effettuate su quattro campioni delle sabbie ad *Amphiope*, unitamente al contesto paleoecologico-tafonomico desunto, indicano che tali sabbie si depositarono in ambiente marino di moderata profondità, in prossimità della costa ed in condizioni di idrodinamismo relativamente elevato. Si suppone che il deposito di Case Genna sia da attribuire al Tortoniano superiore e che debba ritenersi come una sottounità della "Molassa" della Formazione di Terravecchia. La conferma di tale attribuzione cronostatigrafica implicherebbe una estensione della distribuzione di *A. bioculata*, precedentemente nota dall'Aquitano al Tortoniano inferiore, sino alla porzione superiore di questo ultimo piano.

INTRODUCTION

The last exhaustive overview on the Cenozoic echinoid assemblages from Sicily, after the pioneering work of Scilla (1670) and the nineteenth-century works of Agassiz & Desor (1846), Aradas (1850-55), Desor (1855-58), Cafici (1880) and Coppa (1898), dates back to Checchia-Rispoli (1907, 1916a, 1916b, 1917a and 1917b), who analysed Neogene-Pleistocene material. Basing on the old record by Coppa (1898), only two sand dollar species, the scutellines *Scutella subrotundata* Leske, 1778 and *S. truncata* Valenciennes, 1841 from the Miocene of Siracusa (SE Sicily), are known from Sicily. These sea urchins, namely tropical to temperate flattened and irregular clypeasteroids, experienced Miocene explosive radiations in the Mediterranean (Nebelsick & Kroh, 2002).

The main aim of the present work is to report the Sicilian occurrence of the Oligo-Miocene sand dollar *Amphiope* Agassiz, 1840, based on the discovery of

Amphiope bioculata (des Moulins, 1837) from a few meter thick sandy deposit cropping out in western Sicily. Palaeoenvironmental and stratigraphic settings of this deposit, previously unreported in the geo-palaeontological literature, is discussed below by means of the sedimentological and taphonomic contexts of the here reported finding.

MATERIAL AND GEOLOGICAL SETTING

The analyzed material was recovered in the vicinity of Case Genna, at about 12 km ENE from Marsala and 2.5 km ESE from the small village of Parrinello (Trapani, western Sicily), at coordinates 37°50'32" N, 12°33'47" E (Fig. 1b). It was collected from a six meters thick sandy deposit, with strata inclined along the cliff plane of about 45° north-northwestward. The sandy deposit extends laterally for at least 70 m, in WSW-ENE direction, and overlaps a mainly clayey succession belonging to the

upper Langhian - lower Tortonian “Marne di San Cipirello” (San Cipirello marls) Formation (see Ruggieri & Sprovieri, 1970a and 1970b; D’Angelo & Vernuccio, 1997). No contact between these lithologies is visible. At about 0.5 km south and 1 km north of Case Genna, the sediments of the San Cipirello Formation are in contact with the overlying upper Tortonian-lower Messinian terrigenous deltaic succession, known as “Molassa” of the Terravecchia Formation, which shows, in some places south of Case Genna, a thrust faults system (D’Angelo & Vernuccio, 1997).

In particular, most of the investigated Miocene succession from Case Genna (Fig. 1a) is formed by frequently bioturbated yellowish, locally cemented sands, containing very few, scattered and discretely rounded pebbles (also muddy pebbles), with a diameter of 1-5 cm.

Six interbedded, 10-20 centimetres thick, matrix-supported conglomeratic layers occur along the section; few centimetres thick lens-shaped marly layers are present in the lower and middle part. An undulated surface occurs at about 1 m from the base of the analyzed section. In the uppermost part of the succession, the yellowish sands gradually change into whitish sands (about 60 cm thick), which yield fragmented bivalves, mostly pectinids and ostreids; some disarticulated spondylids were also observed. At the top of the Miocene section, a marked erosion surface is filled by weakly cemented, coherent sands, up to at least 6 meters in thickness, with Quaternary (very likely Holocene) terrestrial molluscs, such as *Mastus pupa* (Linnaeus, 1758), *Rumina decollata* (Linnaeus, 1758), *Cochlicella* sp., *Trochoidea* sp., *Xerotracha* sp.

