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ORDOVICIAN GRAPTOLITES AND ACRITARCHS FROM THE BARRANCOS REGION (OSSA-MORENA ZONE, SOUTH PORTUGAL)

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INTRODUCTION

Ordovician fossils are relatively scarce in the Portuguese part of the Ossa-Morena Zone, one of the most distinctive Paleozoic domains of the Iberian Massif, where most of the available data come from the Barrancos region and needs an accurate review.

The first account on the existence of Ordovician rocks near the Portuguese small city of Barrancos were published by Delgado (1901, 1908, 1910), who mentioned some graptolites and ichnofossils and defined three lithostratigraphic units from his "lower Silurian" division. In ascending order, these are the Fatuquedo shales, the Barrancos shales (including the "*Phyllodocites* shales" at its upper part) and the Colorada greywackes and quartzites formations. The paleontological record was virtually restricted to the fine shales of the Barrancos Fm. and especially to their "*Phyllodocites* shales", a local facies of very micaceous, grey, green or red slates, not represented in the Spanish counterpart of the Estremoz-Barrancos-Hinojales domain of the Ossa-Morena Zone (Robardet et al., 1998). The age of the overlying Colorada Formation remains unknown, but graptolites recorded just above its top are already representative of the earliest Silurian (Piçarra et al., 1995).

Ordovician graptolites from the Mestre André quarry east of Barrancos (Fig. 1) were first identified by Delgado (1901, p. 215) as *Didymograptus geminus* His., and then as *Didymograptus sparsus* Hopk. (Delgado, 1908 p. 187; 1910, pl. 27). New graptolite findings from the same locality were illustrated by Perdigão (1967, pl. 1, figs. 3-4), who recorded a broken stipe of *D. sparsus* and a proximal fragment of *Didymograptus hirundo* Salter, being the latter species indicative of an "upper Skiddawian" (= late Arenigian) age for the "*Phyllodocites* shales".

The existence of Ordovician rocks in the Barrancos region was questioned in 1981 by Teixeira (publ. 1982), who considered the graptolites from the Mestre André quarry as of Silurian age, following the ideas of Romariz (1962). These authors, in agreement with certain data from Delgado (1908), extended the range of some Ordovician genera like *Didymograptus, Phyllograptus* and *Tetragraptus* into the Silurian (see also Teixeira, 1984). Romariz (1962) also cited the occurence of *Pristiograptus* sp. immediately east of the

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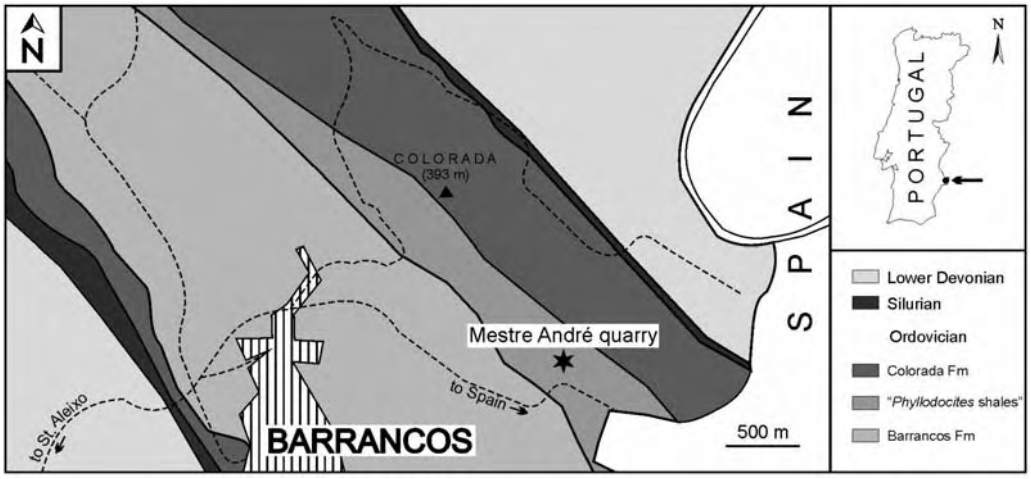

Figure 1. Simplified geological map of the Barrancos Region, with indication of the Mestre André quarry in the "*Phyllodocites* shales", bearing ichnofossils, acritarchs and graptolites.

