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Permian paleogeography of west-central Pangea: Reconstruction using sabkha-type gypsum-bearing deposits of Parnaíba Basin, Northern Brazil

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ABSTRACT

Extreme aridity during Late Permian – Early Triassic period was the main factor for resetting the entire paleoclimate of the planet. Permian evaporite basins and lacustrine red beds were widely distributed along the supercontinent of Pangea. Sulphate deposits in Western Pangea, particularly in Northern Brazil, accumulated in an extensive playa lake system. Outcrop-based facies and stratigraphic analysis of up to 20 m thick evaporite-siliciclastic deposits reveal the predominance of laminated reddish mudstone with subordinate limestone, marl and lenses of gypsum. The succession was deposited in shallow lacustrine and inland sabkha environments associated with saline pans and mudflats. Gypsum deposits comprise six lithofacies: 1) bottom-growth gypsum, 2) nodular/micronodular gypsum, 3) mosaic gypsum, 4) fibrous/prismatic gypsum, 5) alabastrine gypsum, and 6) rosettes of gypsum. Gypsum types 1 and 2 are interpreted as primary deposition in saline pans. Bottom-growth gypsum forms grass-like crusts while nodular/micronodular gypsum indicates displacive precipitation of the crust in shallow water and the groundwater capillary zone. Types 3 and 4 are early diagenetic precipitates. Abundant inclusions of tiny lath-like anhydrite crystals suggest a primary origin of anhydrite. Alabastrine gypsum, fibrous gypsum (satinspar) and rosettes of gypsum probably derived from near-surface hydration of anhydrite. The gypsum-bearing deposits in the Parnaíba Basin contribute towards understanding paleogeographic changes in Western Pangea. A progressive uplift of East Pangea, culminated in the forced regression and retreat of epicontinental seas to the West. Restricted seas or large lakes were formed before the definitive onset of desert conditions in Pangea, leading to the development of extensive ergs.

1. Introduction

During the Late Permian, arid conditions prevailed worldwide as a consequence of the global eustatic sea-level fall, disappearance of glacial areas and the multiplication of closed basins resulting from the agglomeration of Pangea (Parrish et al., 1986; Zharkov and Chumakov, 2001; Ford and Golonka, 2003). The intense continentalization of this supercontinent brought about the development of extensive deserts and sabkhas environments (Ford and Golonka, 2003; Linol et al., 2015). Massive precipitation of evaporite minerals and saline crusts occurred as a consequence of arid/semiarid zones and restricted basin interactions (Kendall and Harwood, 1996; Schreiber and El Tabakh, 2000; Warren, 2010). These deposits are commonly concentrated in equatorial Pangea, and are considered a guide for Permian beds in several parts of the world (Alsharhan, 2006; Betzler and Pawellek, 2014; Benison et al., 2015).

Extremely acidic and saline environments with abundant sulphate deposits were regionally extensive along the coast of Pangea: in the North American sedimentary basins (Benison and Goldstein, 2000; Powers and Holt, 2000; Zambito and Benison, 2013; Benison et al., 2015); the Zechstein Basin of northwestern Europe (Betzler and Pawellek, 2014); and the Rub al Khali Basin of Saudi Arabia (Alsharhan, 2006). On the other hand, inland sabkha environments characterize the Permian mixed siliciclastic–evaporite deposits of Northern Brazil (Góes and Feijó, 1994; Abrantes and Nogueira, 2013). The effect of the widespread Permian–Triassic climatic events on that supercontinent recorded in the Parnaiba Basin of Brazil is little-documented. This study focuses on the sedimentology and petrography of the gypsum-bearing deposits of the Permian Motuca Formation as the main record of arid conditions preceding the extreme continentalization of the Triassic. Petrographic and diagenetic analysis has contributed significantly to paleoenvironmental interpretations, as well as allowing more precise inference of the saltpan genesis in western Pangea. The combination of these techniques with existing stratigraphic studies of the South American sedimentary basins, coupled with the paleogeographic understanding of Western Pangea, has led to a more concise (Fig. 1).