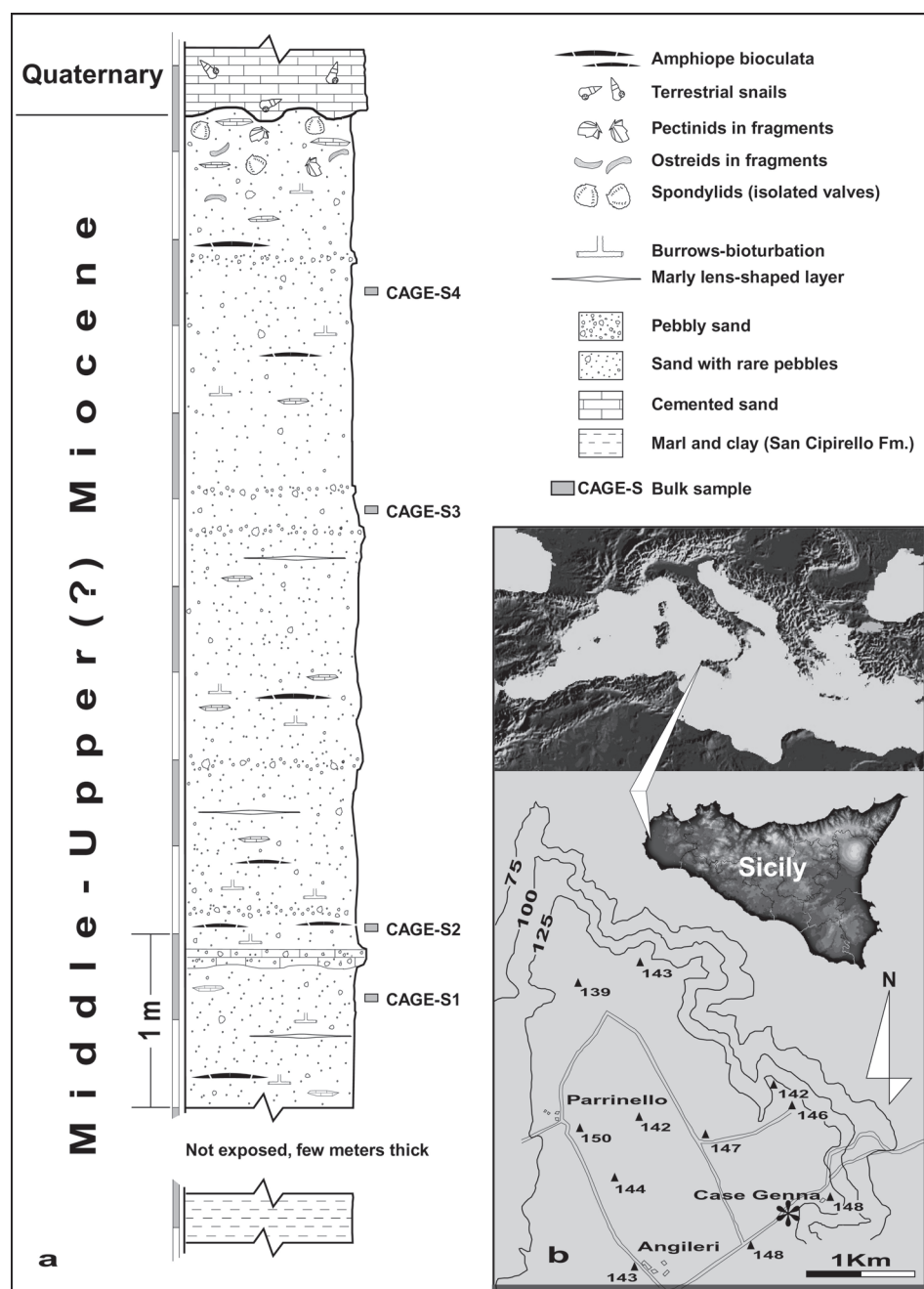


Fig. 1 - Stratigraphic log (a) and location (b) of the *Amphiope bioculata*-bearing deposit (asterisk) near Case Genna (W Sicily). The topographic sketch and elevations a.s.l. (meters), in Fig. b, are from IGM sheet n. 605-Paceco, scale 1:50000.

