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GEOSCIENCES

# Description of the stratotype section and proposal of hypostratotype section of the Lower Cretaceous Quiricó formation, São Francisco Basin, Brazil

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**Abstract:** The Quiricó Formation presents an abundant and diversified fossil record, and is the only formation from the Cretaceous of the São Francisco basin with the occurrence of ostracodes. This formation was described from the banks of the Quiricó creek, tributary of the Prata river, which is the type locality. However, a stratotype section was not described. The present work presents the description of the stratotype section of the Quiricó Formation and proposal of hypostratotype section, based on the lithologic description and fossiliferous occurrences. The studied sections are located in the Minas Gerais State, Brazil: 1. stratotype section of the Quiricó Formation, by the banks of Quiricó and São José creeks, Presidente Olegário County; 2. hypostratotype section of the Tereza Farm, near the Olhos D'água community, João Pinheiro County.

**Key words:** Hypostratotype section, Ostracoda, Quiricó Formation, Stratotype section.

## INTRODUCTION

The Quiricó Formation was first introduced by Barbosa (1965), to designate a Continental Cretaceous succession of sandstone layers intercalated with claystone layers outcropping by the banks of the Quiricó creek, tributary of the Prata river, Minas Gerais State. Also, a type locality was stablished; however, the stratotype section was never formally described. Therefore, the present work describes the stratotype section of the Quiricó Formation, and formally proposes a hypostratotype section, following the procedures of the International Stratigraphic Guide (Salvador 1994, Murphy & Salvador 1999) and North American Commission on Stratigraphic Nomenclature (2005).

The International Stratigraphic Guide (Salvador 1994, Murphy & Salvador 1999), which was developed to promote international agreement on stratigraphic classification, states that a formal lithostratigraphic unit should have a stratotype (type section) and type locality with a clear and precise definition and characterization, in order to define the stratigraphic unit. Also, the designation of a hypostratotype section – supplementary reference section proposed after the original designation – might extend the knowledge of the lithostratigraphic unit and complement its definition (Murphy & Salvador 1999, North American Commission on Stratigraphic Nomenclature 2005). From the description of the stratotype section, a new step in stratigraphy, especially regarding advanced correlation studies, is open to be conducted in the São Francisco basin, as well as other basins of Gondwana.

### Locality

The present work approaches two sections of the Quiricó Formation, from the Minas Gerais State, southeastern Brazil, which are: stratotype section of the Quiricó Formation, from the banks of the Quiricó and São José creeks, Presidente Olegário County; hypostratotype section of the Quiricó Formation from the Tereza Farm, João Pinheiro County (Fig. 1). Both Quiricó and São José creeks are confluents and tributary of the Prata river and they are very close to each other. The São José creek begins near the BR-365 and flows into the Quiricó, which then names the body of water (Fig. 2).

## GEOLOGIC SETTINGS

The São Francisco basin is an intracratonic basin. The basement of the basin is constituted by Proterozoic sedimentary rocks, covered by Phanerozoic sedimentary rocks. The Phanerozoic cover consists of sedimentary remnants of the Permian-Carboniferous, sedimentary rocks of the Lower Cretaceous, volcanic rocks of the Upper Cretaceous, and by a plateau composed of sandstones of the Upper Cretaceous. From base to top, the stratigraphic column of the São Francisco basin was filled by four supersequences: rift, intracratonic, intracratonic-foreland and sanfranciscan (Zalán & Silva 2007)

