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Study of the West Gondwana Floras during the Late Paleozoic: A paleogeographic approach in the Paraná Basin – Brazil

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ABSTRACT

The Late Paleozoic in West Gondwana was a period of significant climatic changes, ranging from a glacial climate in the Late Carboniferous to a semi-arid climate in the Late Permian. The Floristic Province of Gondwana in the Paraná Basin was directly affected by such changes, and underwent a transformation regarding composition and geographic distribution. Thus, the climatic phases were divided into three intervals: Phase A containing interglacially developed flora; Phase B, containing floras of immediate post-glacial temperate climates, and phase C, identified with floras related to the decline of dryness. Regarding their geographical distribution, the floras were concentrated in the far-northern and far-southern portions of the basin during the Glacial interval, and, with a gradual increase in temperature, went on to occupy the entire basin. Finally, we can see that the floras located in the Argentinean portion of West Gondwana are older and have greater species diversity than those present in the Paraná Basin and Africa during Phase A. In Phase B, there is a decline of Argentinean flora species, a large increase in the Paraná Basin floras, and an average increase in African floras. In the final stage, the floristic province no longer exists in Argentina, the flora of the Paraná Basin also suffers a decrease of specimens, and the African flora undergoes its moment of greatest development. Such diversity change also reflects a west-to-east migration throughout the Late Carboniferous.

1. Introduction

The Gondwana represented the largest continental crust unit on the planet for 200 million years. It included the present continents of South America, Africa, Antarctica, and Australia, as well as Madagascar and the Indian subcontinent, which, together, currently represent 64% of the planet's emersed lands. Additionally, other fragments such as Florida, Central America, Southern Europe, South-Central, and Southeast Asia may also have been a forming part of the continental crust, as portions of this supercontinent, during part of its long existence (Torsvika and Cocks, 2013).

At a global level, the Carboniferous – Permian interval represented a gradual climatic transformation. The Late Paleozoic Ice Age (LPIA), which began in the Late Devonian - Early Carboniferous, left several traces of its existence as geological records (such as tillites, rhythmites, varves, and glacial striations). Such glacial records are found in the southern part of Gondwana as far as 30° S (Parrish et al., 1986; Fielding et al., 2008). This ice age is marked by several pulses, which are observable up to the Artinskian/Kungurian Stage, and deglaciation occurred relatively faster when compared with the total duration of the event (Gibbs et al., 2002). Poulsen et al. (2007) state that in Pangea, at the end of glaciation, drier conditions and higher temperatures were found in equatorial regions (central Pangea), and, thus, a trend in biomes of expansion of deserts and contraction of forests can be observed. Such a process of progressive global warming peaked during the Triassic.

Several studies have been conducted on the Neopaleozoic climate. Among them, it is worth mentioning the work of Limarino et al. (2014), which presents an impressive picture of the paleoclimatic history of Gondwana in South America.

Several areas of the Gondwana paleocontinent, which were largely covered by ice during the Carboniferous, became covered by an exuberant flora during the Permian (Christiano-de-Souza and Ricardi-Branco, 2013). It is in this scenario that the Floristic Province of Gondwana is admitted, consisting of sequences of paleofloras in several stages of development.

Informally, two floras are currently accepted for this period: *Pre-Glossopteris* and *Glossopteris* floras. The *Pre-Glossopteris* flora has been mainly recorded during the Late Carboniferous, during the retraction of glacial pulses. The *Glossopteris* flora, on the other hand, represents the time of Gondwana paleocontinent warming, when a great diversity existed of genera and species. The flora of *Dicroidium* is also found in the Gondwana, in the Triassic Period (Anderson and Anderson, 1985), after the extinction of the Glossopteris flora. However, the present study only focused on the two oldest floras: *Pre-Glossopteris*, and *Glossopteris*.