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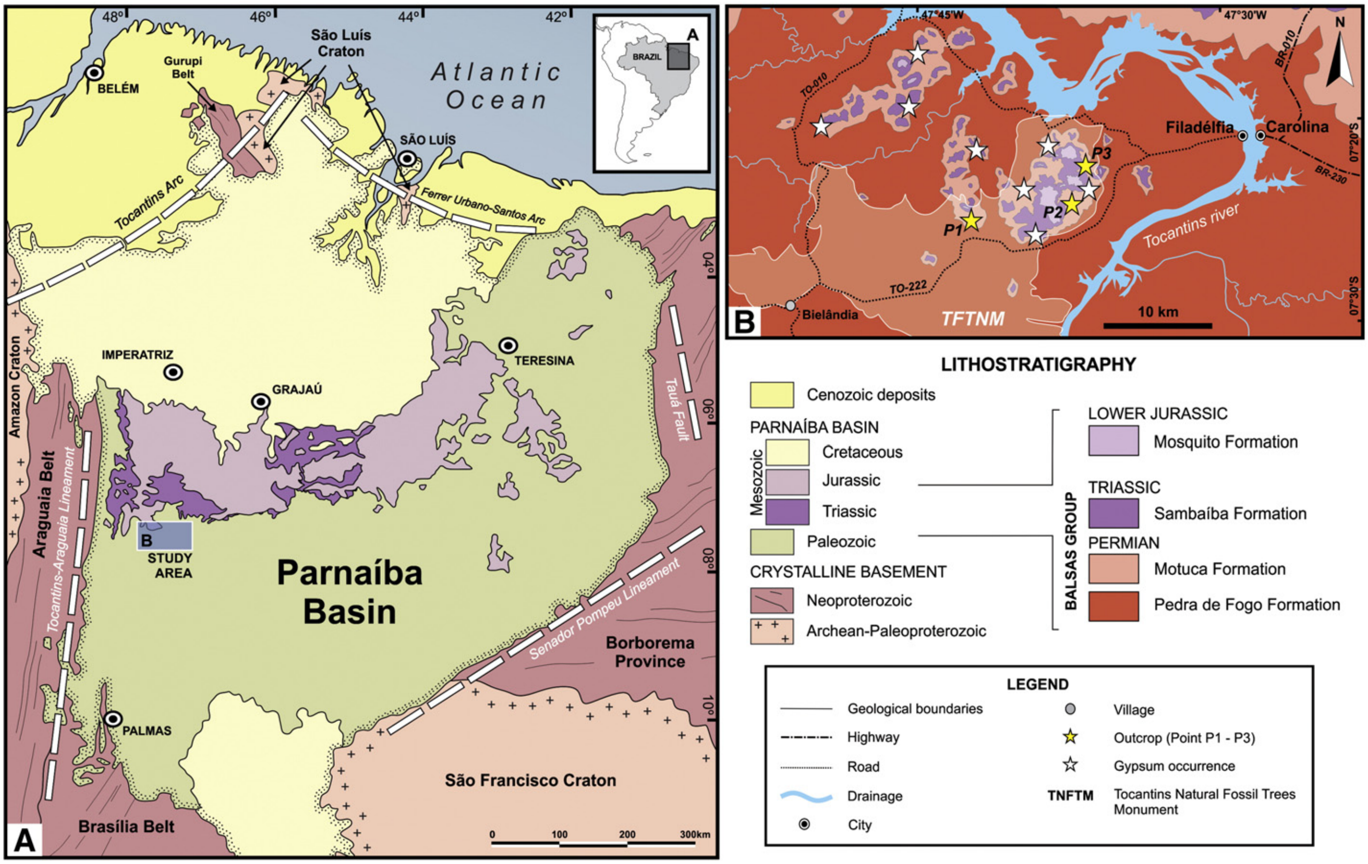

Fig. 1. Location map of the study area. (A) Simplified geological map of the Parnaiba Basin showing the distribution of Precambrian basement rocks and Phanerozoic sediments (Modified from Schobbenhaus et al., 1984; Santos and Carvalho, 2004). (B) Lithostratigraphic relationships and studied outcrops.

