Sedimentary Facies and Palaeoenvironmental Records of an Intracratonic Basin Lake: Aptian Lacustrine Crato Formation, Jatobá Basin, NE Brazil*

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Abstract

The purpose of this study was to characterize the Aptian lacustrine sequence of the Jatobá Basin in Northeastern Brazil. Emphasis was placed on the carbonate sedimentation within the Crato Formation of the Santana Group. We analyzed lithofaciological, petrographic, paleontological, geochemical, and paleoenvironmental aspects of samples collected in twelve outcroppings, in addition to the well. Forty-seven sections were selected and studied: twenty- nine from the stratigraphic well, and eighteen from the outcroppings. Of these samples, thirty- eight represent carbonates and nine from sandstone and silt rock layers. Study of the well core permitted identification, in the lacustrine sequence, of three facies associations: a) association of deltaic facies consisting of three lithofacies, b) association of terrigenous lacustrine facies, comprised of eleven lithofacies, and c) association of carbonate facies, consisting of four groups of microfacies. The combination of carbonate facies is made up of the following lithofacies: clay- carbonate rhythmites, where two microfacies were individualized; limestone layers consisting of eight microfacies; the marls and, finally, the bioclastic limestones, also represented by only one microfacies. Twelve species of ostracods were identified, belonging to nine genera from four distinct families. Of particular note was the *Ilyocyprididae* family with six species, followed by the *Cyprideidae* family with four species, along with the *Darwinulidae* and *Limnocytheridae* families, each with one species. The results of X-ray diffraction showed a prevalence of calcite in the limestone layers. Expansive clays were identified in the shales, with a predominance of interstratified illite-smectite followed by illite, kaolinite, and chlorite. Calcite is sometimes present, essentially as cement.

Introduction

Lacustrine basins can be extremely important at a regional scale as it occurs in China, Southeast Asia (e.g. Indonesia) and the divergent continental margins of West Africa and Brazil. In Brazil, up to 85% of the oil source rocks are regarded as lacustrine in origin (Katz, 1990; Mello and Maxwell, 1990; Smith, 1990; Katz, 2001).

The palaeoenvironments described for the Mesozoic Brazilian lacustrine basins range from freshwater to hypersaline lakes with variable marine influence.

Some inner onshore basins, as the Jatobá Basin, contain similar lacustrine successions to the ones placed at the continental margin offshore.

The marginal basins have attracted the major interest since they are responsible for most of the oil recovered from the offshore oil fields, but the inner onshore basins might be of interest for the sake of analogue studies.

The Jatobá Basin is located in the Pernambuco-Alagoas massif, NE Brazil. The elliptical basin, orientated NE-SW, is characterized by a semi-graben structure with tilted blocks toward NW direction. The analysed section consists of Aptian shales, marls, sandstones, limestones and dolostones, and represents the third lacustrine phase of the basin infill. This sequence is similar to the Aptian lacustrine sediments of the Araripe Basin (Bueno, 1996 and Magnavita et al., 2003).

Geological Setting

The Jatobá Basin is located in northeastern Brazil, in the Pernambuco-Alagoas Terrain of the Borborema Province (Figure 1A). It corresponds to the northern extremity of the Recôncavo- Tucano-Jatobá Rift system. The Borborema Structural Province resulted from a complex collisional process, associated with the convergent movement of plates, possibly involving amalgamation and accretion of microplates. This process was consolidated at the end of the Brasiliano Event (580 – 540 Mya). The pre-Mesozoic basement consists of Precambrian gneisses and migmatite terrains, which were deformed along interior fold belts. This basement was affected by extensive Jurassic–Cretaceous rifting processes, related to the split between Africa and South America during the break-up of Pangea.

The study area is located in the north central portion of the Jatobá Basin, where Cretaceous (Aptian) lacustrine sequences crop out extensively (Figure1B). The deposition of alluvial and fluvial-lacustrine Jurassic to Early Cretaceous successions (Aliança, Sergi, Candeias and São Sebastião Formations, and Ilhas Group) took place during successive pre-rift and syn-rift stages. Finally, after a significant erosive episode, a post-rift period with slow subsidence led to deposition of the fluvial and lacustrine Aptian Santana Group, which includes several formations (Marizal, Crato, and Romualdo Formations). The Cenomanian fluvial Exu Formation overlies a widespread erosive unconformity, developed at the top of the Santana Group (Figure 1B).

