








An Unusual Fossiliferous Site in the Romualdo Formation in the Socorro Basin (Northeast Brazil)

Um Sítio Fossilífero Incomum da Formação Romualdo, Bacia do Socorro (Nordeste do Brasil)

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Abstract

The Santana Group, from the base to the top, comprises the Barbalha, Crato, Ipubi, and Romualdo formations. Calcareous concretions from the Romualdo Formation are found in the Araripe Basin, but the geographic extension of this sequence has evidence in the Socorro Basin on the border of the state of Pernambuco; however, these areas outside of the Araripe Basin have rarely been investigated. The purpose of this research was to carry out a data survey of fossils collected in the Romualdo Formation from the Socorro/Santo Ignácio Basin area that were found in the northeastern portion of Ouricuri municipality in the state of Pernambuco; a new fossiliferous site, known as the Cara Branca site, is reported. Samples were collected from the surface and often in the off-season. This area is cleared by tractors for planting, either exposing fossils or moving some of the fossils. This disturbance reinforces the need for fossil rescues and excavations in this area, where weathering, agricultural machinery, and erosion can damage the fossil record. According to the initial paleontological sampling, the obtained taphonomic information pointed to rapid burial, and the degrees of disarticulation observed in some specimens indicated that disarticulation occurred through necrolysis.

Keywords: Santana Group; Fossil fish; Calcareous concretion

Resumo

O Grupo Santana, composto da base ao topo, compreende as formações Barbalha, Crato, Ipubi e Romualdo. As concreções calcárias da Formação Romualdo são encontradas a partir da Bacia do Araripe, mas a extensão geográfica desta sequência tem testemunhos na Bacia do Socorro na divisa do estado de Pernambuco, porém, essas áreas, localizadas fora da Bacia do Araripe, têm sido pouco exploradas. O objetivo desta pesquisa foi realizar um levantamento de dados fossilíferos coletados na Formação Romualdo na Bacia do Socorro/Santo Ignácio, encontrada na porção nordeste, nas proximidades do município de Ouricuri, estado de Pernambuco, realizando assim, a comunicação do novo sítio fossilífero conhecido com sítio Cara Branca. Amostras foram coletadas na superfície e, muitas vezes, na entressafra essa área é arada por tratores para plantio, expondo parte dos fósseis. Isso reforça a necessidade de resgate fossilífero e escavações nesta área, onde intempéries, máquinas agrícolas e erosão podem causar danos ao registro fóssil. De acordo com a amostragem paleontológica inicial, as informações tafonômicas obtidas apontavam para soterramento rápido, e os graus de desarticulação observados em alguns espécimes indicavam que a desarticulação ocorreu por necrólise.

Palavras-chave: Grupo Santana; Peixe fóssil; Concreções calcárias

1 Introduction

The Araripe Basin is situated in the Transversal Zone of the Borborema Province, which is known for its pre-Cambrian terrains (Neves et al. 2000). It is positioned to the south of the Patos Lineament and is considered the largest among the interior basins in the northeastern of Brazil. Notably, the Araripe Basin exhibits a geology that is more intricate compared to the other basins in the region (Assine 2007). Located between southern Ceará, eastern Piauí, and northwestern Pernambuco, the Araripe Basin is known for its excellent preservation state, diversity, and abundance of fossils, specifically in the Crato and Romualdo formations of the Santana Group (Assine et al. 2014). Previously, studies in the Araripe Basin were intense and focused on fossil prospecting in basically the northern zone of the basin in the state of Ceará (Figure 1).

The Santana Group, from the base to the top, comprises the Barbalha, Crato, Ipubi, and Romualdo formations (Assine et al. 2014). The Romualdo Formation is composed of gray-green shales, with intervals of carbonate concretions, fine sandstones, and limestones; pyrobituminous shale is rare in this unit (Saraiva et al. 2021). The Romualdo Formation is renowned for its extensive fossil record of fish, including both bony fish (Actinopterygii) and cartilaginous fish (Chondrichthyes) (Maisey 1991). Numerous species of fish have been discovered and described from this formation, providing valuable insights into the diversity and evolution of aquatic life during the Early Cretaceous (Batista & Silva 2021).