2. Geological setting

The Parnaíba Basin is an intracratonic sag basin, covering an area of over 600,000 km^2 in northern Brazil (Milani and Zalán, 1999). The infilling sedimentary strata have a thickness of 3500 m in the basin depocenter (Góes and Feijó, 1994; Vaz et al., 2007). The Early Paleozoic history of the basin reflects the last stage of the Brasiliano Orogeny (Neoproterozoic–Cambrian) until the Caledonian Orogeny (Silurian–Devonian), resulting in the subsidence of a large cratonic area of Gondwana (Caputo, 1984; Milani and Zalán, 1999). Intensive rifting stages preceded the Parnaíba Basin deposition, the driving mechanism for this intracratonic subsidence (Castro et al., 2014; Darly et al., 2014). The Pennsylvanian–Eotriassic Supersequence (Balsas Group) consists of four lithostratigraphic units: Piauí, Pedra de Fogo, Motuca and Sambaíba formations (Góes and Feijó, 1994; Vaz et al., 2007). The assembly of Gondwana and Laurasia formed the Pangea supercontinent during Pennsylvanian to early Triassic time (Golonka and Ford, 2000). The Pennsylvanian sedimentation of the Parnaíba Basin was strongly-influenced by marine and coastal processes (Piauí Formation; Caputo, 1984; Milani and Zalán, 1999; Zharkov and Chumakov, 2001). During the Early to Late Permian times, the continuing collision and uplift of orogenic belts triggered the retreat of epicontinental seas and formation of isolated interior basins (Pedra de Fogo and Motuca formations; Zharkov and Chumakov, 2001; Ford and Golonka, 2003). Permian–Triassic sedimentation was influenced by arid conditions, yielding red lacustrine-alluvial sediments, frequently gypsum-bearing, sabkha-related and eolian (Motuca Formation; Scotese et al., 1999; Chumakov and Zharkov, 2003).

The Motuca Formation is exposed along of the western to central part of the Parnaíba Basin, reaching a thickness of around 280 m in the basin center (Góes and Feijó, 1994). It consists of red mudstones and sandstones, bedded gypsum and/or anhydrite, and lenses of limestones (Góes and Feijó, 1994; Vaz et al., 2007). These deposits become predominantly sandy in the eastern Parnaíba Basin with an absence of sulphate beds. Salt layers are thin-bedded and mark the upper Motuca succession. The depositional environments have been interpreted as shallow lakes, mudflats and saline pans (Abrantes and Nogueira, 2013). Vaz et al. (2007) assigned the succession to the Upper Permian to the Lower Triassic based on palynological analyses from the Pedra de Fogo Formation (Dino et al., 2002). The Motuca Formation concordantly overlies the sandstones and mudstones with abundant silicified stems of the Permian Pedra de Fogo Formation, interpreted as continental in origin (Andrade et al., 2014). During the Triassic time an extensive eolian desert was formed along the equatorial to middle-latitudes in Pangea, as a response to increased aridity (Sambaíba Formation; Rodríguez-López et al., 2014). Aeolian sandstones of the Triassic Sambaíba Formation gradually overlay the Motuca Formation, showing locally abrupt and erosive contacts.

3. Facies associations

The siliciclastic–evaporitic deposits of the Motuca Formation are discontinuously exposed along the main highways and gypsum quarries in the Filadélfia region (Fig. 1). Three outcrop sections reaching up to 20 m thick have been described in the base of 250 m-high Sambaíba aeolian sandstone cliffs (Fig. 2). These deposits consist predominantly of laminated red mudstone with subordinated limestone, marl and lenses of gypsum/anhydrite. Evaporite beds reach up to 6 m thick, extend laterally for up to 100 m, pinch out in the succession and are generally interbedded with mudstones.

The Motuca Formation is divided here into nine sedimentary facies (Table 1). The facies are grouped in two facies associations (FA):