Four bulk samples (CAGE-S1-CAGE-S4, see Fig. 1a) were collected in order to provide the granulometric characterization of the yellowish sands yielding clypeasteroid remains, with particular regard to the lower part of the sandy succession, where echinoids are more abundant. Each sample was dried and weighted. Subsamples of 800 g were washed in a battery of sieves with mesh of 2, 1, 0.5, 0.25, 0.125 and 0.063 mm; a large bottom pan was used to collect decanted particles smaller than 0.063 mm. Sieved fractions were dried and weighted. As indicated by results in Fig. 2, samples CAGE-S1, CAGE-S2 and CAGE-S4 prevalently consist of fine sand, while in the sample CAGE-S3 the most representative fraction is medium sand, even if fine and coarse sands are very large. The considerable amount of the fraction < 0.063 mm, with relatively high value in sample CAGE-S4, might be due, at least partly, to the disgregation of occasional muddy pebbles.

Echinoid tests occur in most part of the Miocene section and are scattered, with a maximum density of about 1 specimen per 1-1.5 linear meters in the lower part. They are oriented in life position, with their oral side facing downwards. Two almost complete and seven fragmented specimens were collected from the lower part

of the section. They often show a primary radial interplate fracturing and grain impressions due to sediment particles pressed into the skeleton; skeletal implosion also occurs around the peristome of the most complete specimen (Pl. 1, fig. 2). A diffractometric analysis performed on a test fragment indicates that they have been partially replaced by SiO_2 . Nevertheless, the microstructure is not completely obliterated, in places preserving the stereom structure.

SYSTEMATICS

Class Echinoidea Leske, 1778
Order Clypeasteroida Agassiz, 1872
Family Astriclypeidae Stefanini, 1912
Genus *Amphiope* Agassiz, 1840

Amphiope bioculata (des Moulins, 1837)
Fig. 3 and Pl. 1, figs. 1-6

- 1837 *Scutella bioculata* DES MOULINS, pp. 72-73.
1895 *Amphiope Lovisatoi* COTTEAU, p. 16, Pl. 3, fig. 15.
1907 *Amphiope bioculata* (Desmoulins) - LAMBERT, p. 46.
1911 *Amphiope Montezemoloi* LOVISATO, pp. 42-47, Pl. 6, figs. 1a-b.