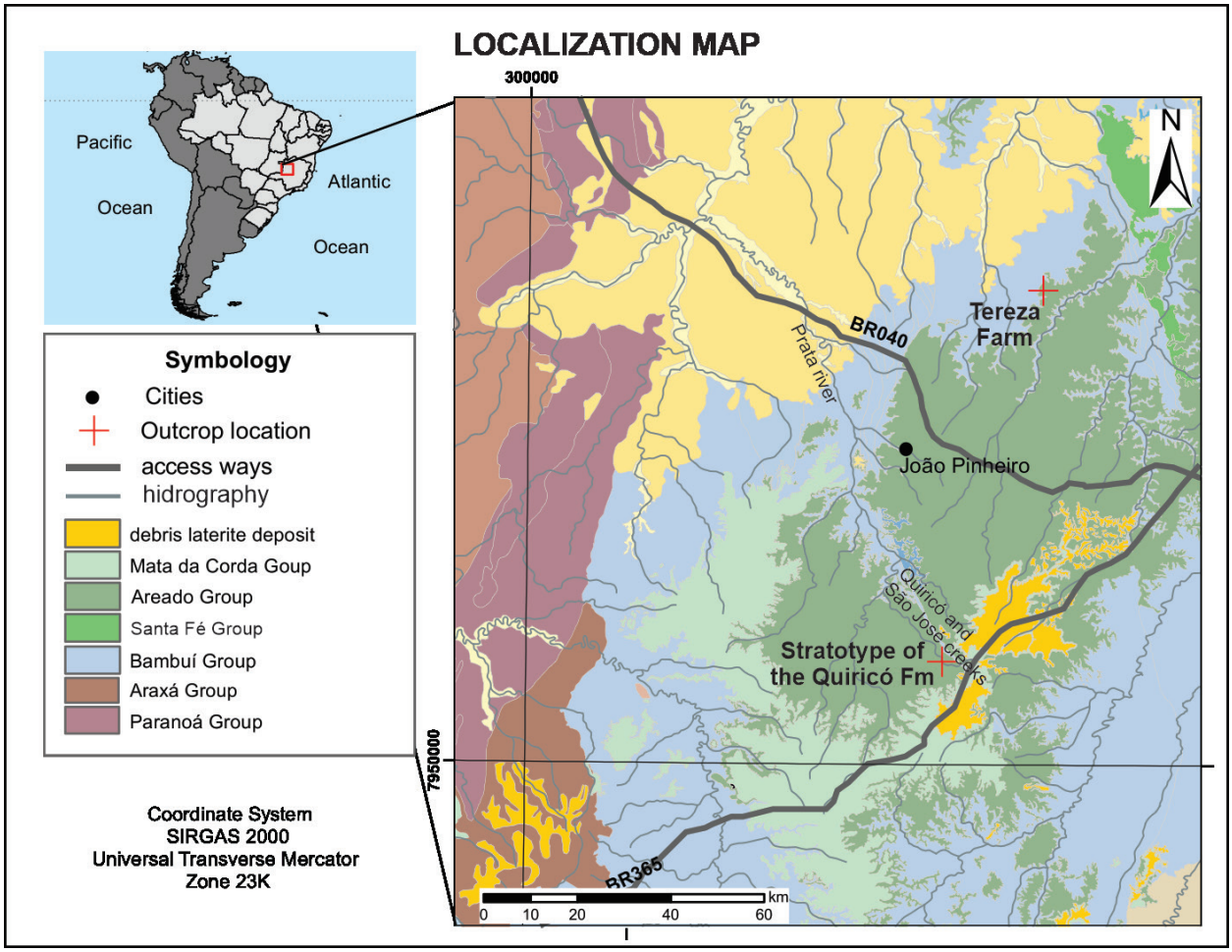


**Figure 1. Localization map with the regional geology (modified from GeoSGB – CPRM).**

The rift supersequence, from Paleoproterozoic to Mesoproterozoic, is constituted by the Supergroup Espinhaço. The Neoproterozoic intracratonic supersequence is constituted by the Macaúbas and Paranoá groups. The Neoproterozoic intracratonic-foreland supersequence is constituted by the Bambuí Group (Zalán & Silva 2007).

The Phanerozoic sequence of the São Francisco basin is distributed among the states of Minas Gerais, Bahia, Piauí, Tocantins, and Maranhão (Bueno 2012). From base to top, the groups are: Santa Fé, Permian-Carboniferous; Areado, Lower Cretaceous; and Mata da Corda and Urucuia, Upper Cretaceous (Fig. 3) (Campos & Do Carmo 2005, Zalán & Silva 2007). The Santa Fe Group consists of glacial records with fluvio-glacial, glacial-lacustrine and periglacial eolian facies. The Areado Group consists of sedimentary rocks, and will be approached in detail in the present work. The Mata da Corda Group is composed by volcanic pyroclastic alkaline rocks and by proximal epiclastic sedimentary rocks. The Urucuia Group is composed of sandstones of eolian origin, as well as fluvial sandstones, conglomerates and pelites (Campos & Do Carmo 2005).