In addition to fish, the Romualdo Formation also contains a variety of other fossil organisms, these include reptiles such as turtles, crocodiles, pterosaurs (flying reptiles), and dinosaurs (Bantim 2021). The Romualdo Formation is also notable for its well-preserved plant fossils, including leaves, stems, and reproductive structures (Lima, Saraiva & Sayão 2012). These fossils provide valuable information about the flora that existed in the region during the Early Cretaceous.

In the western portion of the Araripe Basin in Pernambuco state, there are higher occurrences of outcrops from the Ipubi and Romualdo formations. This is primarily due to extensive mining activities focused on extracting gypsum from the Ipubi Formation, which has resulted in the exposure of rocks from these two stratigraphic units (Duque & Barreto 2018). In the municipality of Araripina in Pernambuco state, one of the most famous outcrops of the Romualdo Formation in Pernambuco is present. The outcrops with intervals of gypsum are commonly found, and immediately below this layer are the dark shales of the Ipubi Formation, where fishes of the genus *Dastilbe*, *Tharrhias*, and *Vinctifer* are preserved, and *Caridea* shrimp, are abundant (Barros et al. 2019; 2020; 2021).

Calcareous concretions from the Romualdo Formation can be found in the surroundings of the municipalities of Santana do Cariri, Crato, Missão Velha, Porteiras, Potengi, Araripe, and Jardim (Ceará state); Exu, Araripina, Trindade, Serrita, Moreilândia, and Ipubi (Pernambuco state) as well as Simões, Marcolândia, and Caldeirão Grande do Piauí (Piauí state) (Barros & Oliveira 2023; Beurlen 1963; Saraiva et al. 2021) (Figure 1).

