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Eurydesma–Lyonia fauna (Early Permian) from the Itararé group, Paraná Basin (Brazil): A paleobiogeographic W–E trans-Gondwanan marine connection

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ABSTRACT

Here, the biocorrelation of the marine invertebrate assemblages of the post-glacial succession in the uppermost portion of the Late Paleozoic Itararé Group (Paraná Basin, Brazil) is for the first time firmly constrained with other well-dated Gondwanan faunas. The correlation and ages of these marine assemblages are among the main controversial issues related to Brazilian Gondwana geology. In total, 118 brachiopod specimens were analyzed, and at least seven species were identified: *Lyonia rochacamposi* sp. nov., *Langella imbituvensis* (Oliveira),? *Streptorhynchus* sp.,? *Cyrtella* sp., *Tomiopsis* sp. cf. *T. harringtoni* Archbold and Thomas, *Quinquenella rionegrensis* (Oliveira) and *Biconvexiella roxoi* Oliveira. The presence of *Tomiopsis* sp. cf. *T. harringtoni* and the bivalve *Atomodesma* (*Aphanaia*) *orbirugata* (Harrington) in the Teixeira Soares beds plus *Myonia argentinensis* (Harrington) and *Heteropecten paranaensis* Neves *et al.*, both of which recorded in deposits in the Teixeira Soares and Mafra beds (Butiá), suggests a biocorrelation with the *Eurydesma* fauna from the Bonete Formation, Sauce Grande-Colorado Basin, Argentina. Furthermore, the presence of *Lyonia* Archbold and *Praeundulomya* cf. *subelongata* Dickins in the Taciba Formation indicates affinities with deposits in the Lyons Group, Carnarvon Basin, and the Fossil Cliff Member, Perth Basin (Western Australia), suggesting a late Asselian–early Sakmarian age. Even more importantly, the collected data suggest the existence of an W–E trans-Gondwanan marine seaway between the Paraná (Brazil), Sauce Grande-Colorado (Argentina), Huab (Hardap shale of the Dwyka Group, Aranos area, Namibia, southwest Africa), the Carnavon (Western Australia) basins, and beyond eastward to the Cimmerian region. A V proto-rift system through two major axes of extensional basin development facilitated the W–E marine connection. Main axes formed by a north-northwesterly trending axis paralleling the future South Atlantic and a broadly north-northeasterly trending line of separation related to the future Indian Ocean. This proto-rift system coupled with a sea-level rise of at least 100 m, favored the establishment of a long narrow shallow seaway, allowing the exchange of *Eurydesma* fauna between eastern and western Gondwana.

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1. Introduction

The Gondwanan affinity of the Permian marine macrofossils of the Itararé Group (Bashkirian/Moscovian–early Permian, Holz et al. 2010), Paraná Basin, is well known on the basis of its molluskan faunas, particularly those recorded in some strata from southern Brazil (Rocha Campos and Rösler, 1978; Neves et al., 2014a, b). The marine assemblages recorded in the upper portion of the Taciba Formation cropping out in the Mafra and Teixeira Soares regions, in the states of Santa Catarina and Paraná, respectively, are especially noteworthy. The Taciba Formation records a succession of depositional environments tied to the demise of late Paleozoic glaciation (França and Potter, 1988; Santos et al., 1996; Mineropar, 2007). The faunal assemblages are poorly diversified, showing a scattered distribution, both vertically and geographically, and are mainly dominated by bivalve mollusks (Rocha Campos, 1967; Simões et al., 1998, 2012; Neves et al., 2014a, b). These occurrences have been known since E.P. Oliveira announced the discovery of marine macrofossils in that unit in 1908 in a letter to Woodworth (1912, in Lange, 1954). These fossils were

