Turkish Journal of Earth Sciences

http://journals.tubitak.gov.tr/earth/

Research Article

Turkish J Earth Sci
(2014) 23: 444-451

doi:10.3906/yer-1401-20

First report of sphaeronitid blastozoans (Echinodermata) in the Middle Ordovician of the Taurides, Turkey

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Received: 17.01.2014 • **Accepted:** 14.05.2014 • **Published Online:** 17.06.2014 • **Printed:** 16.07.2014

Abstract. Articulated echinoderm remains are described for the first time in the Ordovician of Turkey. They occur massively, forming a relatively thick "cystoid bed" within the detrital limestone succession of the Sobova Formation (latest Dapingian–earliest Darriwilian) in the western Taurus Mountains. The "cystoid bed" encompasses a monospecific echinoderm assemblage of densely packed, 3-dimensionally preserved thecae. The presence of numerous suborganised plates with diplopore respiratory structures suggests probable affinities with sphaeronitid blastozoans. Comparable sphaeronitid dense beds are well known in the early Darriwilian of Baltica, and in the mid Darriwilian of the Middle East and Asian terranes.

Key words: Antalya, Adana, Taurides, Ordovician, echinoderm, cystoid bed

1. Introduction

Along with brachiopods, molluscs, and trilobites, echinoderms are a major component of the Great Ordovician Biodiversification Event in Middle and Late Ordovician times (Sprinkle and Guensburg, 2004; Lefebvre et al., 2013). However, our precise knowledge of the palaeobiogeographic patterns of the diversification of echinoderms in Mid-Ordovician times remains largely biased, for historical reasons, towards regions of modern Europe, North Africa, and North America, while very little information is available from other parts of the world. This observation is largely true as far as peri-Gondwanan echinoderms are concerned: most data on Mid-Ordovician echinoderm assemblages are from high-latitude regions (e.g., Czech Republic, France, Morocco, Spain; Barrande, 1887; Chauvel, 1941, 1966; Gutiérrez-Marco et al., 1984) and to a lesser extent from low-latitude areas (e.g., Burma, China, Thailand; Bather, 1906; Reed, 1917; Sun, 1936, 1948). Very little is known on peri-Gondwanan echinoderm assemblages from intermediate palaeolatitudes, and in particular from the Middle East. For example, the presence of isolated skeletal elements of unidentified echinoderms was briefly mentioned in Middle Ordovician deposits of the Taurides (Dean and Monod, 1970; Kozlu et al., 2002), as well as in the Upper Ordovician of south-eastern Turkey (Dean, 1967). In addition, the presence of a "cystoid bed" was reported in sedimentological and micropalontological studies, without any further details (Dean and Monod, 1970; Sarmiento et al., 2003; Göncüoğlu et al., 2004; Paris et al., 2007; Ghienne et al., 2010). The only description of Mid-Ordovician echinoderm assemblages in the Middle East is from the Lashkarak Formation of Alborz Mountains, Iran (Lefebvre et al., 2005). The aim of this paper is to help partly filling this gap by documenting the occurrence of abundant articulated remains of blastozoan echinoderms within a thick bed (or "cystoid bed") of the Sobova Formation in the Taurus Mountains (southern Turkey, Figure 1). In Mid-Ordovician times, this region belonged to the Tauride-Anatolide composite terrane (Dean and Monod, 1970; Göncüoğlu et al., 1997), which was located at relatively intermediate palaeolatitudes, close to the Gondwanan margins (Dean and Monod, 1990; Dean et al., 1999; Fortey and Cocks, 2003). Consequently, the main objectives of this brief report are to describe the first articulated echinoderm remains collected in Ordovician rocks from Turkey and to discuss their palaeobiogeographic affinities.