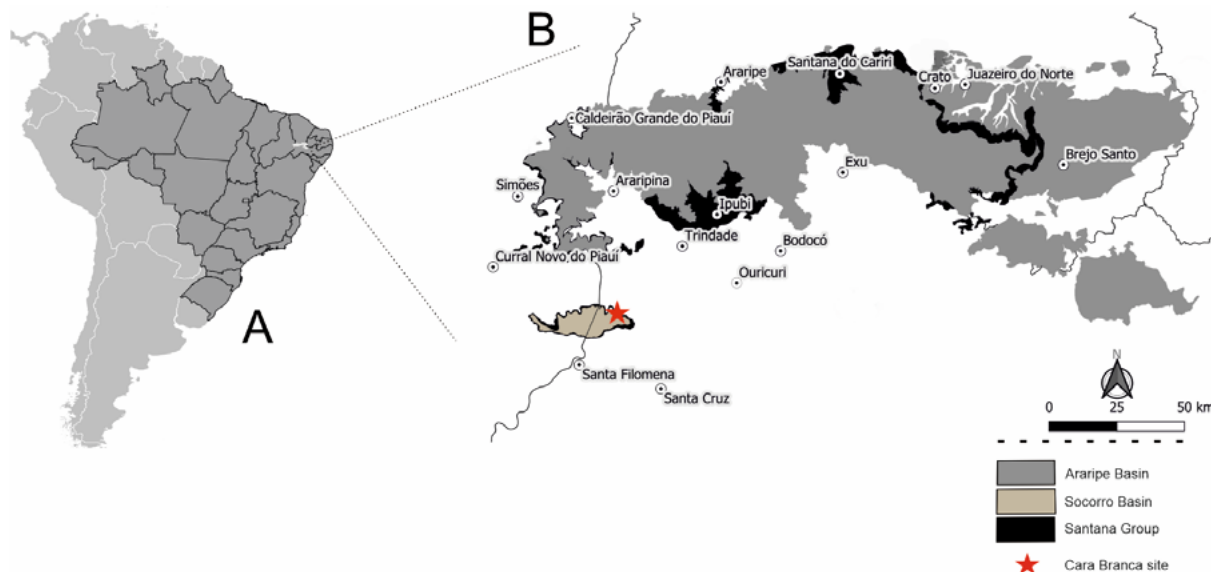


Figure 1 A. Map of South America with Brazil highlighted; B. Features of the Cara Branca site, which is the locality of the collection of fossiliferous samples in the Socorro/Santo Ignácio Basin.

The geographic extension of this stratigraphic sequence is in the Socorro Basin on the border of the states of Pernambuco and Piauí and in the Serra Negra in the Jatobá Basin, where the sequence is almost completely preserved, including at altitudes similar to those of the Araripe Basin (Assine 2007; Braun 1966; Mabesoone & Tinoco 1973); the stratigraphy consists sequences limited by regional unconformities, which represent the fragmentary record generated in different tectonic environments (Assine 2007). However, these areas that are localized in Pernambuco and Piauí, since they are farther away from large urban centers, have been rarely investigated, even though they show certain characteristics in their fossil content, taphonomy, and lithology, which is different from the concretions observed in the eastern portion of the Araripe Basin, as observed by a previous study (Beurlen 1963).

Considering the coverage area of the Romualdo Formation, eventually, new fossiliferous areas are likely to be found (Saraiva et al. 2016). Thus, this work describes a new fossiliferous site of this geological unit in the state of Pernambuco based on surface prospecting activities carried out in this region.

2 Geological Setting of the New Site

The new fossiliferous site, named Cara Branca, is located in the Barra de São Pedro district (7°59'15.6"S, 40°29'03.2"W), Ouricuri city, Pernambuco state (Figure 1). Access is by the PE-585 highway, 195 km from the city of Crato (Ceará) and 685 km from Recife, the capital of Pernambuco, with access by the Br-232 highway. The survey was conducted on private property with the full consent of the landowners, who granted us permission to access and conduct surface and area surveys. Furthermore, our team obtained official authorization from the Agência Nacional de Mineração (ANM) to carry out this work, ensuring compliance with all applicable regulations and protocols.

In this region of the Socorro Basin, various fossil materials were found, mainly fish, which are easier to find due to the plowing of the soil during the planting seasons. With the fossils collected, it was possible to make inferences about the paleobiota of the Santana Group. Although the collected samples were mostly composed of fossil fish, the number of three-dimensionally preserved specimens stands out.

During the off-season, deforestation is frequently observed in this area. Tractors, commonly equipped with

plows, clear the land for agricultural purposes, resulting in the exposure of concretions that subsequently accumulate on the surface. It is noteworthy that this specific site aligns with the lithostratigraphic context of the Romualdo Formation. The presence of carbonate concretions, which contain fish fossils (ichthyoliths), along with the discovery of greenish shales in nearby ravine areas, further reinforce the association of this location with the Romualdo Formation.

3 Materials and Methods

To identify this new fossil locality, a comprehensive mapping effort was conducted in the municipality of Ouricuri and surrounding areas. These regions are characterized by the presence of calcareous concretions of the Romualdo Formation, which provides ample opportunities for surface prospecting and the discovery of fossil evidence. The collected samples were meticulously analyzed and subsequently deposited in the Paleontology Laboratory of the Universidade Regional do Cariri - URCA.

The precise geographical coordinates of the Araripe Basin were determined using the QGIS Geographic Information System software (version 3.12 - QGIS.org) and the SIRGAS 2000 coordinate system, as provided by the Instituto Brasileiro de Geografia e Estatística (IBGE, Brazil) and the Companhia de Pesquisa de Recursos Minerais (CPRM, Brazil). The stratigraphic framework of the Santana Group was depicted by the authors, drawing upon the work of Assine et al. (2014) as a primary reference.