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subsequently studied by various authors (Oliveira, 1930; Mendes, 1952, Lange, 1952; Kegel and Costa, 1952; Beurlen, 1954; Rocha Campos, 1966, 1969, among others). However, more comprehensive contributions regarding the taxonomic composition, age and affinities of these marine fossils have only been reported recently (Simões et al., 2012; Neves et al., 2014a, b). On the basis of the presence of *Myonia argentinensis* (Harrington, 1955), *Atomodesma* (*Aphanaia*) *orbirugata* (Harrington, 1955) and *Heteropecten paranaensis* (Neves et al., 2014a), researchers have emphasized the correlation of the Taciba bivalve fauna with those of the *Eurydesma*-bearing Bonete Formation, Pillahuincó Group, Sauce Grande-Colorado Basin, Buenos Aires Province, Argentina. This indicates a possible Asselian age for the post-glacial bivalve fauna of the Taciba Formation. However, our view regarding the marine fossils of the Taciba Formation is mainly "bivalvecentric" (= biased towards this mollusk class). Indeed, much less is known about the identity, affinities and age of the brachiopods of the Taciba Formation, which co-occur in the same lithofacies. In this paper, we describe, illustrate and discuss, in modern terms, a surprisingly "diverse" and well-preserved brachiopod fauna of the Taciba Formation. Although these faunas have been known since Oliveira (1930) and Rocha Campos (1966, 1969), we have added new information on the composition and age of the marine invertebrate faunas recorded in the uppermost portion of the Itararé Group. Furthermore, re-examination of faunal affinities allowed us to improve our understanding of the paleobiogeographical relationships between close and/or coeval Gondwanan faunas of southern Brazil (Paraná Basin) with other South American and Patagonian late Paleozoic basins (Sauce Grande-Colorado, Uspallata-Iglesia and Tepuel-Genoa basins) as well as those of South Africa (western Kalahari/Aranos Basin) and Western Australia (Carnarvon, Canning, Perth basins). In this context, a new paleobiogeographic hypothesis is presented and discussed.

2. General geological setting

Carboniferous to early Permian glacial-related successions in the intracratonic Paraná Basin (Brazil) are recorded at the base of the Gondwana 1 Supersequence (Milani et al., 2007). These glacial non-marine and glaciomarine rocks are referred to as the Itararé Group, a ~ 1500 m thick unit that includes conglomerates, diamictites, sandstones, rhythmites, mudstones, shales, and a few coal seams (Milani et al., 2007; Holz et al., 2008, 2010). These rocks rest unconformably either on metamorphic/igneous Precambrian–pre-Silurian basement or sedimentary Devonian strata (Rocha Campos, 1967; Holz et al., 2008).

In the study area, in the states of Santa Catarina and Paraná (Fig. 1), the Itararé Group comprises rocks belonging to the Taciba Formation. According to França and Potter (1988), this unit encompasses a third major fining upward cycle of the Itararé Group including three members (*i.e.*, in ascending order the Rio Segredo sandstone, Chapéu do Sol diamictite, and Rio do Sul rhythmite, siltstone, and shale; see also Castro, 1999; Weinschutz and Castro, 2004, 2005, 2006). The Taciba Formation is equivalent to the Rio do Sul Formation, in the sense of Schneider et al. (1974) (excluding the basal Lontras shale).

In the Mafra region, in the state of Santa Catarina (Fig. 1C), Weinschutz and Castro (2006) have recognized two main depositional sequences within the Taciba succession, which were generated under glacial and post-glacial conditions (Taciba I and II), respectively (Fig. 2). In outcrops, the deglacial interval (Taciba II) comprises a succession of a 10 m-thick stratified diamictite, overlain by thin stratified conglomerate and sandstone and an intensely bioturbated, fossil-rich sandstone, which is succeeded by shales (Weinschutz and Castro, 2006; Simões et al., 2012) (Fig. 2). As noted below, most of the studied brachiopods come from that sandstone bed (= Butiá assemblage, sense Rocha Campos and Rösler, 1978) (Table 1).