2. Geological setting and stratigraphy

The Sobova Formation (Middle Ordovician) is part of the non-metamorphic shallow marine Palaeozoic succession overlying the pre-Cambrian basement of the

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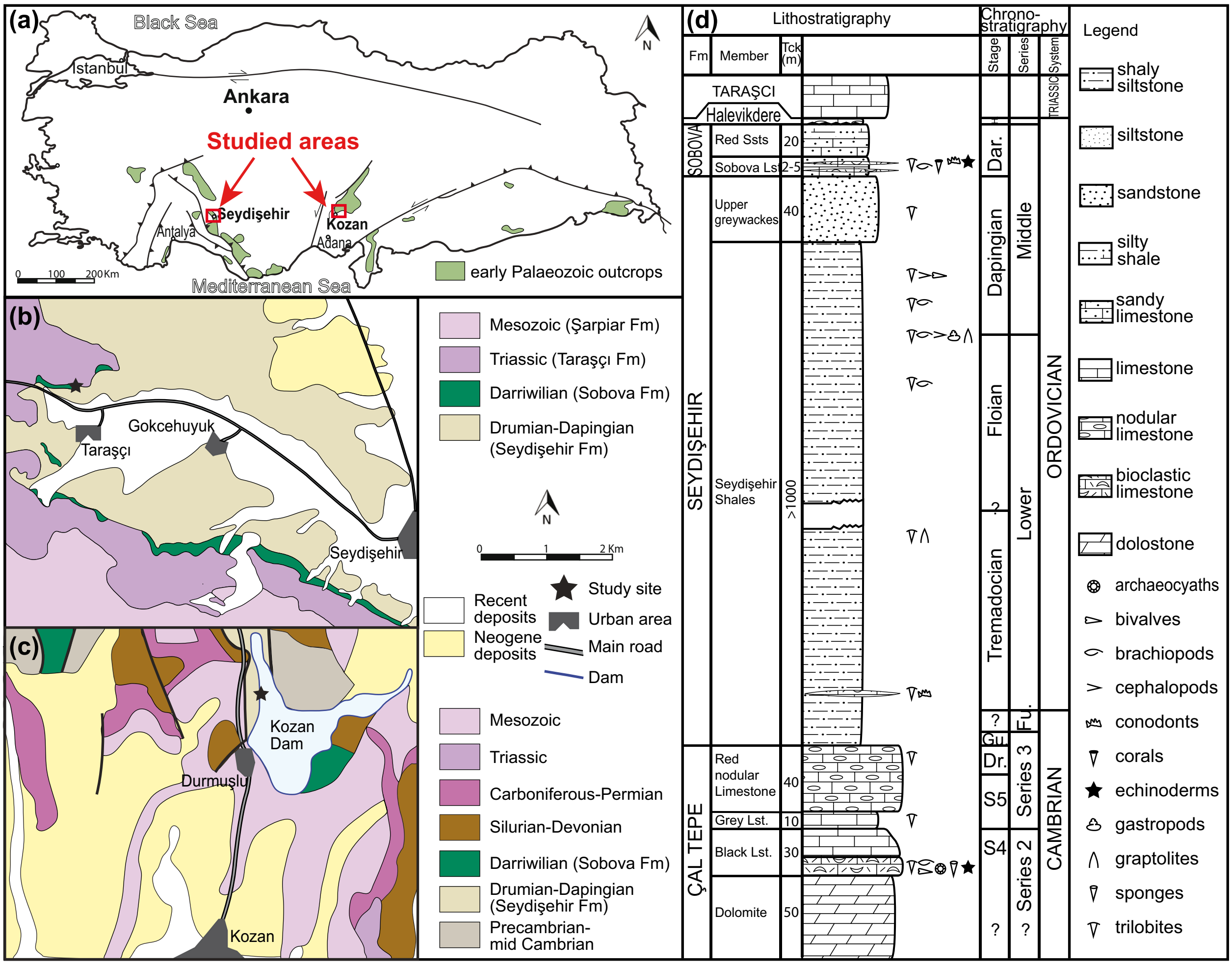

Figure 1. Location and stratigraphy of the studied sections in both Antalya and Adana provinces (southern Turkey). (a). Map of early Palaeozoic outcrops in Turkey. (b). Geological map of the Taraşçı area; modified from Dean and Monod (1970). (c). Geological map of the Kozan area; modified from Şenel (2005). (d). Stratigraphic position of the sphaeronitid bed within the Sobova Formation in the Taraşçı area (*norrlandicus* conodont Zone, late Dapingian–early Darriwilian); modified from Dean and Monod (1970).