4 Results and Discussion

4.1 Characterization of the Area

The Cara Branca site is characterized by mounts covered in "Caatinga" vegetation, typical of the Brazilian seasonal tropical dry forest, as well as plowed areas dedicated to agriculture. It is within these plowed areas that fossils (carbonate concretions) can be easily found (Figure 2A). The carbonate concretions exposed on the surface of the soil, have been utilized in this research. This highlights the importance of fossil rescues and excavations in the area, as weathering, agricultural machinery, and erosion pose risks to the preservation of the fossil record. Surface prospecting activities were conducted in the area to search for fossil evidence, leading to the initial discovery of fossil gastropods (Figures 2B and 2C).



Figure 2 Cara Branca site, an extension of the Romualdo Formation in the Socorro/Santo Ignácio Basin, State of Pernambuco: A. Partial view of the collected area; B. Calcareous concretions on the soil; C. Emphasis on the mass mortality of gastropods.

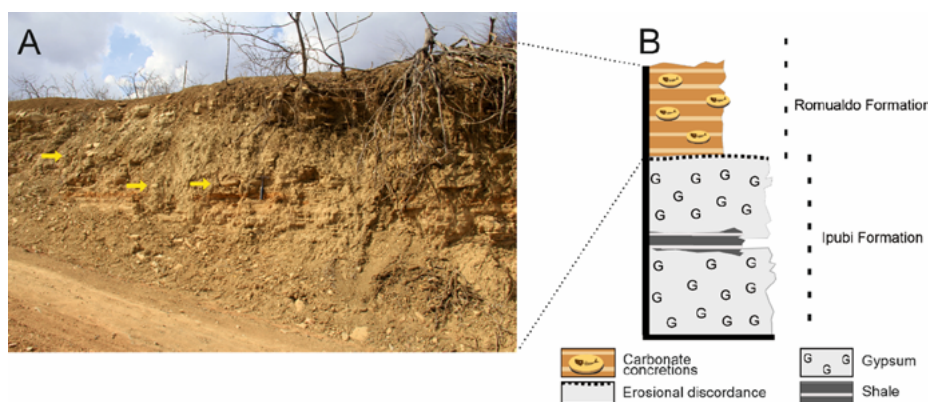


Figure 3 Photo showing the carbonaceous concretion level: A. Romualdo Formation outcrop at the Cara Branca site; the arrows indicate calcareous concretions in shales; B. generalized lithological section of part from the Santana Group.

4.2 Fossiliferous Content

Although a controlled excavation has not yet been carried out in this site, the prospection and collection of material found on the surface of the soil were quite significant, resulting in three-dimensionally preserved fish. The concretions that were collected are of micrite limestone and were wrapped in gray-green shales containing yellow marlstone and thin sandstone (Figures 3A and 3B). These geological features are typical of the Romualdo Formation (Saraiva et al. 2007).

The concretions had the same format as proposed by Saraiva et al. (2007), i.e., a scarce matrix in a median position with three-dimensional preservation and an ovoid shape (Figure 4). Upon examining the collected samples from the new fossiliferous site, we discovered a diverse assemblage of fossils, including fish remains, coprolites, and conglomerates containing gastropods. Many of the

samples displayed signs of mechanical wear caused by agricultural machinery and natural weathering processes (Figures 4A and 4B). Among the fish taxa found are *Vinctifer comptoni* (Agassiz, 1841) (the most representative, Figure 4C), *Rhacolepis buccalis* Agassiz, 1843 (Figure 4D), *Tharrhias araripis* Jordan and Branner, 1908 (Figure 5B), and some indeterminate fishes due to the fragmentary nature of the samples (Figure 4A).

The concretions collected in the area vary in color from beige to reddish, with regular and irregular shapes, and they are easily found on the ground. They have an ovoid shape with a slightly laminated texture, with fossil content represented mainly by fishes (Figure 5A-C).