Mestre André quarry, a record that was reviewed by Gutiérrez-Marco (1981) and reassigned to indetermined dichograptoid stipe fragments coming from an Ordovician outcrop. In his report, Gutiérrez-Marco (1981) confirmed the Ordovician age of the graptolite specimens illustrated by Perdigão (1967), as being most probably indicative of the upper Arenigian *Expansograptus hirundo* Zone.

Palynological research in the "*Phyllodocites* shales" led Cunha and Vanguestaine (1988) the discovery of Lower Ordovician acritarchs in two samples taken west of Barrancos, at km 94.2 of the road to Santo Aleixo, in the western flank of the Barrancos anticline (outside the frame of Fig. 1). The moderately preserved association was placed close to the Tremadocian-Arenigian boundary. A second report on acritarchs from the same unit was recently presented by Borges et al. (2008). The latter samples come from several pieces of rock labelled as "Mestre André quarry, Barrancos", originally from the Delgado collection, deposited at the LNEG Geological Museum in Lisbon. A preliminary palynological study presented by Borges et al. (2008) concludes a Floian age for the acritarch assemblage, which is briefly examined below.

Further research of the present authors in typical outcrops of the "*Phyllodocites* shales" in the Barrancos region, including the Mestre André quarry, didn't produce any positive result for macrofossils or microfossils, despite several sampling campaigns carried out in the region by the present team on the last three decades. For this reason, we suspect that previous records of graptolites by Delgado (1901,1908, 1910) and Perdigão (1967) may have involved lenticular intercalations of fossiliferous shales temporally exposed during the exploitation of the slate quarry. The review of the original samples preserved in the Delgado collection show that these graptolite-bearing shales are very different to the green to reddish micaceous slates, with common ichnofossils, obtained in the Mestre André quarry for building and roofing purposes. In this sense, the matrix of the fossiliferous samples is usually of grey colour, only lightly micaceous, and have a higher argillaceus content, being more affected by the regional foliation.

The purpose of this note is to present a more detailed revision of the original samples labelled as "pedreira do Mestre André, Barrancos" coming from the Delgado collection. Among them we have restudied the graptolites illustrated in his posthumous monograph (Delgado, 1910), as well as some sponges also recovered from his collection, but coming from a different site (samples no. IGM-10862). Reinvestigation of selected samples has added more detailed palynostratigraphic information to that

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presented by Borges et al. (2008). In addition to this, information derived from the abundant, but confusing, record of trace fossils in the same strata is briefly examined for paleoenvironmental discussion.

GRAPTOLITES

We have examined seven specimens of Ordovician graptolites from the Delgado collection, nos. 6000-6005, plus one unnumbered. Specimens 6000, 6004 and those without number are stipe fragments, and the remaining correspond to proximal parts of the rhabdosome usually including the complete sicula. They are all labelled as "*Didymograptus sparsus* Hopk.", except specimen no. 6004 that was misidentified by Delgado's handwritting as the Silurian graptolite "*Monograptus lobiferus* McCoy" (Delgado, 1910, pl. 27, fig. 5). The latter clearly corresponds to a badly preserved stipe of an Ordovician dichograptoid, strongly affected by cleavage. Besides this material, Perdigão (1967, pl. 1, fig. 2) illustrates another specimen of *D. sparsus* from the Delgado collection, but this might not have been reintegrated to the collection and is probably lost.

All graptolites recorded from the Mestre André quarry belong to the form genus *Expansograptus* Bouček and Přibyl, which includes a variety of horizontal didymograptids lacking the dorsal virgella characteristic of *Xiphograptus* Cooper and Fortey, and that could be partly related with the genus *Didymograptellus* Cooper and Fortey *sensu lato* (its type species also possess virgella: Maletz, 2010). The Portuguese material is somewhat expanded tectonically, and the details of proximal developments are not well enough preserved for an unequivocal identification.