In the Imbituva and Teixeira Soares regions, in the state of Paraná (Figs. 1A, B, respectively), only the upper portion of the Taciba Formation crops out (Lange, 1952; Mineropar, 2007; Neves et al., 2014b), which includes diamictites, sandstones, siltstones and mudstones (Passinho shale), succeeded by the sand-dominated, coal-bearing deposits of the lower portion of the Sakmarian–Artinskian, Rio Bonito Formation (Fig. 3) (see below in Stratigraphy and Locality).

3. Material and methods

3.1. Fossil collection

In total, 118 brachiopod specimens from the Taciba Formation were examined: 1 specimen from fossil site A, 11 from fossil site B and 106 from fossil site C (see Tables 2 and 3). These specimens are housed in distinct Brazilian invertebrate fossil collections, including a- CENPALEO (Centro de Paleontologia), Universidade de Contestado, Mafra, Santa Catarina State; b- Departamento de Zoologia, Instituto de Biociências, Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP), Botucatu, São Paulo State; and c- Instituto de Geociências, Universidade de São Paulo, São Paulo State. Other material (*Crurithyris* sp.) is housed at the Laboratorio de Investigaciones em Evolución y Biodiversidad (LIEB), Universidad de la Patagonia "San Juan Bosco", Esquel, Chubut, Argentina.

Abbreviations.- CP, Cenpaleo collection; DZP, Department of Zoology, Paleontology collection, UNESP, Botucatu campus; DGM, Division of Geology and Mineralogy, National Department of Mineral Production, Rio de Janeiro State. Materials with the DGM prefix are housed in the University of São Paulo collection, while GP-1E indicates Institute of Geosciences collection, University of São Paulo, USP, São Paulo, Brazil, and LIEB-PI indicates the LIEB invertebrate fossil collection.

In the laboratory, the fossil material was prepared according to standard paleontological procedures (see Feldmann et al., 1989) using precision tools. Latex casts and plasticine molds were prepared for most of the shells. Brachiopod and bivalve shells were also coated with magnesium oxide sublimate to enhance diagnostic morphological characters for photography (see Neves et al., 2014a, b and references therein). The applied classification largely follows Waterhouse (2013) for Linproductidina, Williams and Brunton (2000) for Orthotetidina, Carter et al. (2006) for Spiriferidina, Carter and Johnson (2006) for Spiriferinidina, Racheboeuf (2000) for Chonetidina and Williams et al. (2000) for Lingulida.

3.2. Stratigraphy and locality

Brachiopods come from three main fossil sites in the states of Paraná (Teixeira Soares) and Santa Catarina (Mafra) in southern Brazil. Table 1 summarizes the main geographic and geologic information for the sampled localities (fossil sites A, B and C). In the study area, the geology and the correlation of the strata of the Itararé Group are relatively well known (see Almeida, 1945; Rocha Campos, 1966; Weinschutz and Castro, 2006; Mineropar, 2007; Neves et al., 2014b). Here the Taciba Formation (França and Potter, 1988) comprises the uppermost unit of the Itararé Group (Fig. 4). In Teixeira Soares County, in the state of Paraná, the rocks of this formation are exposed along the Almas River Valley, ~4 km SE of the town of Teixeira Soares (Oliveira, 1930; Lange, 1954; Almeida, 1945; Mineropar, 2007; Neves et al., 2014b). Locally, the Taciba Formation is a ~ 45 m thick, siliciclastic succession including, in ascending order, a thick (~10 m), polymitic, matrix-supported, massive diamictite with rounded, striated and faceted clasts (granules/boulders) of granites, which may grade upward to crudely stratified mudstones (Mineropar, 2007, p. 106). These are succeeded by a ~ 7 m-thick package of medium-to-fine grained sandstones (Rio da Areia sandstone) with planar cross-stratifications (see Mineropar, 2007, p. 107). In these sandstones, *Planolites*-like traces are associated with ripple marks, and bivalve-dominated shell pavements occur in the uppermost (2 m) portion, above which thin (50 cm), deeply bioturbated fossil-bearing siltstones (Baitaca siltstone) including scattered, splayed-out bivalve shells are recorded (Neves et al., 2014b, p. 212).

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