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The highest-latitude *Foliomena* Fauna (Upper Ordovician, Portugal) and its palaeogeographical and palaeoecological significance

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ABSTRACT

Here we report and describe for the first time the *Foliomena* Fauna fossil record from Portugal (Kralodvorian, upper Katian). This deep-water brachiopod association originates from the uppermost beds of the Porto de Santa Anna Formation (uppermost Katian), cropping out in several localities of the Portuguese Buçaco-Penacova region (Central Iberian Zone). The three studied localities have yielded different associations, composed of 15 species of brachiopods and two trilobites, including both key elements of the deep water *Foliomena* Fauna and taxa typically from shallower benthic biotas, e.g. the *Nicolella* Fauna. The mixed character of the associations indicates that they are probably representatives of the atypical *Foliomena* Fauna, characteristic of relatively shallow benthic assemblages. The Portuguese associations represent the highest-latitude occurrences of the *Foliomena* Fauna so far and one of the youngest. In the analyses carried out, the two Portuguese associations are grouped together with the other peri-Gondwanan associations (Sardinia and Carnic Alps) and are included within a major grouping including associations previously interpreted as inhabiting deep-water environments and also predominantly late Katian in age. According to these results, the association of Locality 2 may have inhabited a slightly deeper environment than the one present in Locality 3. This agrees with the presence in the former of a greater number of deep-water genera. Despite of the occurrence of a great number of deep-water taxa in the association of Locality 2, the co-occurrence of several elements related to the shallower water *Nicolella* Fauna, probably transported offshore as a result of the slope of the inclined shelf, suggest that this association probably inhabited slightly shallower environments than those expected for a typical *Foliomena* Fauna (BA5-6) with no shallow-water elements represented. This inference is also supported by the absence from the association of cyclopygid trilobites.

1. Introduction

Harper (1979) erected the term *Foliomena* Fauna (named after the *Foliomena* Community; Sheehan, 1973) to embrace small, thin-shelled brachiopod-dominated palaeocommunities, frequently associated with pelagic trilobites, interpreted as having inhabited deep-water environments and fine-grained substrates. The *Foliomena* Fauna characterized the early-mid Katian deep-water biotas of low-mid latitude settings (Rong et al., 1999 and references), but younger records (upper Katian) have also been documented in lower (Liang et al., 2014 and references) and higher latitudes (Havlíček and Mergl, 1982; Villas et al., 2002). Three palaeoecologically-different types of *Foliomena* Fauna assemblages have been described (Rong et al., 1999; Rong and Zhan, 1995, 1996): (1) the typical *Foliomena* Fauna, of deep environments (BA4-BA5 or deeper), characterized by the presence of several key taxa such as *Christiania*, *Cyclospira*, *Dedzetina*, *Sericoidea* and *Foliomena* itself; (2) the atypical *Foliomena* Fauna composed of both those key elements and other brachiopods usually found in shallower regimes (lower BA3-upper BA4), such as *Eoplectodonta*, *Glyptorthis*, *Leangella* (*Leangella*), *Skenidioides*, among others and (3) assemblages composed by >90% of shallow-water taxa with subsidiary *Foliomena* Fauna elements (Zhan et al., 2010 and references).

Herein we report and describe for the first time from Portugal, associations with *Foliomena* Fauna, evaluate their palaeoecological and palaeobiogeographical significance and discuss their ascription to one

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of the palaeoecological types proposed by Rong and collaborators (Rong et al., 1999; Rong and Zhan, 1995, 1996).

2. Geographical and geological setting

The Ordovician rocks of the Buçaco Syncline crop out in the Penacova-Vila Nova de Poiares region (Fig. 1), which lies in the western portion of the Central Iberian Zone (CIZ). This syncline comprises two lithostratigraphic sequences, separated by an angular unconformity: the Beiras Group, a monotonous, kilometer-thick series of intercalated shales and greywackes of Neoproterozoic to middle (?) Cambrian age; and the post-Cambrian Palaeozoic metasedimentary sequence, ranging from Lower Ordovician to the Silurian (Oliveira et al., 1992). The Porto de Santa Anna Formation (approx. 140 m thick) was erected by Mitchell (1974) and formalized by Young (1988) in the Penacova region (central Portugal) as part of the Venda Nova Group. It has been assigned to the upper Berounian-Kralodvorian (middle to upper Katian; Ka2-Ka4 stage slices of the global scale). It crops out along the Buçaco Syncline, being much more developed in the northern part than southwards, where it is only one meter thick. The base of this formation is marked by an oolitic horizon that correlates to the Podolí horizon, at the base of the Králův Dvůr Formation of Bohemia (Young, 1992). It is composed of volcaniclastic sediments, which are overlain by silicified beds that originally probably were carbonates. The uppermost part of the formation is composed of a sequence of thinly-bedded fine-grained tuffaceous sediments and limestones intercalated with altered volcanic flows.

The fossil content of the lowermost levels of the Porto de Santa Anna Formation indicates an age of upper Berounian (ca. middle Katian, Ka2 stage slices – see discussion in Pereira et al., 2016). Levels from the middle and upper parts of the formation, below the associations described in this paper, have yielded Kralodvorian (ca. upper Katian, Ka3-4) brachiopods and trilobites (Pereira, 2017). The Riba de Cima Member of the Ferradosa Formation (Young, 1988), lateral equivalent to the upper part of the Porto the Santa Anna Formation, have yielded a benthic association considered uppermost Katian in age (Colmenar et al., 2017). Most of the brachiopods of those associations are representatives of the *Nicolella* Fauna, which thrived in the high-latitude peri-Gondwanan shelves during the late Katian (Colmenar, 2015). The lowermost part of the Ribeira do Braçal Formation, which conformably overlies the Porto de Santa Anna Formation have yielded brachiopods and trilobites characteristic of the well known *Hirnantia* Fauna (Colmenar et al., 2016). All these data allows the assignment of an uppermost Katian age to the Portuguese associations with *Foliomena* Fauna.