The most prominent element occurring in the assemblage (Fig. 2a, e) is a robust *Expansograptus*. This form has a large sicula (3-4 mm in length, with long supradorsal and ventral-apertural free parts), thecae widely spaced (2TRD 2.5-3 mm) with flared apertures, two or three declined thecae in the proximal region with relatively low stipe expansion, spreading from 2 mm at the first theca of each stipe to a maximum width of about 3 mm. All these characters are very distinctive of the species *Expansograptus sparsus* (Hopkinson), already identified in this locality by Delgado (1908, 1910) and Perdigão (1967), which is a form apparently restricted to the Fennian stage of the British Arenig, perhaps crossing its upper boundary with the Llanvirn (Fortey and Owens, 1987; Zalasiewicz et al., 2009). *Expansograptus sparsus* differs from other robust species with long prominent sicula coming from older beds, like *E. protobalticus* (Monsen), by its higher thecal inclination, lower thecal content and shorter declined part (see Maletz, 1996a). *Expansograptus praenuntius* (Törnquist) also superficially recalls the Portuguese form, especially by the high supradorsal part of the sicula exposed; but their stipes are thinner (< 3 mm in width), the thecal density higher (2TRD= 2.2 mm), the stipe expansion different, and the sicula shorter (2.7 mm): see Rushton in Zalasiewicz and Rushton (2008). The rhabdosome of *D. sparsus* Hopk. figured by Perdigão (1967, pl. 1, fig. 2: a retouched photograph) is clearly conspecific with our specimen and has a very similar aspect, but it is not its actual counterpart, since it has longer proximal stipes.

A second species with a shorther sicula also has two robust stipes that widens quickly in the first ten thecae from 2.5 mm to a maximum of 3 mm. The rhabdosome is slightly reflexed (Fig. 2c), with an origin of th 1^{1} high on the sicula, showing a certain degree of isograptid simmetry in obverse view. This form somewhat ressembles *Expansograptus hirundo* (Salter) by the general aspect of rhabdosome, including the slight reclination of the proximal part (Rushton, 1985; Fortey and Owens, 1987). However, the Portuguese specimen has shorter proximal thecae, and the remaining thecae are less inclined than in the cosmopolitan Arenigian form. Several older species with a proximal part slightly reflexed, like *E. similis* (Hall), *E.*

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constrictus (Hall), *E. grandis* (Monsen) or *E. suecicus* (Tullberg) have different dimensions and present a longer ventral apertural wall of the sicula (Williams and Stevens, 1988; Maletz, 1996, 1997). As the Portuguese material is limited to a single flattened specimen, we identified it provisionally as *Expansograptus* sp. A.

A third graptolite species recognized in the assemblage is a thinner horizontal didymograptid, with a relatively thin proximal end and few-inclined thecae, of very low thecal density (2TRD= 3 mm). Its general shape (Fig. 2b, f) is reminiscent of *Didymograptus* (s.l.) *nitidus* (Hall) and of some other species variously included in the genera *Expansograptus, Didymograptellus* or *Xiphograptus*. The poor preservation of our material, which is strongly flattened and slightly deformed, prevents an accurate identification, and the two Portuguese specimens are here regarded as *Expansograptus*? sp. B.

Finally, a fourth graptolite species from the Mestre André quarry is represented by the wide-stiped horizontal didymograptid described by Perdigão (1967, pl. 1, fig. 4) as *Didymograptus hirundo*. The retouched photograph provided by this author makes the presence of this species at the locality very probable, with the specimen showing a relatively short sicula, broad stipes (3.5 mm in width), and thecae highly inclined (aprox. 60º in the free ventral part). However, not having been possible to examine the original specimen, its provisional identification stands as *Expansograptus* cf. *hirundo* (Salter). According to Zalasiewicz et al. (2009) and previous works, *E. hirundo* is a long-ranging species, widespread (at least) from the earliest Dapingian to the early Darriwilian. It was the nominal species of a British graptolite zone, formerly representative of the late Fennian regional stage, which has recently been renamed as *Aulograptus cucullus* Zone, to take into account the fact that *E. hirundo* originates much earlier, in the *Isograptus victoriae* Zone.