Several significant lacustrine depositional episodes have been recognised in the Jatobá Basin. A first episode took place during the Late Jurassic (Pre-rift stage) and led to deposition of the fine-grained siliciclastic, shallow lacustrine successions in the Aliança Formation, which have been reported from the subsurface and from extensive outcrops. The second lacustrine episode (Early Barremian) is comprised of fine-grained siliciclastic, also shallow lacustrine successions of the Candeias Formation. The third lacustrine episode (Late Aptian) includes the upper part of Marizal and the Crato Formations, and is the main subject of this study.

Material and Methods

The studied core was drilled in the Jatobá Basin, which is underlain and surrounded by the crystalline basement of the Borborema Province (NE Brazil).

113 samples were analysed by X-ray diffractometry, 17 of which were selected for clay mineral analysis. Sandstones were also studied by polarising microscopy and scanning electron microscopy.

Stable isotope analysis was carried out on carbonates and organic matter.

Results and Discussions

Similar to the Aptian lacustrine phase of the Araripe Basin (Neumann et al., 2003) the Crato Formation of the Jatobá Basin consists of a succession of lacustrine sediments with pronounced phases of deltaic siliciclastic influence.

Petrographically, five main lithologies can be observed (Vortisch et al., 2011): (1) generally silty grey shales, (2) grey marly shales to shaly marls, (3) generally fine-grained, argillaceous sandstones (4) micritic limestones, occasionally with a minor content of dolomite, and (5) dolostone (dolomite > calcite).

These lithologies can be subdivided in eleven lithotypes (se core 2-JSN-1-PE, Figure 2): a) laminated limestone, b) peletoidal limestones, c) marly limestone, d) marl, e) calcareous sandstone (partially fine-grained, f), g) fine-grained sandstone, h) siltstone, i) claystone, j) shale, and k) laminated shale. Shales are partially marly.

In many of the shales, expandable clay minerals are dominant among the clay mineral suite (predominantly illite-smectite), followed by illite, kaolinite, and chlorite.

In contrast to the shales, sandstones can contain considerable amounts of smectite, besides illite and minor proportions of kaolinite and chlorite. Quartz and feldspars are usually the main components. Calcite is sometimes present. Some of the sandstones show high contents of unweathered biotite, often marking sedimentary structures like ripple cross bedding as dark layers.

The presence of fresh biotite, frequently occurring within sandstones, indicates mild continental weathering conditions or fast erosion of crystalline rocks in the provenance area and rapid transport to the basin during Aptian lacustrine phase, represented by the study sediments of the Crato Formation. It is also generally accepted that the occurrence of chlorite as fine-grained clastic component in shales is indicating mild regional weathering conditions.

Explosive volcanic activity during the studied part of Aptian is strongly indicated by aggregates of diagenetic smectite in the sandstones. These smectite components were probably formed from volcanic glass particles (e.g. Do Campo et al., 2010).

The occurrence of dolomite is uncommon for lacustrine freshwater environments. Freshwater conditions are indicated by oxygen isotopes and ostracods, however small pseudomorphs of halite and the occurrence of gypsum near the base of the studied section, indicate ephemeral conditions of evaporation. Thus, the occurrence of dolomite together with high organic matter content and intensive bacterial activity (Gratzer et al., 2011) may explain lacustrine dolomite formation without permanent evaporitic conditions (e.g. Deng et al., 2010).

TOC content varies from 0.5-13 wt%, Hydrogen and Oxygen Indices from 6 to 715 and 4 to 44 respectively. The organic matter is immature (R_o % 0.28) and is represented by kerogen Type I in the lower section. In the upper section it is modified by the addition of terrestrial organic matter. A ~3 m thick clay-rich shale separates the sections.