Lycian-Bozkir Nappes in the Taurides belt of the Tauride-Anatolide terrane (Göncüoğlu et al., 1997; Göncüoğlu and Kozlu, 2000). The Sobova Formation corresponds to well-bedded, massive, pink-coloured detrital limestones, about 20 m thick in the western Taurides, and about 50 m thick in the eastern Taurides (Dean and Monod, 1970, 1990; Kalafatçıoğlu, 1975; Ghienne et al., 2010). These successions were interpreted as a shallowing-upward sequence on a carbonate-dominated platform (Kozlu et al., 2003). The grey bioclastic limestone bands and lenses of the Sobova Formation are very rich in brachiopods, trilobite fragments, and corals. Abundant pluricentimetric thecae of cystoids (up to 6 cm in diameter) occur in the upper part of the succession, in a pinkish grey, ca. 2 m thick, medium to thick-bedded, sandy limestone band (Figure 1d). Associated macrofauna within the "cystoid bed" is scarce, composed of a few brachiopods (e.g., *Eodelmanella* sp.) and rare trilobite fragments (Dean and Monod, 1970). The "cystoid bed" layer is interpreted as a relatively condensed horizon in an open marine carbonate depositional environment. The "cystoid bed" was investigated in 2 sections about 360 km away from each other, but showing strongly similar lithostratigraphic successions (Figure 1a). The first locality is about 1 km north of Taraşçı, in the western Taurus Mountains, Antalya Province, Turkey (37°27′11.37″N; 31°45′06.89″E; Figure 1b). Echinoderm accumulations are here located at the top of the calcarenitic beds in the lower part of the Sobova Formation (Ghienne et al., 2010). The second section is located at Kozan Dam, about 8 km north of Kozan, in the eastern Taurus Mountains, Adana Province, Turkey (37°28′44.88″N; 35°47′46.48″E; Figure 1c). Echinoderm accumulations occur either at the base or in the middle of the greyish-pinkish micritic limestone beds in the lower part of the equivalent of the Sobova Formation (Figures 2a–2c) (Ghienne et al., 2010). The pinkish grey limestones containing the "cystoid bed" have yielded a diverse conodont fauna assigned to the *Baltoniodus norrlandicus* Zone (latest Dapingian), based on the occurrence of the index species in both the western and eastern Taurides (Sarmiento et al., 2003). In the western Taurides, the highest part of the Sobova Formation comprises thin bands/lenses of dark red sandy limestones interlayered with siltstones, and at the top, reddish silty sandstones (Figure 1d). In the eastern Taurides, the echinoderm-bearing limestones at the base of the Sobova Formation are overlain by grey silty shales.

3. Material

The "cystoid bed" consists in an accumulation of densely packed, articulated thecae of blastozoan echinoderms, associated with rare disarticulated brachiopods and trilobite fragments. No stems or brachioles are preserved. This type of preservation is typical of "type 2" echinoderms, as defined by Brett et al. (1997). The skeleton of "type 2" echinoderms consists of weakly articulated portions (appendages), prone to rapid disarticulation, and of more tightly sutured, decay-resistant modules (theca). The absence of columnals and/or of stem modules in the "cystoid bed" may result either from an original absence (stemless blastozoans) or from a taphonomic bias. Moreover, the detailed, in situ examination of large slabs of the "cystoid bed" indicates that the echinoderm assemblage is very likely monospecific. As a consequence, one single specimen was extracted from the "cystoid bed" at locality 1 (Taraşçı, western Taurus Mountains), and prepared for taxonomic purposes. The specimen is deposited in the collections of the Department of Geological Engineering of METU (Middle East Technical University, Ankara, Turkey) under the number METU 2003.