PALYNOSTRATIGRAPHY

Preliminary palynostratigraphic research was established in several samples from the N. Delgado collection of the Geological Museum. Standard palynological laboratory procedures were employed in the extraction and concentration of the palynomorphs from the host sediments (Wood et al., 1996). The slides were examined with transmitted light, using a BX40 Olympus microscope equipped with an Olympus C5050 digital camera. All samples, residues and slides are stored in the LNEG-LGM (Geological Survey of Portugal) at S. Mamede Infesta, Portugal.

The acritarchs are abundant and reasonably well preserved in the studied samples. The assemblage includes the forms *Acanthodiacrodium costatum* Burmann (Pl. 1, fig. 1), *A.*? *dillatum* Molyneux (Pl. 1, fig. 5), *Acanthodiacrodium* spp., *Arbusculidium* cf. *filamentosum* (Vavrdová) (Pl. 1, fig. 4), *Coryphidium* cf. *bohemicum* Vavrdová (Pl. 1, fig. 2), *Cymatiogalea messaoudensis* Jardiné et al. (Pl. 1, fig. 14), *Cymatiogalea* sp. (Pl. 1, fig. 11), *Pachisphaeridium* sp., *Peteinosphaeridium trifurcatum* Eisenack (Pl. 1, fig. 10), *Polygonium* sp., *Micrhystridium* sp. (Pl. 1, fig. 7), *Stelliferidium stelligerum* Deunff et al. (Pl. 1, fig. 6), Stelliferidium sp., *Striatotheca principalis parva* Burmann (Pl. 1, fig. 8), *S. rugosa* Tongiorgi et al., *S. rarirrugulata* Eisenack et al. (Pl. 1, fig. 9), *Vavrdovella areniga* Loeblich and Tappan (Pl. 1, fig. 3), *Veryhachium trispinosum* (Eisenack) (Pl.1, fig. 12) and *V. lairdii* (Deflandre) (Pl. 1, fig. 13). Also common in the studied assemblage are the cryptospores *Virgastasporites rudi* Combaz (Pl. 1, fig. 15) and *Gneudnaspora divellomedia* (Tchibrikova) (Pl. 1, fig. 16).

The palynological assemblage is mainly composed of long ranging acritarch species recorded in a wide rank of Early Ordovician ages. Some forms such as *Arbusculidium filamentosum*, *Coryphidium* and

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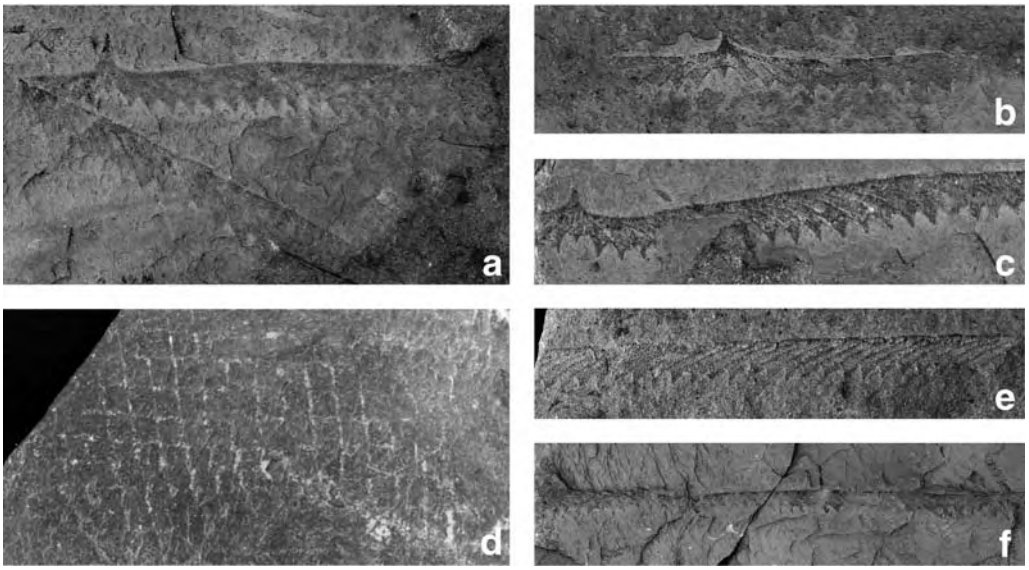