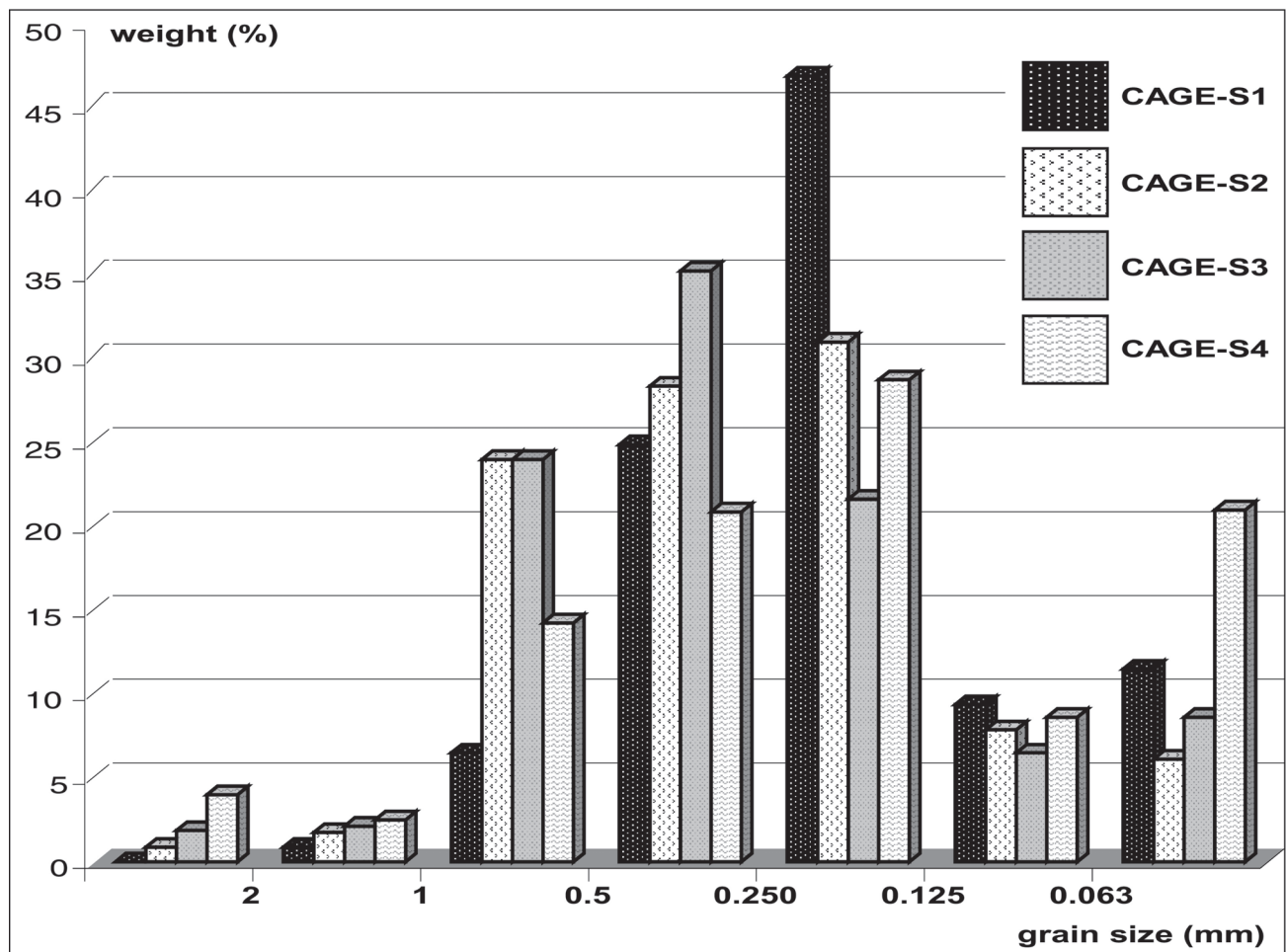


Fig. 2 - Histograms of the grain-size distribution for the four bulk samples (CAGE-S1 – CAGE-S4) collected from the sand dollar-bearing deposit at Case Genna.

- 1955 *Amphiope bioculata* (Desmoulins) var. *montezemoloi* Lovisato - COMASCHI CARIA, p. 184, Pls. 14-15.
 1998 *Amphiope bioculata* (Desmoulins) - PHILIPPE, pp. 152-167, Figs. 12-17, Pl. 16, figs. 1-8.
 2005 *Amphiope bioculata* (des Moulins) - KROH, pp. 97-101, Figs. 42 a-b, Pl. 46, figs. 5 a-b; Pl. 47, figs. 1 a-b; Pl. 48, figs. 1-3.

Material - Two almost complete tests (CAGE-E1 and CAGE-E2), 7 fragmented tests (CAGE-E3 –CAGE-E9) and several small uncatalogued fragments. All material is housed in the APEMA collection, Museo Geologico G.G. Gemmellaro, University of Palermo (Italy).