The specimen consists of a 3-dimensionally preserved, slightly distorted, calcitic recrystallised mould of a large, polyplated, incomplete theca (Figures 2b and 2c). The preserved portion of the theca is ovoid. It is about 47 mm long and 41 mm wide. The theca is made of several tens of pentagonal and hexagonal plates, apparently organised in regular circlets. Numerous, small (<0.5 mm) respiratory pores are preserved on the thecal plates. They are arranged in pairs (diplopores), with a density of about 13 pairs per 5 mm^2. Diplopores can be either subparallel to plate margins or more longitudinally arranged, when they occur in the central portion of the plates. Diplopores are preserved all over the theca, without any regular pattern. Neither the adoral part of the theca (with the primary openings) nor its aboral portion (with the attachment disc) is preserved in specimen METU 2003.

The presence of diplopores all over the theca clearly supports the assignment of specimen METU 2003 to any of the 4 blastozoan clades traditionally united within the (polyphyletic) "class" Diploporita Müller, 1853. Within diplopore-bearing blastozoans, an assignment to the superfamilies Aristocystitida Neumayr, 1889, Asteroblastida Bather, 1900, and Protocrinitida Paul, 1984 is unlikely. Aristocystitids are characterised by a more elongate, ellipsoidal theca, and the morphology of their respiratory structures is different (see Paul, 1972). Both protocrinitids and asteroblastids have a regular stem, a prominent oral area, and a more bowl-shaped theca. The ovoid shape of the theca and the thecal plate pattern both rather suggest an attribution to the superfamily Sphaeronitida Neumayr, 1889. A more precise taxonomic assignment is difficult, as the morphology of both adoral and aboral regions is unknown. However, the size of the theca, the subregular organisation of thecal plates into circlets, and the distribution pattern of the diplopores are all suggestive of probable affinities with the genera *Sphaeronites* Hisinger, 1828 and/or *Diplosphaeronis* Paul, 1973.

4. Palaeobiogeographical implications

The "cystoid bed" described herein from 2 distinct localities of the Taurus Mountains represents the first report of such levels in the Ordovician of Turkey, and it increases the palaeogeographical distribution of sphaeronitid beds (Figure 3). Sphaeronitid beds were already documented in Darriwilian deposits of the Alborz terrane (Lashkarak Formation, *pseudoplanus* conodont Zone, Alborz Mountains, Iran; Lefebvre et al., 2005), as well as in various regions of Baltica, such as Gotland (e.g., Lower Asaphus Limestone Formation, *originalis* conodont Zone; Hjorthamm Limestone Formation, *crassus* conodont Zone; Westergard, 1928; Hadding, 1933; Regnéll, 1945; Eriksson et al., 2012) and Öland (e.g., Horns Udde Formation, *variabilis* to *crassus* conodont Zones; Regnéll, 1960; Paul and Bockélie, 1983; Stouge, 2001, 2004). However, in both the Alborz terrane and Baltica, sphaeronitid beds have yielded more diverse echinoderm assemblages than in Turkey.

Sphaeronitids do not necessarily occur within dense beds. In Mid-Ordovician times, the palaeogeographical distribution of large sphaeronitid taxa comparable in morphology to the Turkish specimens was relatively extensive (Figure 3). Large sphaeronitids have been described in various regions from Baltica, e.g., in the *Asaphus* Limestone Formation (*hirundo* graptolite Zone) of Decarlia and Scania (Sweden; Regnéll, 1945; Paul and Bockélie, 1983), and in the Körgekallas Formation (*teretiusculus* graptolite Zone) of Estonia (Bockélie 1984). Large sphaeronitids also occur in several high-latitude peri-Gondwanan areas, e.g., in the Navas de Estana Formation (*teretiusculus* graptolite Zone) of