Figure 2. Some fossils from the "*Phyllodocites* shales" belonging to the Delgado collection, LNEG Geological Museum of Lisbon. a, *Expansograptus sparsus* (Hopkinson), proximal part with very large sicula (figured in Delgado, 1910, pl. 27, fig. 2), coll. no. 6001, x 2.2; b, *Expansograptus*? sp. B (figured in Delgado, 1910, pl. 27, fig. 6), coll. no. 6005, x 2.2; c, *Expansograptus* sp. A (figured in Delgado, 1910, pl. 27, fig. 4), coll. no. 6003, x 2.2; d, articulated spicules of a hexactinellid sponge showing a subquadrate pattern, coll. no. IGM-10862, x 1.3; e, *Expansograptus sparsus* (Hopkinson), fragment of stipe (figured in Delgado, 1910, pl. 27, fig. 1), coll. no. 6000, x 1.7; f, *Expansograptus*? sp. B, proximal fragment with broken sicula (figured in Delgado, 1910, pl. 27, fig. 3), coll. no. 6002, x 1.1.

Striatotheca have their FADs in the *messaoudensis-trifidum* assemblage from late Tremadocian-early Floian strata (Servais and Molyneux, 1997; Servais and Mette, 2000; Molyneux et al., 2007), but some others are more typical of "Arenig *sensu lato*" assemblages (i.e. Floian to lower Darriwilian) that may continue into younger strata, such as *Cymatiogalea messaoudensis, Peteinosphaeridium* sp., *Vavrdovella* areniga, *Veryachium trispinosum* and *V. lairdii*.

In consequence this acritarch assemblage, although incomplete, indicates a palynostratigraphic "Arenig *sensu lato*" (i.e., Floian to early Darriwilian) age, which agrees with the more precise biostratigraphic data provided by the graptolites.

SPONGES

Among the samples of the Delgado collection from the lower part of the Barrancos Formation, we have recognized two sponge fragments, not referred to in his work, coming from a locality placed 250 m north of Monte do Pombal (32 km northwest of Barrancos). They represent the only Ordovician sponges so far recorded in Portugal, and were also mentioned by Piçarra and Rigby (1996) and Rigby et al. (1997), but are figured here for the first time. The best preserved specimen (Fig. 2d) is a flattened mesh of spicules showing a subquadrate pattern, of very similar aspect to the reticulose pentactine clusters described from the Klabava Formation of Bohemia (Mergl, 2008). However, the skeletal structure is not preserved in the

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Portuguese specimens, perhaps indicating a dictyonine grade, but are taxonomically indeterminable due to the state of preservation.