The Areado Group presents a broad lateral variation of lithofacies. The formations, from base to top, are: Abaeté, Quiricó and Três Barras. The Abaeté Formation presents two distinct sedimentary contexts, in the southern portion of the basin it consists of immature matrix-supported conglomerates and in the rest of the basin it consists of mature grain-supported conglomerates. The chronostratigraphic attribution of this formation relies on the fact that the Santa Fé Group represented an important source material for the conglomerates of the Abaeté Formation; therefore, it is superimposed on the Santa Fé Group and restricted to the base of the Areado succession, not being observed in superior stratigraphic portions (Fig. 2) (Campos & Do Carmo 2005). The distribution of this

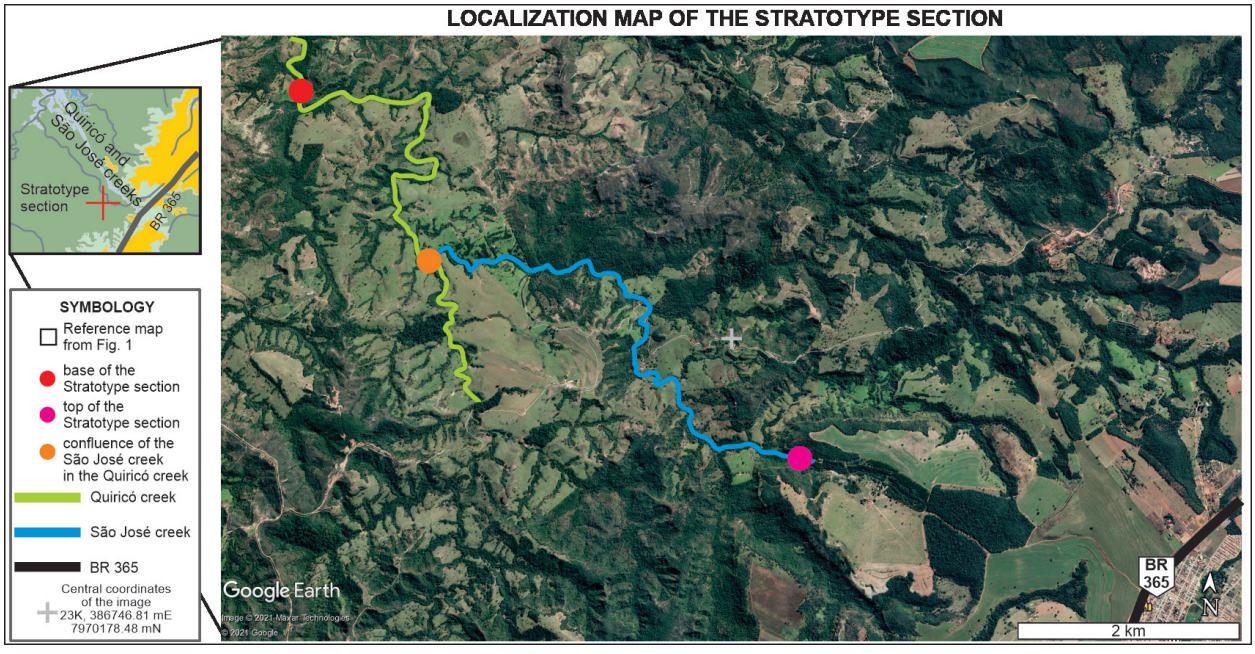


**Figure 2. Localization map of the stratotype section of the Quiricó Formation. The base of the section is located in the banks of the Quiricó creek and the top of the section in the banks of the São José creek. Central coordinates of the image: 23K, 386746.81 mE, 7970178.48 mN (adapted from Google Earth).**

formation is horizontally broad, mainly in the central-south portion of the basin, but it is not continuous. In the southern portion of the basin, the Abaeté Formation was deposited by alluvial fans, while in the rest of the basin it was deposited by interlaced river systems (Campos & Dardenne 1997a, Campos & Do Carmo 2005).