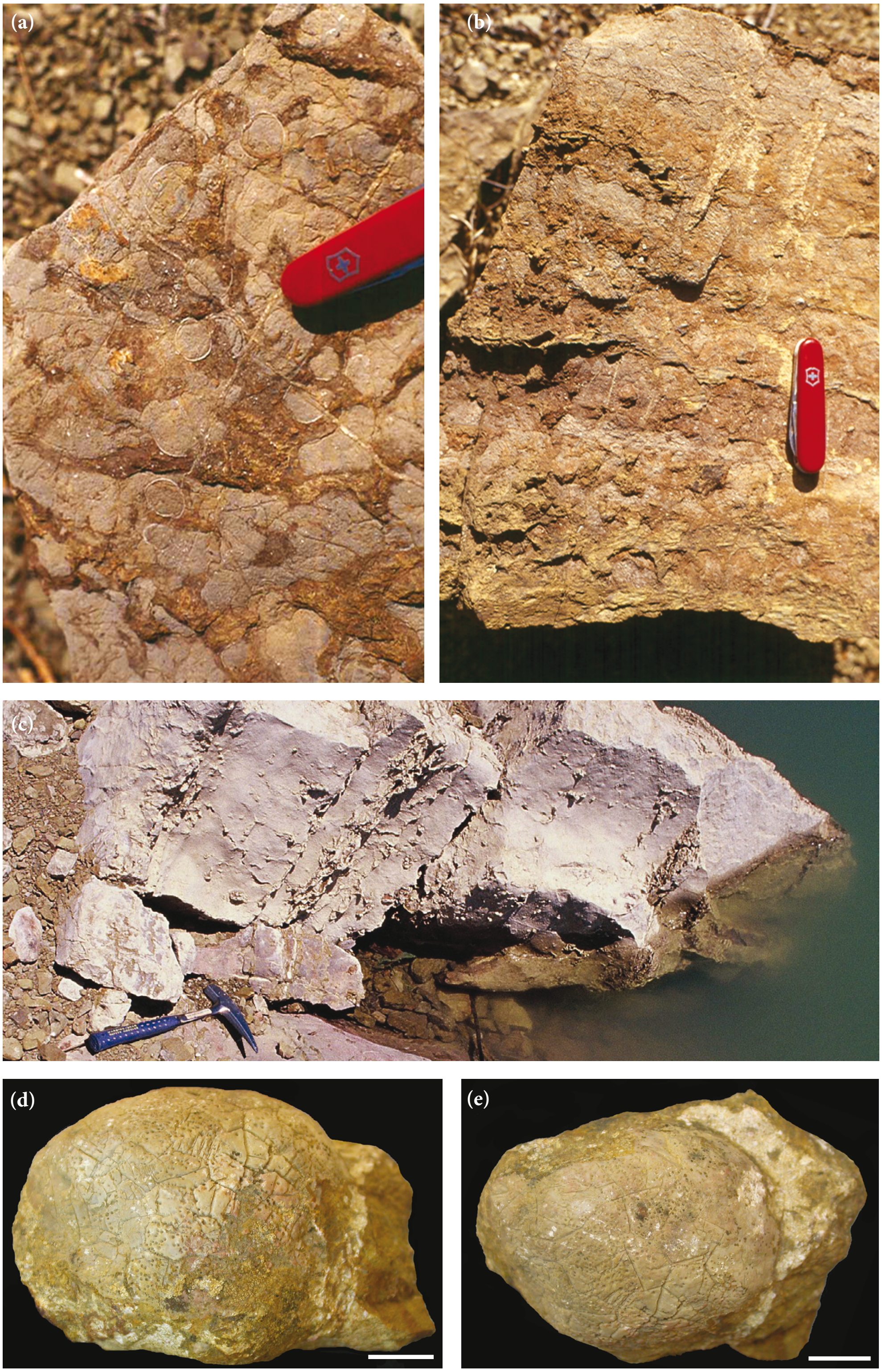

Figure 2. (a) and (b). Top (a) and lateral view (b) of the Sphaeronitid bed of the Sobova Formation at the Kozan Dam section (Adana Province, Turkey). (c). Enlarged view of the "cystoid bed" at the Kozan Dam section. (d) and (e). Specimen METU 2003, extracted from the sphaeronitid bed (Sobova Formation) at the Taraşçı section (Antalya Province). Perpendicular lateral views of the 3-dimensionally preserved sphaeronitid theca, showing diplopores respiratory structures. Scale bar represents 10 mm.