Description - Test medium-sized, disc-shaped, with irregular circular outline. Margin not always complete. Maximum width 70 mm and 75 mm, measured subcentrally in CAGE-E1 and CAGE-E2, respectively. Maximum height about 9 mm (CAGE-E1), measured slightly anterior of the apical disc. Ambitus thin and sharp. Oral surface almost flattened. Lunules, in posterior ambulacra, transversely elongate, subcircular to elliptical and broad: 9 x 5 mm (left), 7.7 x 5 mm (right) and 10.8 x 4.5 mm (left), 9.5 x 5 mm (right) in CAGE-E1 and CAGE-E2, respectively. The internal wall of the lunule shows a cross linked structure comparable to that of *Echinodiscus* Leske, 1778 (see Kroh, 2005, fig. 42B). Marginal indentations in ambulacrum III and interambulacra 1 and 4. Faint indentations in ambulacra II and IV. Apical disc subcentral, slightly anterior. On aboral side, the ambulacra form lanceolate, distally closed, subequal petals. Frontal petal slightly longer, making up about 60% of corresponding test radius. Poriferous zones slightly depressed; interporiferous zones slightly raised. Interporiferous zones as wide as a single poriferous zone. Tuberculation on aboral side dense and homogenous, consisting of small perforate and crenulate tubercles. Interambulacra surface smooth and densely crowded by tubercles, similar to those of ambulacra. Peristome small, anteriorly subcentral, with food grooves leading into it. Primary branching close to peristome; secondary ones hardly visible in examined specimens: posterior pair running around lunules. Periproct small, subcircular, with irregular outline, occurring between first and second pair of post-basicoronal plates, at about 13.5 mm from the margin (CAGE-E4).

Remarks and comparisons - Both *Amphiope* and *Echinodiscus* show two elongate lunules. *Amphiope* is distinguished by the broad, subcircular to elliptical, transversely elongate lunules. In *Echinodiscus* there are long and narrow, longitudinally elongate lunules or notches, and the posterior petals are much shorter than the others.

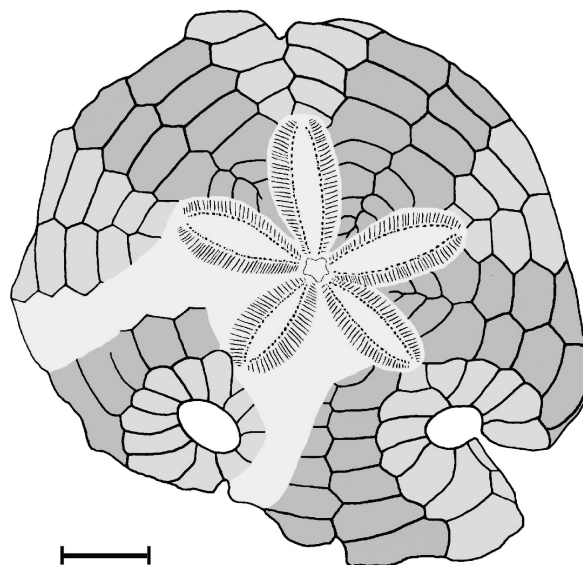


Fig. 3 - Plating diagram of the aboral side of *Amphiope bioculata* (des Moulins, 1837), as far as preserved in specimen CAGE-E1, sandy Miocene deposit of Case Genna (W Sicily). Interambulacral and ambulacral plates coloured in dark and light grey, respectively. Scale bar: 1 cm.

High intraspecific variation and poor nominal species definitions necessitate an exhaustive revision based on type-specimens (Kroh, 2005): among the 40 nominal species included, only *A. bioculata* and *A. boulei* Cotteau, 1913 should be regarded as well-established taxa. The type species, *A. bioculata* (des Moulins, 1937), is characterized by a wide variability, so that several *Amphiope* nominal taxa may turn out to be synonymous of this species (Kroh, 2005). For instance, only two of seven nominal species described from the Rhône Basin are considered to be valid (Philippe, 1998).

To this day *A. boulei*, from the Aquitanian of the Rhône Basin, is the only species of *Amphiope*, besides *A. bioculata*, described and illustrated in a modern way, allowing relevant comparison. It differs from *A. bioculata* by its smaller and longitudinally elongated lunules, and shorter petals.