The Quiricó Formation is composed of siltstones, which occur interstratified and predominant at the base of the sequence; fine, medium and coarse sandstones in the intermediate portion; and shales and micritic limestones, more frequent in the upper part of the sequence. This is the only formation of the Areado Group in which ostracod fossils have been recovered to date. Locally, in the Presidente Olegário County, Minas Gerais State, a black papyraceous shale occurs, rich in organic matter and with the occurrence of fossil fish and leaf impressions. The chronostratigraphic position of the Quiricó Formation will be discussed below. This formation occurs interdigitated with the Três Barras Formation in the upper part of the sequence and was deposited by a lacustrine system (Campos & Dardenne 1997a, Campos & Do Carmo 2005).

The Três Barras Formation presents the largest lithological diversity and the largest volume of rocks, composed of heterogeneous sandstones (Campos & Dardenne 1997a, Campos & Do Carmo 2005). This formation presents an unconformity, dated by Mescolotti et al. (2019) as Cenomanian to Coniacian, because the lower stratigraphic unit of the Três Barras Formation interdigitates with the upper portion of the Quiricó Formation, and the upper stratigraphic unit is overlaid by the Mata da Corda Group. This unconformity separates que sedimentary succession into a lower stratigraphic unit, representing a wet eolian system, and a upper stratigraphic unit, representing a dry eolian system (Mescolotti et al. 2019). The Três Barras

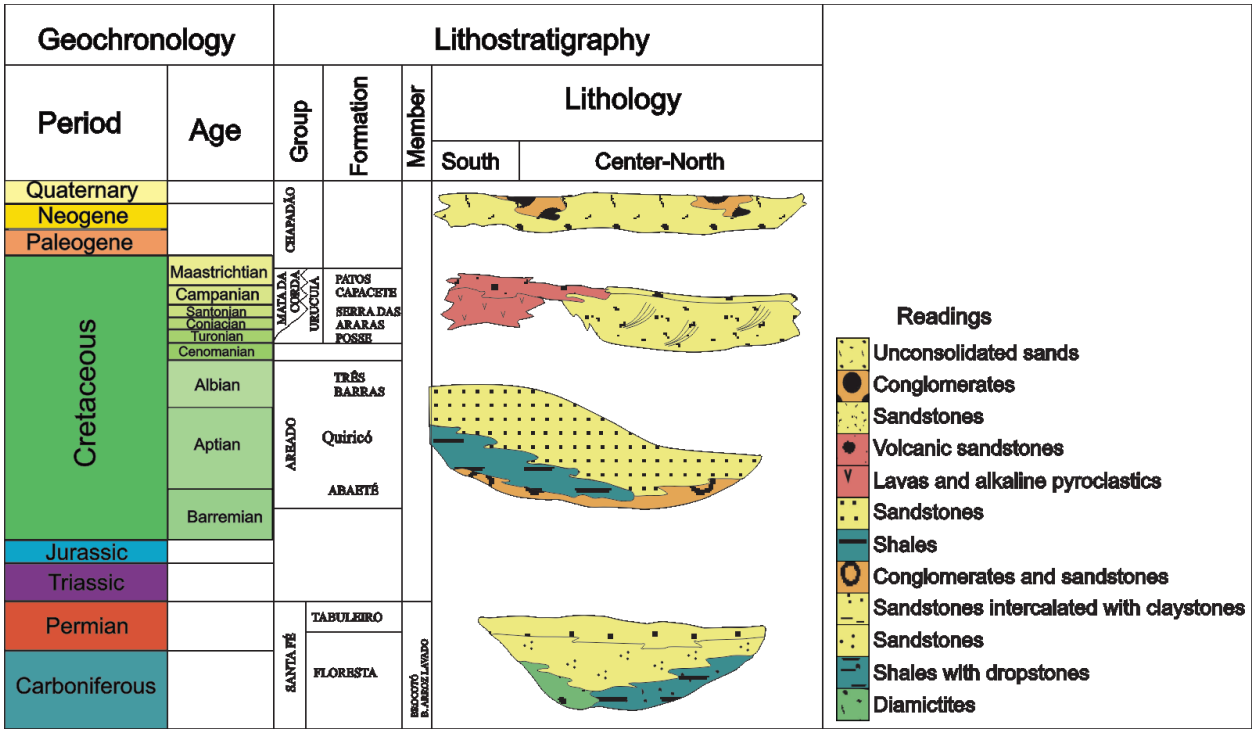


**Figure 3. Chronostratigraphic column representing the Phanerozoic sequence of the São Francisco basin (Do Carmo et al. 2004, adapted according to Campos & Dardenne 1997a).**