ICHNOLOGICAL RECORD

The "*Phyllodocites* shales" were originally named by Delgado (1908) according with the frequent record of trace fossils, partially interpreted by him as annelid impressions (*Phyllodocites, Nereites, Myrianites*), worm traces (*Arenicolites*), cnidarian body fossils (*Oldhamia, Lophoctenium*), molds of marine plants (*Palaeochorda, Palaeophycus, Chondrites, Bythotrephys, Alectorurus, Fraena*), and undetermined crustacean traces. In his most celebrated papers, Delgado (1908, 1910) equated the "*Phyllodocites*" assemblage of Barrancos with similar traces found in nearby outcrops of Devonian flysch (S. Domingos mine and Aljustrel area), causing both to be confused by later authors. Thus, Seilacher (1955) partially redrew the Ordovician and Devonian ichnofossils from Delgado's (1910) photographs, as being part of a single assemblage representative of deep-marine environments in the Paleozoic of southern Portugal. The Ordovician and Devonian "*Nereites* shales" of the region were also studied by Perdigão (1961, 1967). In the complementary data to Uchmann's chapter (2004), the database from the Ordovician of Barrancos appears restricted to *Nereites* isp., *Phyllodocites saportai, Myrianites tenuis, M. andrei* and *Crossopodia* isp. According to the actualized view of Seilacher (2007), in the "Barrancos Shales" there would be *Nereites*, *Dictyodora*, *Urohelminthoida*, *Lophoctenium*, *Paleodictyon*, *Zoophycos* and *Chondrites*. However, some of these are not documented in any previous paper by the author, nor in the illustrations from Delgado (1910).

A comprehensive review of the trace fossil association from the "*Phyllodocites* shales" was presented by Piçarra (2000), who updated the synonymies of former ichnotaxa and recognized the presence in the Mestre André quarry of the following traces: *Nereites jacksoni* Emmons, *Nereites* ispp., *Phyllodocites saportai* Delgado, *Dictyodora*? *andrei* (Delgado), *Dictyodora*? *lorioli* (Delgado), *Dictyodora*? *bocagei* (Delgado), *Dictyodora* ispp., *Lophoctenium geinitzi* Delgado, *Chondrites* ispp., *Glockerichnus*? isp., *Oldhamia* n. isp., *Zoophycos* isp., *Palaeophycus* cf. *striatus* Hall, *Palaeophycus* ispp., *Gordia marina* Emmons, *Gordia* ispp., *Phycodes*? isp., *Cochlichnus*? isp., aff. *Didymaulichnus* isp., *Megagrapton*? isp., *Diplichnites* isp. and *Dimorphichnus*? isp. The type specimen of *Helicolithus delgadoi*, defined from the Delgado collection (Azpeitia Moros, 1933) was not revised by this author. A constructional model of *Dictyodora tenuis* (M'Coy) based in specimens from the Mestre André quarry was presented by Neto de Carvalho (2001), who synonymized with this ichnospecies some forms described by Delgado as *Myrianites andrei, M. lorioli* and *M. tenuis*. To the ichnotaxa list derived from the "*Phyllodocites* shales", we must also add "*Oldhamia pinnata*", mentioned apparently without any ichnotaxonomical formalization (Seilacher,

Plate 1. Acritarchs of the "*Phyllodocites* shales" of Barrancos, Portugal. Each specimen is referenced by a collection number, slide number and microscope coordinates (MC). 1, *Acanthodiacrodium costatum* Burmann, PMA3-1b, MC 1342-56; 2, *Coryphidium* cf. *bohemicum* Vavrdová, PMA3-3, MC 1125-115; 3, *Vavrdovella areniga* Loeblich & Tappan, PMA3-3a, MC 1245-55; 4, *Arbusculidium* cf. *filamentosum* Vavrdová, PMA3-3a, MC 1445-125; 5, *Acanthodiacrodium*? *dillatum* Molyneux; PMA3-1b, MC 1224-89; 6, *Stelliferidium stelligerum* Deunff, Górka and Rauscher; PMA 3-1, MC 1228-35; 7, *Micrhystridium* sp., PMA3-1, MC 1265-128 (800x); 8, *Striatotheca principalis parva* Burmann; PMA3-1b, MC 1188-212; 9, *Striatotheca rarirrugulata* Eisenack, Cramer and Diez; PMA3-3, MC1425-145; 10, *Peteinosphaeridium trifurcatum* Eisenack, PMA3-3a, MC 1115-124; 11, *Cymatiogalea* sp., PMA3-1a, MC 1168-155; 12, *Veryhachium trispinosum* (Eisenack) Deunff, PMA3-1a, MC 1355-13513; 13, *Veryhachium lairdii* (Deflandre) Deunff, PMA3-1C, MC 1186-120; 14, *Cymatiogalea messaoudensis* Jardiné, Combaz, Magloire, Peniguel & Vachey, PMA3-1b, MC 1165-116; 15, *Virgastasporites rudi* Combaz; PMA3-1a, MC 1455-75; 16, *Gneudnaspora divellomedia* (Tchibrikova) Balme; PMA3-1, MC 1035-125.

