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Palaeowind patterns during the latest Jurassic–earliest Cretaceous in Gondwana: Evidence from aeolian cross-strata of the Botucatu Formation, Brazil

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Abstract

The direction of sediment transport in the aeolian sandstones of the Botucatu Formation (latest Jurassic–earliest Cretaceous of the Paraná Basin) has been interpreted on the basis of cross-strata dip directions, which allowed the reconstruction of regional wind patterns in midwestern Gondwana. Regionally, cross-strata dip directions indicate variations of palaeowind directions across the outcrop area of the Botucatu palaeoerg. The northern portion of the palaeoerg was characterized by palaeowinds blowing from the NNE, whereas the southern portion was under the influence of palaeowinds coming from the SW. A wind convergence zone occurred at palaeolatitudes around 24° to 26°S. The identified wind pattern agrees with general circulation models for the Late Jurassic, which predict that, during the summer months (December through February), strong monsoonal winds to the S existed at low latitudes in Gondwana. Southerly winds converged at the ITCZ (at around 24°S) with winds blowing toward the northeast.

Keywords: Gondwana; Palaeowinds; Megamonsoons; Aeolian dunes; Botucatu Formation; Paraná Basin

1. Introduction

Numerous studies have used cross-strata dip directions in aeolian successions to reconstruct regional palaeowind directions (e.g. Opdyke and Runcorn, 1960; Poole, 1962; Bigarella and Van Eeden, 1972; Peterson, 1988; Ulicný, 2004). In this regard, one of the most extensively studied areas is the Colorado Plateau, U.S.A., where different aeolian units that accumulated over a time span of more than 100 m.y. (from the Pennsylvanian through the Middle Jurassic) crop out. The systematic analysis of palaeocurrent inferred from cross-strata dip directions in the different aeolian units has allowed the reconstruction of near-surface wind patterns in different time intervals of the Western Interior, and has enabled the reconstruction and depiction of changes in atmospheric circulation patterns in the area, either caused by regional or global palaeogeographic and palaeoclimatic changes (e.g. Peterson, 1988; Parrish and Peterson, 1988; Loope et al., 2004). The current work aims to present data and a model for the reconstruction of the palaeowind patterns in midwestern Gondwana during the latest Jurassic to earliest Cretaceous based on cross-strata dip directions in aeolian dune deposits of the Botucatu Formation. The Botucatu Formation accumulated over a large area (over 1,500,000 km^2) in midwestern Gondwana, at

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palaeolatitudes between 14° and 32°S, making it an excellent example for palaeowind studies. The comparison between cross-strata dip direction data from the Botucatu Formation and the general circulation model (GCM) proposed by Moore et al. (1992) allows a better understanding of near-surface wind patterns operating in the latest Jurassic/earliest Cretaceous, prior to Gondwana breakup.

2. Geological setting

The Botucatu Formation consists of aeolian sandstones distributed across an area of more than 1,500,000 km^2. It crops out along the borders of the Paraná Basin, in areas of Brazil, Uruguay, Argentina and Paraguay, and has correlative deposits in Africa (e.g. Twyfenfontein Formation; Stanistreet and Stollhoffen, 1999). The Botucatu Formation is defined at the base by a regional unconformity that can be traced across the entire basin (Milani et al., 1998). It is composed of dominantly aeolian deposits, represented by large-scale sets of cross-strata (1–30 m) interpreted as aeolian dune deposits (Almeida, 1954; Bigarella and Salamuni, 1961). Detailed facies studies in the southern portion of the outcrop area (in southern Brazil) have allowed the morphologic reconstruction of the aeolian dunes, suggesting the occurrence of simple to (locally) compound crescentic aeolian dunes, as well as complex linear draas (Scherer, 2000, 2002). The lowermost deposits immediately above the basal contact locally contain conglomerates and gravelly sandstones deposited by ephemeral streams, as well as coarse-grained sandstones interpreted as aeolian sand sheet deposits (Bigarella and Salamuni, 1961; Soares, 1975; Almeida and Melo, 1981; Scherer, 2002). The thickness in the Botucatu Formation varies from 0 to 400 m, the greatest thickness occurring in the northwestern portion of the Paraná Basin (Milani, 1997). The aeolian sandstones are overlain by a 300 to 800 m thick succession of volcanic rocks (Serra Geral Formation). Lava flows covered the previously active aeolian dunes in the erg, thereby entirely preserving their morphologies (Scherer, 2002).

The concordant contact between the Botucatu and the Serra Geral Formations means that dating of the Serra Geral volcanic rocks offers a reliable geochronological reference for the termination of the Botucatu aeolian sedimentation. Ar/Ar radiometric dating has previously been carried out in volcanic rock samples collected at different levels of the Serra Geral Formation in the Alto Piquiri well (Onstott et al., 1993). This well was drilled in the region where the volcanic package is thickest, and the resulting ages span a range from 136.6±1.5 m.y. to 130.8±0.6 m.y. (Onstott et al., 1993). Additionally, Turner et al. (1994) dated several samples collected across the basin, obtaining an age of 137±0.7 m.y. for the oldest volcanic rocks, which suggests an earliest Cretaceous age for the termination of aeolian accumulation in the Botucatu Formation. Dating the onset of sedimentation in the Botucatu Formation, however, is much more problematic. Based on vertebrate ichnofossils identified in aeolian strata, Bonaparte (1996) attributed a Late Jurassic to Early Cretaceous age to the Botucatu Formation. Milani et al. (1998) accepted this age in their proposal of a Mesozoic stratigraphy in the Paraná Basin. Nevertheless, as discussed by Scherer et al. (2000), the intimate relation between the aeolian sandstones and the lava-flow deposits, and the lack of regional-scale unconformities (supersurfaces) within the aeolian package suggest that the Botucatu comprises a shorter time interval. Therefore, a latest Jurassic age seems more adequate for the onset of aeolian sedimentation in the Botucatu Formation.

3. Palaeogeographic setting

The Jurassic was characterized by the fragmentation of Pangea. In the Late Jurassic to Early Cretaceous, the separation between Gondwana and Laurasia was well in progress, and a wide ocean had already developed between those continents (Scotese, 2003). Moreover, the eustatic sea level was high during this time interval, flooding large areas of Laurasia and allowing the development of extensive epicontinental seas. In Gondwana, however, marine deposits apparently formed only at the west margin along a narrow strip of the retro-arc region in the Andes, while the continental interior displayed exclusively continental sedimentation which included the aeolian deposits of the Botucatu Formation (Fig. 1). The absence of epicontinental seas on inland Gondwana is a result of the continental palaeotopography. A wide plateau with an elevation in excess of 100 m developed due to the high thermal flux, and consequently high continental freeboard, analagous to what is observed in Africa today (Worsley et al., 1984).

The period between the end of the Jurassic and the beginning of the Cretaceous was characterized by profound tectonic changes in Gondwana. The fragmentation of Gondwana intensified during this time interval, with the development of continental rift systems leading to the formation of the South Atlantic. While rift basins were formed in the southern and northeastern portions of South America, the region occupied by the Botucatu Formation consisted of a cratonic area where a wide topographic basin accumulated a thick package of aeolian dune deposits (Fig. 1).