Formation was deposited by fluvial-deltaic and eolian fluvial systems (Campos & Dardenne 1997a, Campos & Do Carmo 2005).

## State of the art on stratigraphy of the Quiricó Formation

The term Areado was first used by Rimann (1917), while studying the region of Areado, near the Mata da Corda Mountain in Minas Gerais, to indicate a succession of sandstones from 40 to 100 m, called Areado sandstone. The base consisted of conglomerates or breccia of fluvial origin, with pebbles of granite, crystalline schist, and limestones and mudstones from the Bambuí sequence, and was attributed to the Permian-Carboniferous; followed by a red and white sandstone with eolian structures, attributed to the Triassic (Rimann 1917).

Barbosa (1965) while studying the region of the Triângulo Mineiro, specifically the Mata da Corda region, found Mesozoic layers superimposed on the Bambuí Group, and after further investigation, concluded that it was the Areado sequence mentioned by Rimann (1917). Barbosa (1965) assigned the Areado sandstone as Areado Formation, and divided it into three members, from base to top: Abaeté, Quiricó and Três Barras. The ages of members Abaeté and Três Barras were not assigned. For the Quiricó Member, a Cretaceous age was admitted due to the occurrence of *Dastilbe moraesi* Silva Santos 1955 registered by Scorza and Silva Santos (1955), which will be herein discussed.

Later Costa & Sad (1968) upgraded the Areado Formation to the Group rank and considered the three members as formations. The same nomenclature is used by Ladeira & Alves de Brito (1968), Ladeira et al. (1971) and Grossi Sad et al. (1971). Lima (1979) downgraded the Areado Group, considering the Areado as formation, and the Abaeté, Quiricó and Três Barras as members or facies. Seer et al. (1989) used the same scheme as Lima (1979). Since the publication of papers by Campos & Dardenne (1997 a, b) the designation by Costa & Sad (1968) has been consolidated and adopted.

Biostratigraphy is the main instrument for dating rocks of the Areado Group. However, U-Pb dating in volcanic rocks from the Mata da Corda Group, superimposed on the Areado Group, indicates an age of 75 to 81 Ma, Late Cretaceous (Sgarbi et al. 2004), therefore the Areado Group is older than 81 Ma (Campanian). Nevertheless, the Areado Group still lacks absolute dating.

The chronostratigraphic position of the Quiricó Formation was first mentioned by Scorza & Silva Santos (1955), with the identification of the fish *Dastilbe moraesi* Silva Santos 1955 in Scorza & Silva Santos (1955), recovered from the black papyraceous shale of the Presidente Olegário region. *Dastilbe moraesi* Silva Santos 1955 in Scorza & Silva Santos (1955) belongs to a genus with well-preserved occurrences from the Aptian of the Araripe basin, consisting as the starting point of the systematic study of fossils of the Phanerozoic from the São Francisco basin (Bittencourt et al. 2015). Cardoso (1971) discussed the position of the Areado Group within the Mesozoic, while studying conchostracans recovered in Carmo do Paranaíba, concluding that the unit was attributed to the Upper Jurassic or Lower Cretaceous.

Another important record regarding aquatic vertebrates was the discovery of coelacanths *Mawsonia* Woodward in Mawson & Woodward (1907), in the Tereza Farm, João Pinheiro. The genus is typically attributed to the interval Berriasian-Valanginian-Hauterivian, and it is recorded in the Recôncavo, Tucano, Almada, Sergipe-Alagoas, Araripe, Iguatu and São Luís do Grajaú basins (Carvalho 2002, Carvalho & Maisey 2008). The studied samples probably represent a single population belonging to *Mawsonia gigas* Woodward in Mawson & Woodward 1907

typical of the Candeias Formation, attributed to the Local Stage Rio da Serra (Caixeta et al. 1994, Carvalho 2002, Carvalho & Maisey 2008).