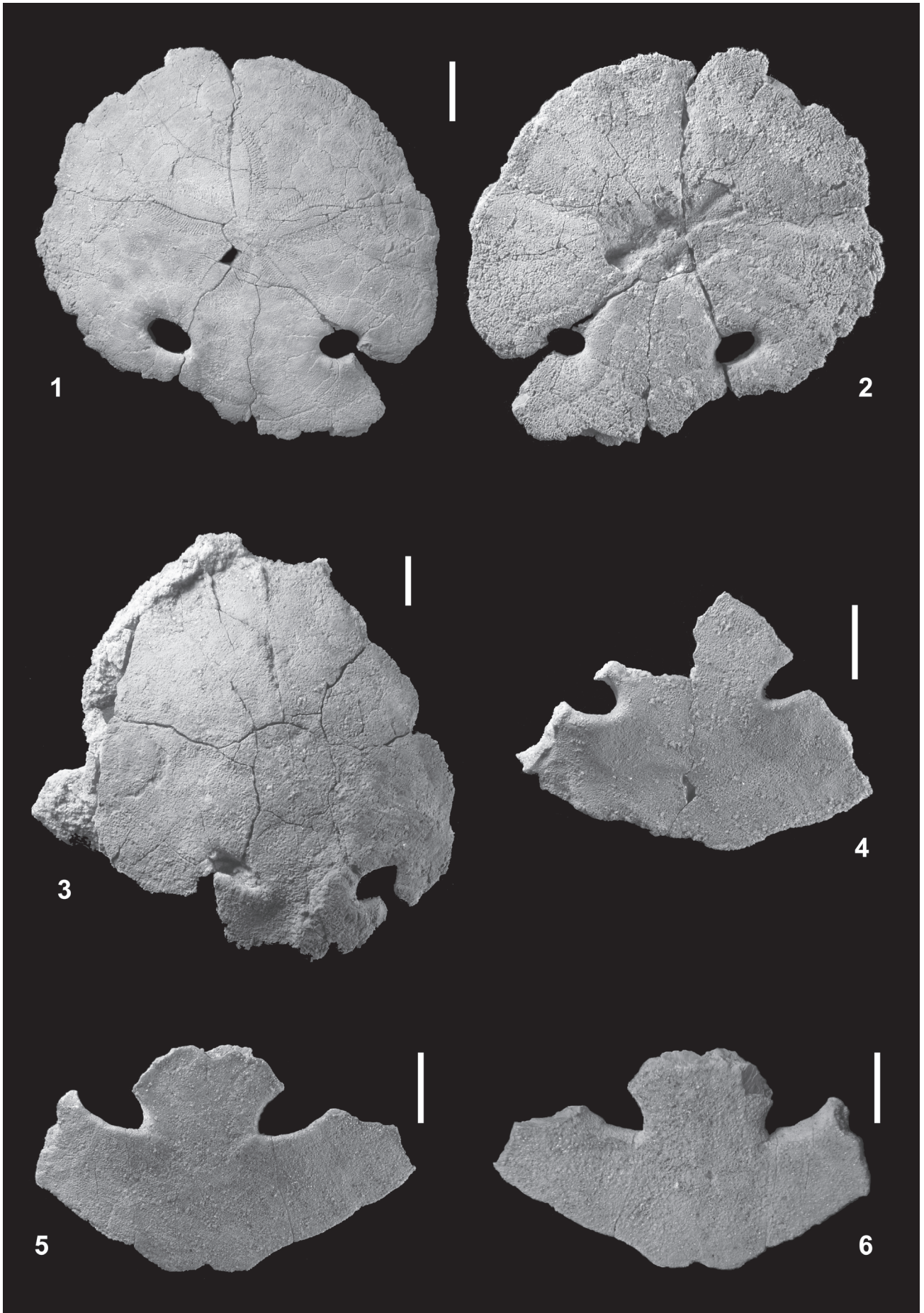
A. hollandei (Cotteau, 1877) from Bonifacio (Corse), Cagliari and Castelsardo (Sardinia; Cotteau, 1895) is distinguishable from *A. bioculata* by having very narrow lunules. Following Cotteau (1895), we consider *A. dessii* (Lovisato, 1895), from Nurri (Sardinia), a variety of *A. hollandei*.