Conclusions

From the biostratigraphic and isotopic studies associated with the faciologic studies of the Crato Formation, it can be suggested that the Aptian Paleolake of the Jatobá Basin is best characterized as a region typified by an elevated lake with low salinity, having the characteristics of a hydrologically closed lake, that has passed through short periods of time as an open lake. Indications are that freshwater and brackish water predominated (oligohaline to mesohaline), with high levels of organic matter, along with intense bacterial activity (eutrophic lake), where a broad diversity of ostracod species developed, confirming its Aptian age.

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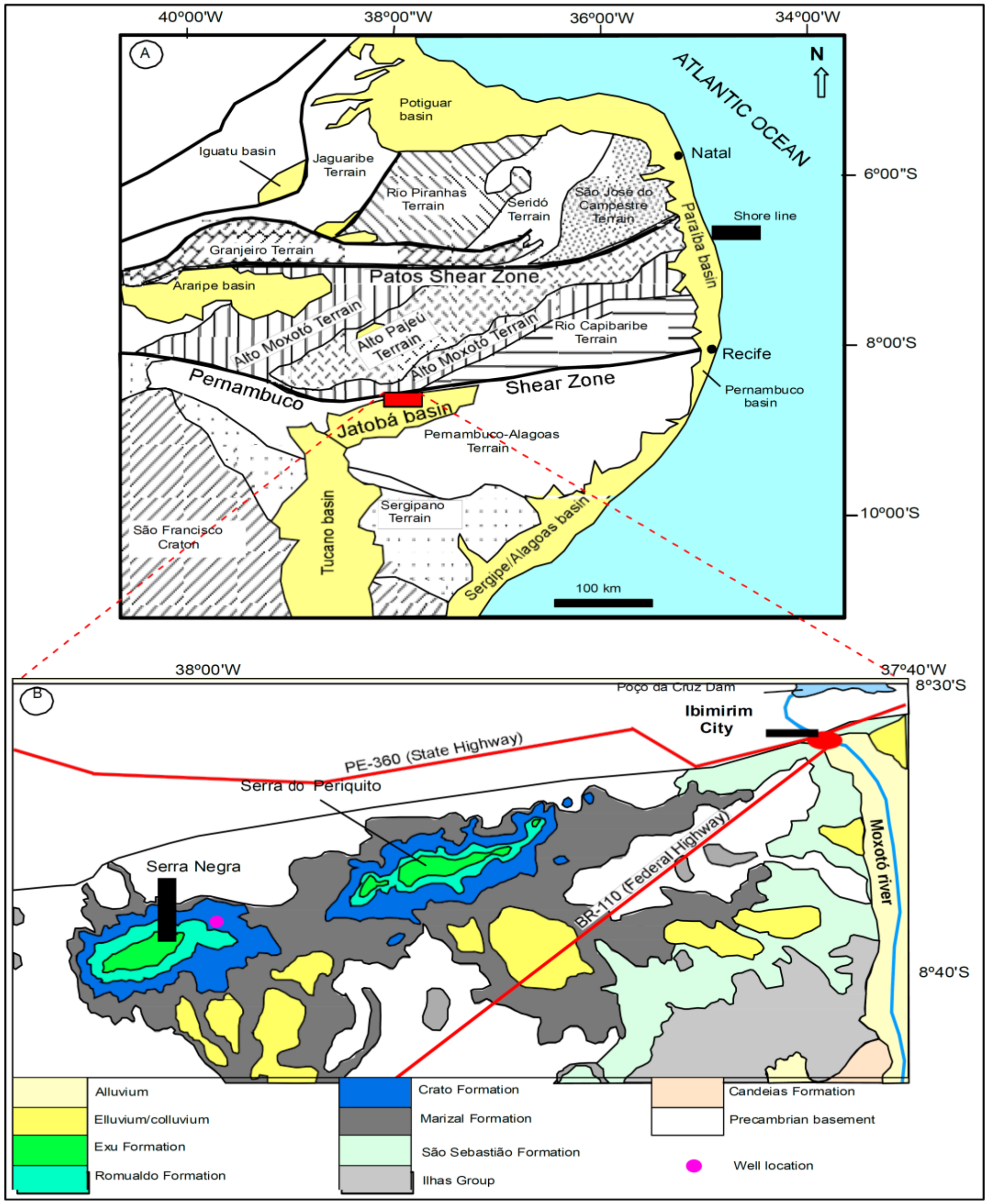

Figure 1. Geological outline of northeastern Brazil with location of Jatobá Basin (A). Geological sketch of part of the basin, showing the main stratigraphic units and the location of the well (B).