Terrestrial vertebrates were first identified in the form of footprints of herbivorous ornithischian dinosaurs, and carnivorous theropod dinosaurs, in outcrops in the João Pinheiro region, composed of typical deposits of eolian dunes and temporary rivers (Carvalho & Kattah 1998) corresponding to the Três Barras Formation (Bittencourt et al. 2015).

The fossil record of the Quiricó Formation was recently revised by Bittencourt et al. (2015), which is summed up in Table 1, with an update from 2015 to the present.

Barbosa et al. (1970), while studying the occurrences of the Areado Group in the regions of Patos de Minas and Carmo do Paranaíba, Minas Gerais State, recovered ostracods, charophytes and bone fragments. They determined that the ostracod fauna corresponded to that found in the Santana Formation, attributing an Aptian-Albian chronostratigraphic interval to the Quiricó Formation. Additionally, palynological studies by PETROBRAS on the black papyraceous shale from the Presidente Olegário region indicated a lower Aptian age (Barbosa et al. 1970). Lima (1979) identified the *Transitoripollis crisopolensis* Palynozone, coded as P-230, corroborated by Arai et al. (1995), which attributed the papyraceous shale to the Barremian(Campos & Do Carmo 2005).

The detailed taxonomy of ostracods was first approached by Do Carmo et al. (2004), who identified 15 distinct species, all of them limnic. *Wolburgiopsis plastica* (Musacchio 1970) and *Wolburgiopsis chinamuertensis* (Musacchio 1970) recovered from the São Bento Farm (Carmo do Paranaíba County), occur in the Barremian of Argentina, attributing the base of the Quiricó Formation in this section to the Barremian and the Quiricó Formation to the Barremian-Aptian interval (Do Carmo et al. 2004).

Leite et al. (2018) detailed the ostracod taxonomy from the stratotype section of the Quiricó Formation and the Tereza Farm (Fig. 1), and identified 20 species, all limnic. *Cypridea hystrix* Krömmelbein 1962, recovered at the Tereza Farm, occurs in the *Paracypridea brasiliensis* Zone (NRT-O04), subzones *Paracypridea bicallosa* (NRT-O04.3) and *Paracypridea maacki* (NRT-O04.4) (Viana et al. 1971, Cunha & Moura 1979, Regali & Viana 1989), Rio da Serra Local Stage (Caixeta et al. 1994), attributing the base of the Tereza Farm to the Valanginian. Coimbra (2020), from the analysis of figures and descriptions from Leite et al. (2018), concluded that all *Cypridea* species were erroneously identified, and, therefore, the attribution of the base of the Quiricó Formation to the Valanginian would be incorrect. Additionally, to Coimbra (op. cit.), these *Cypridea* species would be new taxa. Considering Leite et al. (2018), position followed herein, if someone compared the original description of these four species, would observe that the material recovered from the Quiricó Formation yield all characteristics to identify *Cypridea hystrix* Krömmelbein 1962, *Cypridea conjugata* Krömmelbein & Weber 1971, *Cypridea infima* Krömmelbein & Weber 1971 and *Cypridea jequiensis* Krömmelbein & Weber 1971.

A total of 27 species were recovered for the Quiricó Formation so far (Tab. 2). Of those, 18 species occur in other basins from Brazil, South America and Africa. Especially *Penthesilenula pintoi* Leite et al. 2018, *Alicenula longiformis* Leite et al. 2018 and *Timiriasevia sanfranciscanensis* Leite et al. 2018, were proposed from the Quiricó Formation, and until now, seem to be restricted to this formation. Therefore, their stratigraphic distribution contemplates only their occurrence in the formation in question.