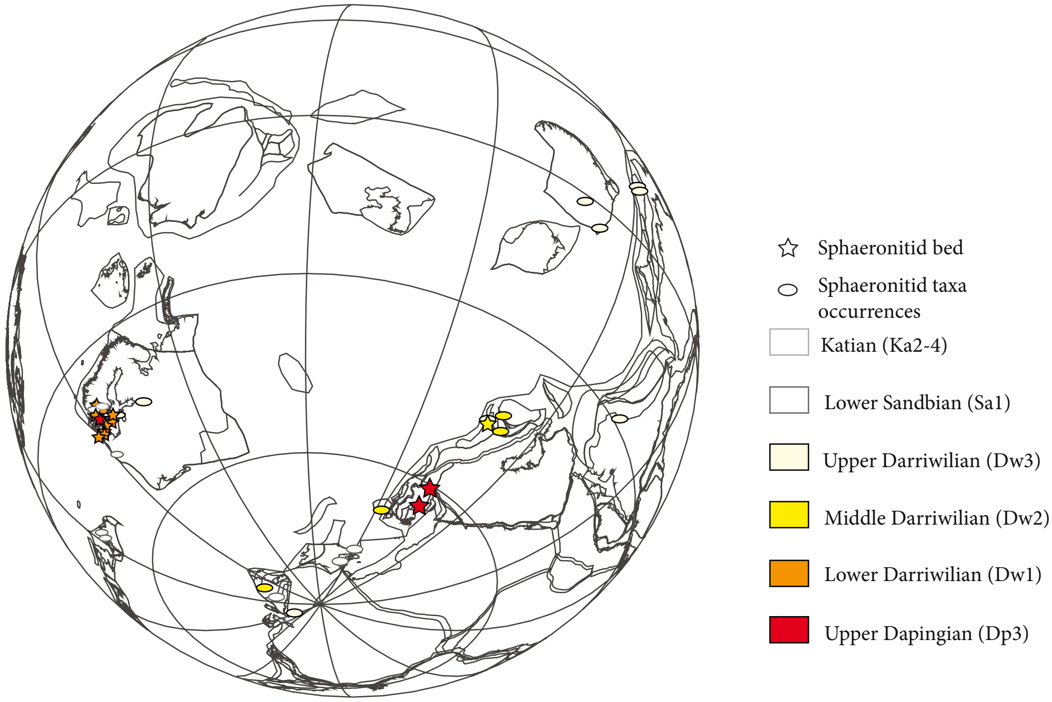

Figure 3. Distribution of large sphaeronitid taxa and sphaeronitid beds on a Middle Darriwilian palaeogeographical reconstruction (produced using BugPlates; Torsvik, 2009). The 2 studied sections are represented by larger red stars.

Spain (Gutiérrez-Marco et al., 1984; Lefebvre and Fatka, 2003), the First Bani Group (late Darriwilian) of Morocco (Chauvel, 1966, 1978), and the Šarka Formation (mid Darriwilian) of Bohemia (Prokop, 1964; Prokop and Petr, 1999; Mergl and Prokop, 2006). Finally, sphaeronitids were also reported from various other peri-Gondwanan regions located at lower temperate palaeolatitudes, e.g., in both the Lashkarak and Shirgesht formations (*variabilis* to *pseudoplanus* conodont Zones) of Iran (Lefebvre et al., 2005), the Gauran Formation (*elegans* graptolite Zone) of Kashmir (Fuchs and Gupta, 1971), the Upper Naungkangyi Beds (*fasciculatus* to *murchisoni* graptolite Zones) of Burma (Reed 1906, 1915, 1936; Fortey and Cocks, 1998), and the Lower Hangshiuitang Limestone Formation (*nanus* to *murchisoni* graptolite Zone) of South China (Reed, 1917; Sun, 1948; Wolfart, 2001; Zhang et al., 2009).