Large test (up to 85 mm in width) of *A. pedemontana* Airaghi, 1899, from the late Oligocene of Liguria and Piedmont (North Italy), shows narrow and longitudinally

EXPLANATION OF PLATE I

- Figs. 1-6 - *Amphiope bioculata* (des Moulins, 1837) from the sandy Miocene deposit of Case Genna (W Sicily).
 1-2 - Aboral (1) and oral (2) views of an almost complete specimen (CAGE-E1) showing radial cracks and central implosion.
 3-5 - Almost complete (3, CAGE-E2) and fragmented (4, CAGE-E4, and 5, CAGE-E3) tests in aboral view, showing lunule shape variation.
 6 - Oral view of the same specimen as in Fig. 5 showing the small periproct.

Scale bars: 1 cm.



elongated lunules (Airaghi, 1899, pl. 6, figs. 1a-b and 1901, pl. 22, fig. 4), like it sometimes occurs in juvenile specimens of *A. bioculata* (Cottreau, 1913; Philippe, 1998). Remarkable differences between these species do exist: *A. pedemontana* has smaller, distally slightly opened petals and its frontal ambulacrum is much longer than the others. The examination of topotypic material, housed at the Museo di Paleontologia, University of Genova (inv. code SM.VI.DN-DS), confirms that *A. pedemontana* is distinct from *A. bioculata* and more closely related to *A. boulei*.

A. montezemoloi Lovisato, 1911 from San Giorgio (Sardinia), characterized by a more irregular outline and large sub-trigonal lunules, should be regarded as belonging to *A. bioculata* (see also Philippe, 1998). Also *A. lovisatoi* Cottreau, 1895, from Chiaromonte (Sardinia), falls in the variability range of *A. bioculata*.

As a whole, the specimens from Case Genna are consistent with the typical morphological features of *A. bioculata*. They show a remarkable variation in the lunule shape, as typically occurs in this species: the lunules are proportionally small and sub circular (Pl. 1, fig. 2 left), slightly elongate and elliptical (Pl. 1, figs. 2 and 3 right), narrow and strongly elongate (Pl. 1, fig. 3 left), proportionally broad and elliptical (Pl. 1, fig. 4). In particular, the broad, elliptical and transversely elongate lunules are close to the common shape described by Philippe (1998) from the Rhône Basin.

The radial interplate cracks and skeletal implosion observed in the material from Case Genna are typical of post-burial events due to the sediment loading of the test (see Nebelsick, 1999), and, together with subaerial erosion, seem to be the main cause of test fragmentation. The grain impressions on the skeleton are due to the pressure solution and represent a diagenetic feature (Nebelsick, 1999).

Occurrence - In the western Mediterranean *A. bioculata* is known from the Aquitanian to Serravallian of France (Desor, 1858; Lambert, 1912; Cottreau, 1913; Philippe, 1998), Corse (Cottreau, 1877) and Sardinia (Cottreau, 1895; Lambert, 1907; Lovisato, 1911; Comaschi Caria, 1955, 1972). The most recent occurrence from that area is from Port de Maó (Minorca, Balearic Islands, Llompart, 1983), in deposits recently dated as lower Tortonian (Pomar et al., 2002). It is also recorded from the Burdigalian to Serravallian of the eastern Mediterranean, Lybia (Cyrenaica, Desio, 1934; Rose, 1974a and 1974b), Turkey (Stchepinsky, 1944) and Egypt (Kroh & Nebelsick, 2003; Kroh, 2005). A sole specimen has been recorded from the central Mediterranean Serravallian of South Italy (Baselice, Benevento, see Barbera & Tavernier, 1989). In the Parathetyan area, it is recorded from the late Burdigalian to the early Serravallian of Austria and Hungary (Kroh, 2005). In the Atlantic region, it is known from the Aquitanian, Burdigalian and Serravallian of western France, at Bordelais, Touraine and Gers (Agassiz, 1841; Agassiz & Desor, 1846; Desor, 1858; Philippe, 1998). Recently, Khaksar & Maghfouri (2007) cited this species also from the Iranian Burdigalian (Eidajti).