The taphonomic analysis of fossils collected from the surface of the soil provides valuable insights into the processes that occurred during their preservation. In this case, the taphonomic information suggests that these fossils experienced rapid burial. The varying degrees of

disarticulation observed in some specimens indicate that was a result of necrolysis, a process that occurred after death. Consequently, only isolated parts of the fish, such as the skull and tail segments, were preserved (Figures 4 and 5). Articulated fossils are indicative of rapid burial and preservation, whereas disarticulated and disassociated fossils suggest slow burial and preservation processes (Holz & Simões 2002).

Furthermore, it is noteworthy that the fragmentation of the body occurred during the biostratinomic phase, as evidenced by the fragmented nature of the specimens themselves. Interestingly, the carbonate concretions surrounding these fossils remained intact, which aligns with previous observations made on fossil fish from the Romualdo Formation (Belfort & Araújo-Júnior 2019; Saraiva et al. 2007).

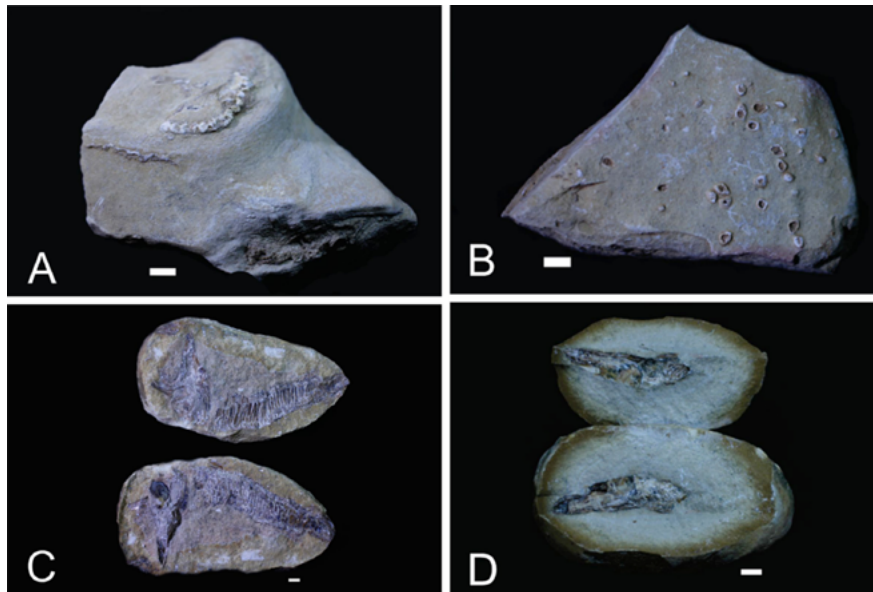


Figure 4 Some samples found in the soil: A. An indeterminate fish; B. Bivalves; C. *Vinctifer comptoni*, an example of a fossil with a scarce matrix and a fossil in a median position in the matrix with a regular shape and three-dimensional preservation; D. *Rhacolepis buccalis*, an ovoid matrix fossil that is in a median position and has three-dimensional preservation. Scale: 1 cm.