**Table I. Fossils from the Quiricó Formation (adapted from Bittencourt et al. 2015).**

| TAXA | | Authors to first recover the taxa |
|---|---|---|
| **Gymnospermae – Coniferophyta – Brachyphyllaceae** | *Brachyphyllum obesum Heer 1881* | In Duarte (1997) |
| **Gymnospermae – Coniferophyta – Podozamitaceae** | *Podozamites lanceolatus* (Lindley and Hutton 1936) Braun 1843 | In Duarte (1997) |
| **Angiospermae – Nymphaeales – Nymphaeaceae** | *Nymphaeites choffatii* (Sap.) Teixeira 1947 | In Duarte (1997) |
| **Angiospermae – Poales – Poaceae** | *Paraleptaspis varjensis* Duarte 1997 | In Duarte (1997) |
| **Angiospermae (palynomorphs)** | *Deltoidospora* sp. | In Lima (1979) |
| | *Punctatasporites* sp. | In Lima (1979) |
| | *Sergipea* sp. | In Lima (1979) |
| | *Transitoripollis crisopolensis* (Regali et al. 1974) emend. Dino 1994 | In Lima (1979) |
| | *Inaperturopollenites* sp. | In Lima (1979) |
| | *Araucariacites australis* Cookson 1947 | In Lima (1979) |
| | *Classopollis classoides* Pflug 1953 | In Lima (1979) |
| | *Classopollis torosus* (Reissinger 1950) | In Lima (1979) |
| | *Monocolpopollenites* sp. 1 | In Lima (1979) |
| | *Monocolpopollenites* sp. 2 | In Lima (1979) |
| | *Cycadopites* sp. 1 | In Lima (1979) |
| | *Cycadopites* sp. 2 | In Lima (1979) |
| | *Clavattipollenites* sp. | In Lima (1979) |
| | *Retimonocolpites* sp. | In Lima (1979) |
| | *Eucommiidites minor* Groot & Penny 1960 | In Lima (1979) |
| | *Psilatricolpites psilatus* Pierce 1961 | In Lima (1979) |
| | *Exesipollenites tumulus* Balme 1957 | In Lima (1979) |
| | *Afropollis* spp. | In Arai et al. (1995) |
| | *Araucariacites* spp. | In Arai et al. (1995) |
| | *Bennettitaepollenites regaliae* Dino 1994 | In Arai et al. (1995) |
| | *Callialasporites* sp. | In Arai et al. (1995) |
| | *Cicatricosisporites* spp. | In Arai et al. (1995) |
| | *Cicatricosisporites microstriatus* Jardine & Magloire 1965 | In Arai et al. (1995) |
| | *Classopollis* spp. | In Arai et al. (1995) |
| | *Eucommiidites* spp. | In Arai et al. (1995) |
| | *Gnetaceaepollenites barghoornii* Pocock 1964 | In Arai et al. (1995) |