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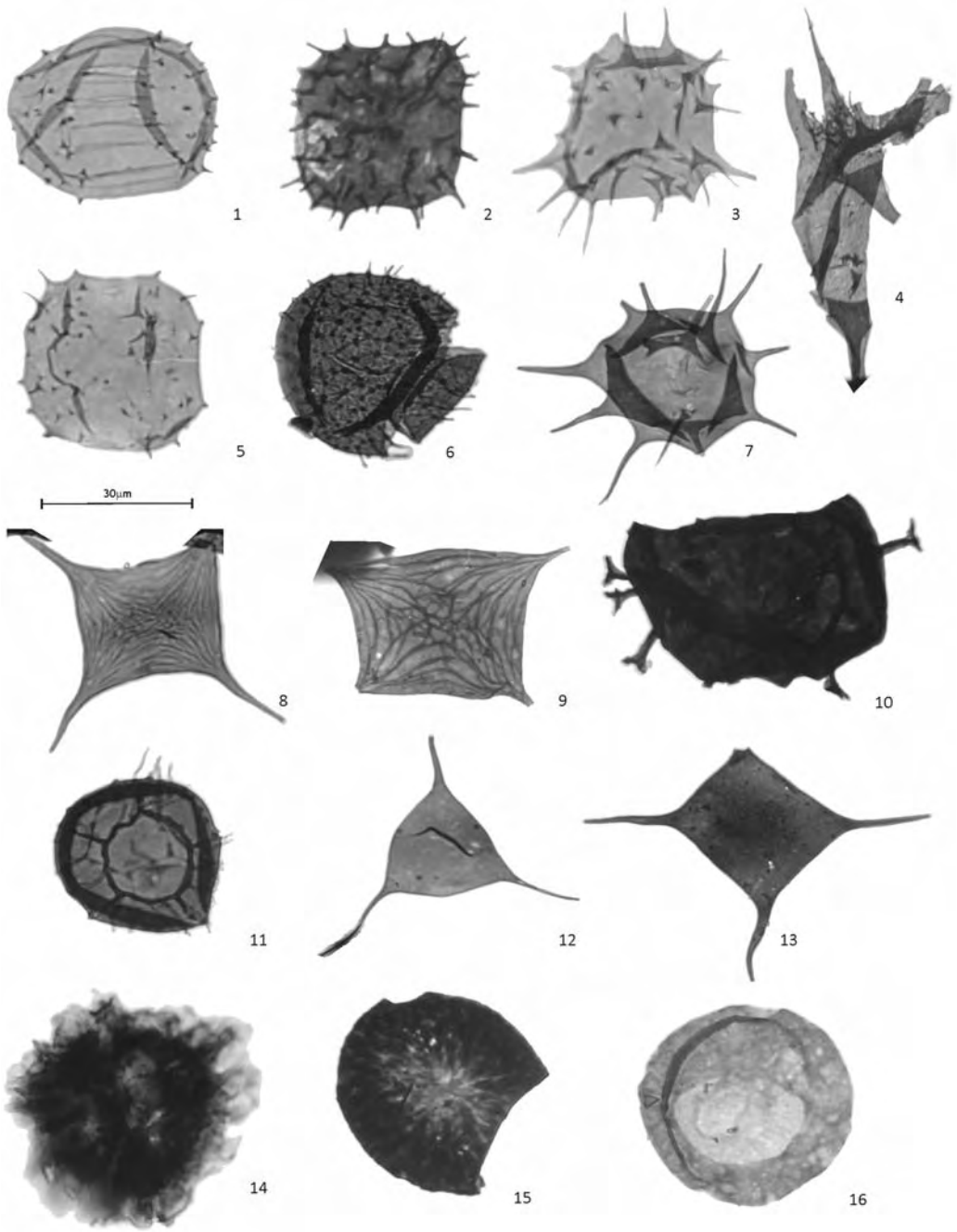