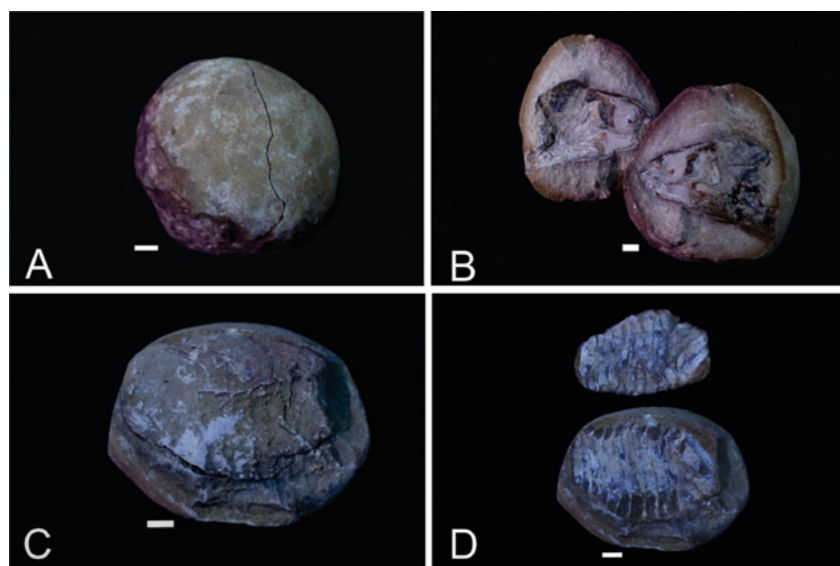


Figure 5 Open and closed concretions, with emphasis on the concretion format: A–C. Concretions with ovoid shapes with slightly laminated textures; B. *Tharrhias araripis* fish head; D. *Vinctifer comptoni*. Scale: 1 cm.

When comparing the fossils found in this new locality with the fossils prospected in the Romualdo Formation (Araripe Basin) in the state of Ceará, specifically at the Baixa Grande site in the municipality of Araripe (Saraiva et al. 2016), its rocky matrix resembles the approximate size and shape (ovoid), with a slightly laminated texture.

Fossils from the Baixa Grande site included specimens of *Vinctifer comptoni*, *Cladocyclus gardineri*, *Tharrhias araripis*, *Calamopleurus cylindricus*, and *Neoproscinetes penalvai* that were preliminarily collected from the surface (Saraiva et al. 2016), according to the classification proposed by Saraiva et al. (2007). The concretions at the Baixa Grande site, which had a regular matrix and ovoid shape with a slightly laminated texture, are concretions containing one fossil; macrofossils are present in their median portion, they are generally compressed in appearance, and they may also have shown fossils in three dimensions, like the fossils found in our results.

5 Conclusions

The Cara Branca site is a new fossiliferous site for the Romualdo Formation, located in the Socorro Basin. This locality has similar to the fossil concretions as in the Romualdo Formation, which are commonly found at the Baixa Grande site (Araripe Basin), because it presents partial fossils, with beige and reddish concretions that are mostly ovoid. The concretions of the Cara Branca site have a regular/scarcely matrix, with an ovoid/oval-elongated format, three-dimensional fossils, and a median position in the matrix, as at the Baixa Grande site.

Although controlled excavations have not yet been carried out in this outcrop, the sampling was quite significant, and the prospection of material found on the soil surface contained three-dimensionally preserved fish. The taxa collected at this site attract attention because they are gathered in a small area and include several species of fish and specimens of gastropods and bivalves.

Intensification of prospecting and paleontological collection work at this fossiliferous site and adjacent areas is necessary, as it will allow a greater knowledge of the biota in the Romualdo Formation. Thereby integrating the discovery of new fossiliferous outcrops in the region, adding to the understanding of the fossiliferous content in its entirety, and contributing stratigraphic information observed during the Aptian–Albian interval in this basin.

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Author contributions

Olga Alcântara Barros: formal analysis; methodology; writing – original draft; visualization. **Antônio Álamo Feitosa Saraiva:** writing – review. **Juliana Trindade Marques de Oliveira:** writing review and editing; supervision. **Edilson Bezerra dos Santos Filho:** methodology; conceptualization. **Ana Maria de Souza Alves:** writing – review and editing; supervision. **Flaviana Jorge de Lima:** writing – review and editing; supervision; visualization. **Renan Alfredo Machado Bantim:** conceptualization; formal analysis; methodology.

Conflict of interest

The authors declare no potential conflicts of interest.

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Data availability statement

All data included in this study are publicly available in the literature.

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