From a palaeoecological point of view, *A. bioculata* should be regarded as a deposit feeder (Kroh & Nebelsick,

2003), burrowing immediately beneath the bottom surface, and feeding on fine detrital material, sieved from the uppermost layer of sand (Smith, 1984). This species is typical of shallow water (shoreface), in fully marine conditions with currents (Nebelsick, 1999; Nebelsick & Kroh, 2002; Kroh & Nebelsick, 2003). Like many other scutellines, it possibly tolerated very low depths, even in the tide zone (Mortensen, 1948; Chavanon, 1974).

CONCLUDING REMARKS

The occurrence of *Amphiope bioculata* at Case Genna represents the first record of the sand dollar *Amphiope* from Sicily. It is also the first circumstantiated finding of that species from the central part of the Mediterranean region.

The granulometric characterization of the deposit, indicating predominance of the fine to medium sand fractions (matching with the ecological requirements of *Amphiope*), and the supposed taphonomic setting suggest the presence of autochthonous palaeocommunities dominated by *A. bioculata*. The poor preservation of the analyzed material is substantially due to post-burial events. These considerations allow to hypothesize that the sandy outcrop at Case Genna formed in very shallow nearshore environments subjected to bottom current.

It is difficult to establish the age of the Case Genna deposit. As a matter of fact, the sand dollar-bearing succession does not appear to be overlaid by the San Cipirello marls and no evidence of lateral contact has been observed. Furthermore, a very consistent bathymetric gap exists between the depositional environments of these deposits, since the San Cipirello Formation formed at bathyal depths of 500-1000 m (Ruggieri & Sprovieri, 1970b). This discards the possibility that the Sicilian *Amphiope*-bearing deposit formed in heteropy with the San Cipirello marls. As a hypothesis, the deep marly to clayey sedimentation of the San Cipirello, which elsewhere continued up to the lower Tortonian, rapidly changed (even stopped?) in the studied area, as a consequence of rising movements by thrust sheet evolution, resulting in strong bottom depth decreasing. Glacio-eustatic sea level drop, e.g. one of those occurred around the Langhian/Serravallian and Serravallian/Tortonian transitions (Harzhauser & Piller, 2004; Shevenell et al., 2004; Lirer et al., 2007), could have played a relatively important role in emphasizing the effects of the supposed regressive trend. According to this hypothesis, the age of the here investigated echinoids-bearing deposit could be included in the range upper Langhian to lower Tortonian, on the basis of the Mediterranean known distribution of *A. bioculata* (Aquitanian to lower Tortonian) and the whole stratigraphic range of the Marne di San Cipirello Formation (upper Langhian-lower Tortonian). However this consideration appears contrived. An alternative hypothesis would suggest that the Case Genna deposit represents a subunit of the early part of the deltaic upper Tortonian-lower Messinian "Molassa" (Terravecchia Formation) that is consistent with the shallow water palaeoenvironment of the *Amphiope*-dominated facies. The Mediterranean stratigraphic range of *A. bioculata*

should hence be extended to the upper Miocene, probably upper Tortonian, depending on the age attributed to the Case Genna deposit.

From a palaeogeographic point of view, the vicinity of a (palaeo)Sicilian land mass, as inferred by the above supposed palaeoenvironmental setting, is consistent with the palaeogeographic reconstructions of the central Mediterranean at that time (e.g. Rögl, 1999), when (palaeo)Sicily was partially emerged, very likely forming the southernmost part of an archipelago extending approximately from north to south.

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