The main purpose of the analysis presented here was to demonstrate the evolution and comparison of *Pre-Glossopteris* and *Glossopteris* Floras on the eastern border of the Paraná Basin (Brazil) during different climatic moments, through the mapping of the occurrences of fossil

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plants. Detailed comparison charts were used as an auxiliary tool. Moreover, comparisons with the Gondwana Floristic Province occurrences in other Gondwana basins during the same period were made.

The importance of the study of floras is related to the close relationship of plants with climate and the environment. They not only act as driving forces for climatic changes (through their influence on the balance between O_2 and CO_2 on the planet), but also they are highly susceptible to changes in such gas balances (which can lead to speciation and extinction events). In addition, fossil plants conform highly to the place where they are found, since preservations take place in a para-autochthonous manner, considering their development locations (Christiano-de-Souza et al., 2014).

2. Geology

During the Carboniferous – Permian, the Paraná Basin was located in the southwestern portion of Gondwana. Currently, its sedimentation area covers more than 1,500,000 km^2, and is positioned in the southwestern portion of South America. Sometimes called the Chaco Paraná Basin, there is geological evidence that, during the Permian and Late Carboniferous, the Paraná Basin was interconnected with the Karroo (in Africa), Paganzo, and Tarija (Argentina) Basins.

The paleoflora found in such locations is different from those set out in the northernmost portions of the Gondwana paleocontinent. One example is the Parnaíba Basin, also deposited in the Late Carboniferous – Permian interval, which has distinct elements from *Pre-Glossopteris* and *Glossopteris* paleofloras. In fact, its characteristics are closer to the northern hemisphere floras of Pangea (or Laurasia) than those observed in the floras of Gondwana (Dolianiti, 1972).

Geologically, Milani (1997) divided the development of the Brazilian portion of the Paraná Basin into 5 megacycles of deposition. The study presented here involved rocks of the Gondwana I megacycle, which began with a glacial stage throughout the Kasimovian, when the Gondwana portion where the basin was located was at high latitudes (between 60° and 90° S). The megacycle deposition ended during the Capitanian period, during which the paleocontinent had already shifted to its northernmost portions (between 60 º and 30° S) (Santos et al., 1996; Castro, 2004; Milani et al., 2007). The following lithostratigraphic units, separated by wide-range disagreements, are formally accepted within the Gondwana I megacycle: the Itararé Group, the Guatá Group, and the Rio Bonito Group (Fig. 2).

The Itararé Group, throughout its history, had various divisions, which demonstrates the complexity and great difficulty of working with such a unit, associated to the deposition of the glacial/interglacial cycle (Barbosa and Almeida, 1949; Schneider et al., 1974; França and Potter, 1988). The stratigraphic proposal developed by França and Potter (1988), and later used by Milani et al. (2007) to elaborate the currently accepted stratigraphic chart of the Paraná Basin, was used in the present research.

The Itararé Group consists of deposits of glaciogenic origin, such as massive and stratified diamictites, with lithologies that indicate different source areas and the action of glaciers. The sandy facies are massive, with unidirectional ripples, which are related to turbidites (Eyles et al., 1993). Pelites are also identified, and usually related to decantation, as well as facies, where there is clear evidence of resedimentation. Subordinately, rhythmites are also found (Rocha-Campos, 1967), and these are true varvites and tillites. Finally, glacial striations in a NS or NW-SE direction are present (Rocha-Campos, 1967; Gesicki et al., 1996) which indicate the direction of glacial fronts. Several studies (Barbosa and Almeida, 1949; Barbosa and Gomes, 1958; Schneider et al., 1974; and others) were performed on the stratigraphy of the Itararé Group. The last subdivision was proposed by França and Potter (1988), and based on drill cores. The authors divided the Itararé Group into three formations: Lagoa Azul, Campo Mourão, and Taciba (from the base to the top). In this stratigraphic proposal, the fossil plants of the Itararé Group would be related to the Campo Mourão Formation, especially to siltstones and rare coal beds (such as Monte Mor, Itapeva, and