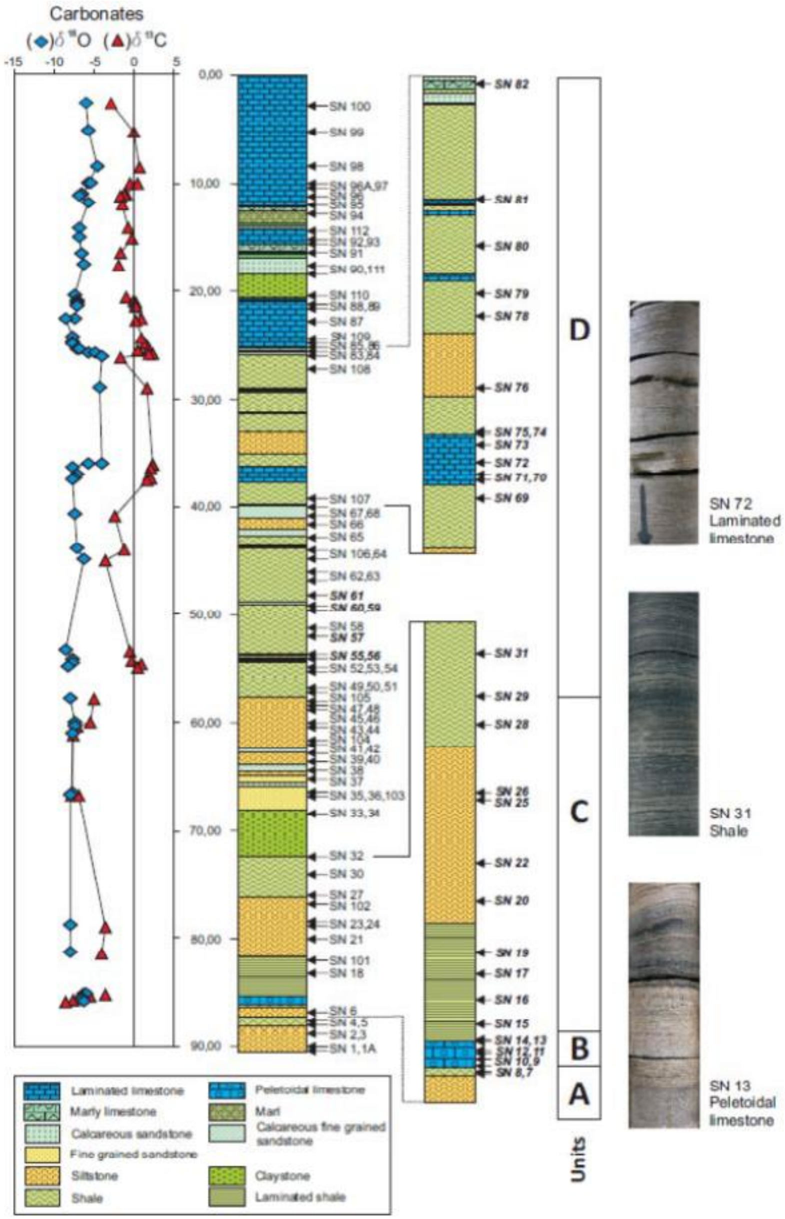

Figure 2. Schematic lithological profile and stable isotope data of carbonates of the core 2-JSN-1-PE (Crato Formation) with lithotypes and depicted core units. Units A-D are defined by means of sedimentological and geochemical data, see 4.2. Sample positions are marked by arrows; italic letters depict samples used for organic geochemical investigations.