In summary, in Mid-Ordovician times, both sphaeronitid beds and large sphaeronitid taxa were apparently widespread over a relatively short stratigraphic interval. Their palaeobiogeographical distribution extends from the western margin of Baltica (Estonia, Sweden) to a wide range of peri-Gondwanan regions located from high to intermediate palaeolatitudes (e.g., Bohemia, Burma, Iran, Kashmir, Morocco, South China, Spain, Turkey). The oldest occurrences of large sphaeronitids, either as isolated individuals or as dense beds, have been reported in both Sweden and Turkey (latest Dapingian–earliest Darriwilian). This observation is in good agreement with the strong Baltic affinities already reported for both trilobites (Dean and Monod, 1970; Dean, 1971, 1973; Dean and Martin, 1992) and conodonts (Kozlu et al., 2002) during the same time interval. However, both older and younger Ordovician faunas of the Taurides (e.g., brachiopods, trilobites) do not exhibit such Baltic affinities but in contrast relatively strong affinities with either higher or lower latitude peri-Gondwanan areas (Fortey and Cocks, 2003). Moreover, the short-lived incursion of Baltic faunas (including sphaeronitids) in the Taurides during the latest Dapingian–earliest Darriwilian time interval coincides with the deposition of carbonates within a predominantly siliciclastic sequence (Figure 1c). Consequently, this dramatic faunal and lithological shift observed in the Taurides during the latest Dapingian–earliest Darriwilian time interval possibly results from a brief episode of climate warming.

In younger deposits (mid Darriwilian to Upper Ordovician), sphaeronitids have not been found in Turkey, but they are relatively widespread in both Baltica and peri-Gondwanan areas. Although sphaeronitids are known by a limited number of occurrences at intermediate palaeolatitude regions, their palaeogeographical distribution apparently shows a regular shift towards lower latitudes. Sphaeronitids are documented successively in Turkey (latest Dapingian–earliest Darriwilian), then in Alborz and Lut terranes (mid Darriwilian), and finally in Burma and South China (mid to late Darriwilian, with uncertainty about the age; Zhong and Hao, 1990). If this pattern is correct, then it could suggest a possible migration of the sphaeronitids along the Gondwanan margin from high latitude to tropical regions during the early–mid Darriwilian time interval, possibly favoured by the first pulse of the major transgressive trend (Nielsen, 2004; Haq and Schutter, 2008) and/or by a presumed short cooling event (Nardin et al., 2011; Cherns et al., 2013). In any case, the occurrence in the Middle Ordovician of Turkey and other temperate peri-Gondwanan terranes (e.g., Iran) of echinoderm assemblages showing a mixture of various affinities (e.g., Baltica, Mediterranean Province, Sibumasu, South China) is in good accordance with the supposed palaeogeographical position of these areas (Fortey and Cocks, 2003). Similar distribution patterns have been described for other Darriwilian invertebrates, such as trilobites (Ghobadi Pour and Popov, 2009; Bassett et al., 2013), brachiopods (Turvey, 2005, 2007; Zhan and Jin, 2005), and ostracods (Ghobadi Pour et al., 2006).

Acknowledgements
This study is a contribution to the UMR CNRS 5563 Géosciences Environnement Toulouse and to IGCP Project 591 "The Early to Middle Palaeozoic Revolutions", and to the team "Vie Primitive, biosignatures, milieux extrêmes" of the UMR CNRS 5276, LGLTPE. It is also a contribution to the ANR project RALI ("Rise of Animal Life"). EN was funded by the project SYSTER AO2012-786879 and partly also by the SYNTHESYS project ES-TAF-2991. The authors greatly thank Dr Hüseyin Kolzu for his kind assistance in the field and in the discovery of the cystoid bed and Dr Samuel Zamora for his helpful and constructive comments.

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