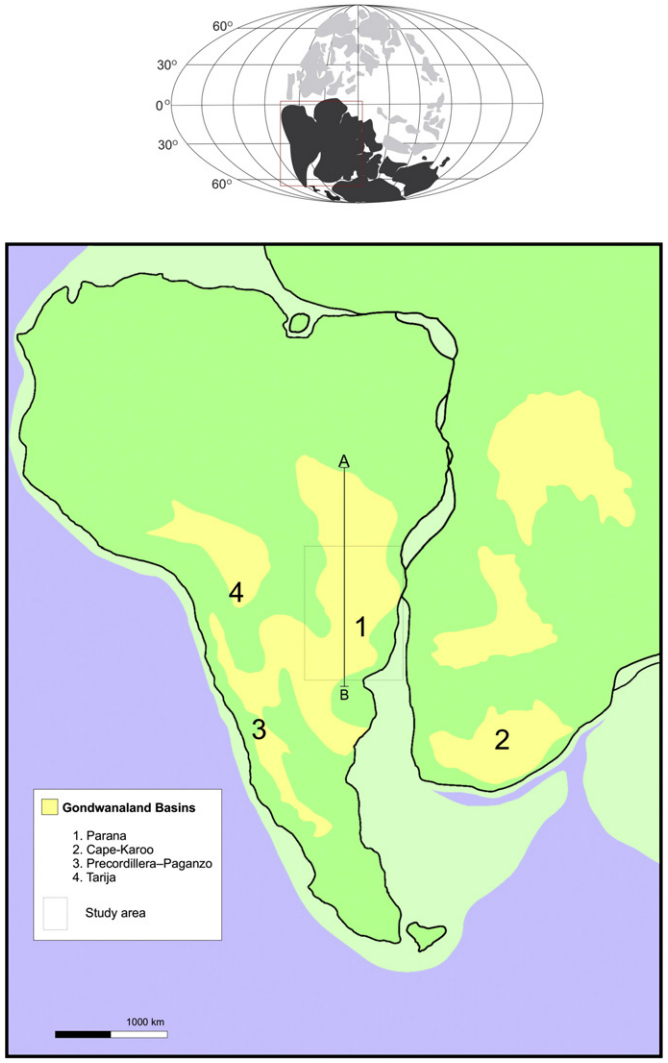

Fig. 1. Location of Gondwana during the Permian and location of its sedimentary basins. The cross-section represented by A and B is detailed in Fig. 2.

Cerquilho), which are conventionally related to interglacial and glacier contraction periods. The Aquidauana Formation occupies the northernmost portion of the east border and the west border of the Paraná Basin. Such formation is mainly composed of reddish sandstones and has very few fossil records; it corresponds stratigraphically to the Itararé Group.

The Guatá Group consists of greenish-gray siltstones and sandstones, alternated with coal layers and carbonaceous shales (Schneider et al., 1974). The Guatá Group, in general, is said to have developed in a temperate climate interval. The group's name was initially proposed by Gordon (1947). The basal portion of the Group was interpreted as deltaic front deposits (Rio Bonito Formation), and the top portion, as marine deposits (Palermo Formation).

The Rio Bonito Formation was first defined by White (1908) as "Rio Bonito layers". Only in 1974, with the study by Schneider et al. (1974), were the "Rio Bonito Layers" raised to the category of Formation. Its lithology was divided by Medeiros et al. (1972) and Thomas and Medeiros (1972) into three members, which were subsequently named by Schneider et al. (1974) as Triúnfo, Paraguaçu, and Siderópolis, from the base to the top. At the base of the Triúnfo Member, levels of coal are observed locally, which are sometimes related to coastal fringes. Sequentially, in the Paraguaçu Member, grains tend to thin towards the base, since its base contains fine sandstones associated with calcirudites and the top has a dominance of medium-to-coarse sandstones alternated with carbonaceous layers (Schneider et al., 1974). The presence of