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1997, 2007; Seilacher et al., 2005), which was already illustrated by Delgado (1910, pl. 38, fig. 1) and is usually confused with *"Lophocteniun geinitzi"* owing to a plate mistake in his posthumous publication.

FINAL REMARKS

According with graptolite and palynological data, the age of the "*Phyllodocites* shales" of the Barrancos anticline can be mainly envisaged as early Darriwilian, equivalent to the Da1 stage slice of Bergström et al. (2009). This dating is close to the provided by another acritarch assemblage recorded from the Barrancos Formation in Spain, in a section located SSE of Cañaveral de León (Mette, 1989), belonging to the same Estremoz-Barrancos-Hinojales domain of the Ossa-Morena Zone.

Owing to the common record of trace fossils and sedimentary structures in the Mestre André quarry, the "*Phyllodocites* shales" have been linked to littoral (Delgado, 1908; Perdigão, 1967) or deep marine environments (Seilacher, 1955, 1974; Burke et al., 2005), with some authors even suggesting a distal turbiditic sequence (Neto de Carvalho, 2001). However, the dominant siltstones and shales do not show any sedimentological characteristic that can support their interpretation as turbidites. Instead, the high concentration of clastic muscovite in these rocks, and especially along bedding planes, seems more typical of shelf sediments. The rare extensiform didymograptids belong to a graptolite ecomorphotype widely distributed in the epipelagic biotope, but normally confined to shelf sediments (Cooper et al., 1991; Cooper and Sadler, 2010). The presence of cryptospores (terrestrial primitive contribution), as well as *Leiosphaeridia* spp. and common acritarchs (acanthomorphs, sphaeromorphs, netromorphs and polygonomorphs) may indicate proximity to an inner-shelf environment (Al-Ameri, 1983).

On the other hand, the trace fossil record of the "*Phyllodocites* shales" has been ascribed to the *Nereites* ichnofacies, typical of deep-sea environments (bathyal-abyssal according to Seilacher, 1967, 2007), with sporadic matgrounds representative of the *Oldhamia* ichnofacies. In our opinion, the assemblage would be alternatively explained as the opportunistic colonization of a dissaerobic environment by marine benthos, developed in an outer-shelf setting, not necessarily in a deep environment. This oxygen-depleted bottom could be consequence of a water-mass stratification or paleotopographic differentiation of the platform by extensional tectonics, similar to the fact observed in the Middle Ordovician shales of central Portugal that bear some flysch-like trace fossils locally recorded in an inner shelf setting (Gutiérrez-Marco and Sá, 2006).

Thus, the paleoecological restriction observed in the "*Phyllodocites* shales", cannot be primarily related with its placement in a deep-turbiditic or abbysal zone; their lateral continuity over a relatively reduced area with regard to the remaining outcrops of the Barrancos Formation both in Portugal and Spain also conflicts with the interpretation of an oceanic-related paleoenvironment.

In any case, the "*Phyllodocites* shales" are not representative of typical inshore settings and its sedimentary circumstances fully concur with the general paleogeographic trend of the Ossa-Morena Zone. The Ordovician and Silurian sequences of this zone are characterized by more distal and deeper environments and faunas (cyclopygid trilobite biofacies) than the remaining successions coevally known for the same periods in the Iberian Massif, to which the Central Iberian Zone (the proximal part of the same platform) was tectonically juxtaposed as the result of Variscan transcurrent displacement along the Badajoz-Córdoba Shear Zone (Robardet et al., 1998; Robardet and Gutiérrez-Marco, 2004 and references therein).

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