The brachiopods and trilobites of middle and upper parts of the Porto de Santa Anna Formation allows a direct correlation with other Upper Ordovician units, such as the Gabian Formation from the Montagne Noire, the Uggwa Limestone and Wolayer formations from the Carnic Alps, Austria (Schönlaub, 1998), the Estana Formation from the Spanish Central Pyrenees (Gil-Peña et al., 2004), the Cystoid Limestone from the Iberian Chains (Villas, 1985), the Portixeddu and Domusnovas formations from Sardinia (Leone et al., 1991), the Rosan Formation from the Armorican Massif (Mélou, 1990) and the Upper Djeffara Formation from Libya (Buttler & Massa, 1996).

The studied material comes from three localities of the uppermost Porto de Santa Anna Formation, situated in Palheiros (Locality 1, 40°19′57″N; 8°20′57″W and Locality 2, 40°19′55″N; 8°20′57″W), in the Penacova municipality and in Ribeira Cimeira (Locality 3, 40°10′ 26.5″N; 8°11′01.1″W), Vila Nova de Poiares municipality, both located in the northern part of the Coimbra district (Fig. 1). More specifically, the material originates from the ashy mudstones and from the silicified tuffaceous calcareous beds at the top of uppermost part of the Porto de Santa Anna Formation (Fig. 2).

The fossils from Locality 1 come from the type section for the upper part of the Porto de Santa Anna Formation, at Chão das Figueiras (Fig. 3A). The fossils were recovered from this section at about 15 m below the mudstones of the Vale da Ursa Formation (Silurian). The fossils occur in thinly bedded, partly silicified, decalcified tuffs and tuffaceous carbonates.

The material from Locality 2 originates from an exposure on a path located about 100 m southwest of Locality 1 (Fig. 3A), occurring in decalcified, partly silicified, tuffaceous carbonates. Although detailed correlation is difficult because of the large gaps in exposure in these sections and because of the tectonic disturbance near the contact with the Silurian Vale da Ursa Formation, it seems probable that this locality is stratigraphically slightly higher than Locality 1.

Locality 3 is located on the east limb of the Rio Ceira inlier (Fig. 3B), where the Porto de Santa Anna Formation is represented by a highly-condensed sequence (only 1.6 m thick). The base is marked by an oolitic ironstone bed (15 cm), overlain by about 1.25 m of fine-grained tuffaceous sediments. These are unfossiliferous in the bottom of the valley of the Ribeira do Braçal where a complete section crops out. However, on a track cutting 50 m to the south, the uppermost 20 cm of this formation are richly fossiliferous.

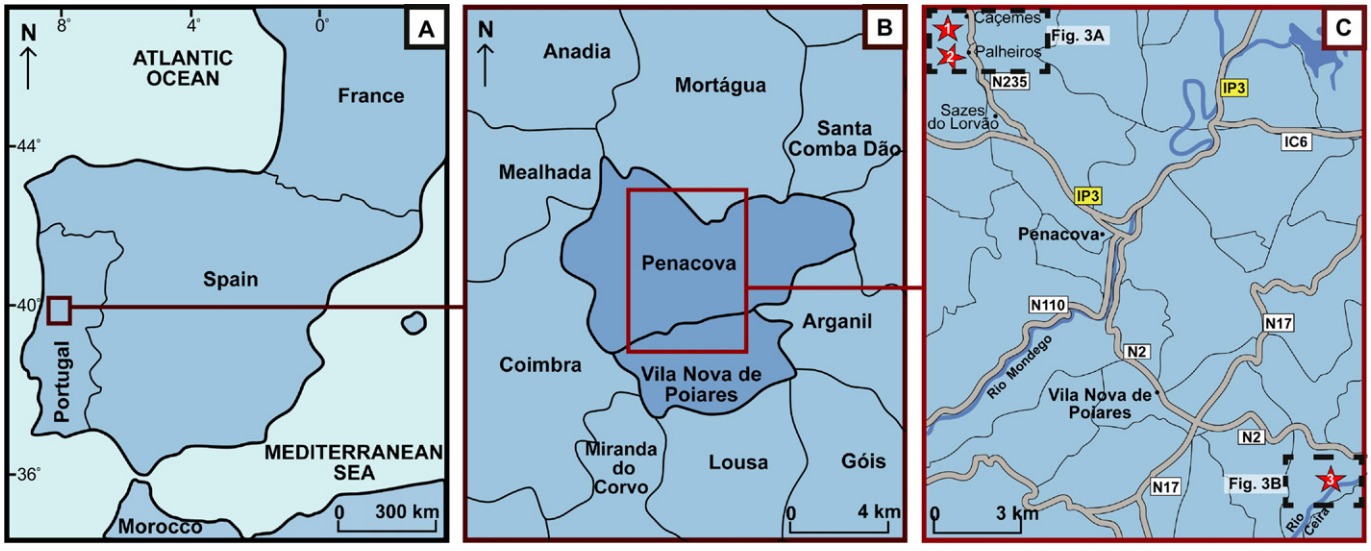

Fig. 1. Geographic location of the Riba de Cima Member fossil localities. Locality 1, Chão das Figueiras (Penacova); Locality 2, Palheiros (Penacova); Locality 3, Rio Ceira Inlier (Vila Nova de Poiares).