**Table I.** Continuation

| | | |
|---|---|---|
| | *Inaperturopollenites* spp. | In Arai et al. (1995) |
| | *Leiosphaeridia* spp. | In Arai et al. (1995) |
| | *Liliacidites kiowaensis Ward 1986* | In Arai et al. (1995) |
| | *Retimonocolpites* sp. | In Arai et al. (1995) |
| | *Sergipea cf. naviformis* Regali et al. 1974 | In Arai et al. (1995) |
| | *Tricolpites cf. vulgaris Pierce in Srivastava 1969* | In Arai et al. (1995) |
| **Metazoa – Arthropoda – Insecta – Heteroptera** | *Saucrolus silvai* Santos 1971 | In Santos (1971) |
| **Metazoa – Arthropoda - Spinicaudata** | *Platyestheria abaetensis* Cardoso 1971 | In Cardoso (1971) |
| | *Cyzicus* cf. *barbosai* (Almeida 1950) | In Cardoso (1971) |
| | *Palaeolimnadiopsis freybergi* Cardoso 1971 | In Cardoso (1971) |
| | *Palaeolimnadiopsis* cf. *reali* (Teixeira 1960) | In Cardoso (1971) |
| **Metazoa – Vertebrata – Chondrichthyes – Hybodontiformes** | *Hybodontiformes* indet. | In Carvalho & Maisey (2008) |
| | *?Tribodus* sp. | In Fragoso et al. (2019) |
| | *Hybodontiformes* indet. Morphologies 2 to 8 | In Fragoso et al. (2019) |
| **Metazoa – Vertebrata – Osteichthyes – Actinopterygii - Seminotiformes** | *Semionotiformes* indet. | In Carvalho & Maisey (2008) |
| **Metazoa – Vertebrata – Osteichthyes – Actinopterygii – Amiiformes** | *Amiidae* indet. | In Carvalho & Maisey (2008) |
| **Metazoa – Vertebrata – Osteichthyes – Actinopterygii – Gonorynchiformes** | *Dastilbe moraesi* Santos 1955 | In Scorza & Silva Santos (1955) |
| **Metazoa – Vertebrata – Osteichthyes – Actinopterygii - Neopterygii** | Gen. et sp. indet. | In Bittencourt et al. (2017) |
| **Metazoa – Vertebrata – Osteichthyes – Actinopterygii – Osteoglossiformes** | *Laeliichthys ancestralis* Santos 1985 | In Santos (1985) |
| **Metazoa – Vertebrata – Osteichthyes – Sarcopterygii – Coelacanthiformes** | *Mawsonia gigas* Woodward 1907 | In Carvalho & Maisey (2008) |
| **Metazoa – Vertebrata – Osteichthyes – Sarcopterygii – Dinosauria - Sauropoda** | *Tapuiasaurus macedoi* Zaher et al. 2010 | In Zaher et al. (2011) |
| | *Rebbachisauridae* | In Carvalho & Santucci (2018) |
| **Metazoa – Vertebrata – Osteichthyes – Sarcopterygii – Dinosauria – Theropoda** | *Abelisauroidae* indet. | In Zaher et al. (2011) |
| | *Nosauridae* | In Silva (2013) |
| | cf. *Carcharodontosauridae* | In Carvalho & Santucci (2018) |
| | *Abelisauridae* | In Carvalho & Santucci (2018) |

## MATERIALS AND METHODS

The study in the São Francisco basin, aiming the description of stratotype section and hypostratotype section began in Leite (2017). Field campaigns were performed between the years of 2015 and 2018. From these fieldtrips, the main outcrops of the Quiricó Formation were identified (Fig. 1). Lithostratigraphic columns were elaborated for each section, presenting fossiliferous intervals and detailed sampling. The classification of lithofacies based on their primary depositional attributes follows Miall (1996), regarding bedding, grain size, texture and sedimentary structures, as well as biogenic structures and fossils.

The stratotype section of the Quiricó Formation was first studied on the taxonomy perspective by Leite et al. (2018), but was initially identified as the outcrop of the São José Farm by the banks of the São José creek. Later, it was concluded that this outcrop extends to the banks of the Quiricó creek, consisting of a complete section of the Areado Group and thus composing the stratotype section of the Quiricó Formation.

### Description of the stratotype section

The stratotype section of the Quiricó Formation begins in the banks of the Quiricó creek, where the base of the section is, and after approximately 5 km extends to banks of the São José creek, where the top of the section is, Presidente Olegário County, Minas Gerais State, southeastern of Brazil (Fig. 1, 2). The coordinates of the section (UTM), Datum WGS84, are: for the base of the section, 23K, 382425.00 mE, 7972508.00 mN; for the top of the section, 23K, 387776.00 mE, 7968917.00 mN. The three formations of the Areado Group – Abaeté, Quiricó and Três Barras –, as well as the Santa Fé Group outcrop in this locality (Fig. 4, 5).

In this area, specifically in the banks of the Quiricó creek, the Quiricó Formation rests conformably over conglomerates and sandstones with limestone nodules (Fig 4a) of the Abaeté Formation, 5 m thick, which in turn is in erosional contact with friable red sandstones of the Permian-Carboniferous Santa Fé Group, formation unidentified, approximately 4 m thick. In the banks of the São José creek, the Quiricó Formation, about 63 m thick, is in conformable contact with fine/medium red sandstones, with thin layers of chert up to 1 cm thick, of the Três Barras Formation, at least 30 m thick.

As for the description of the Quiricó Formation, the lithostratigraphic sequence, from base to top, is: fine red sandstone with carbonate cement, intercalated with thin layers of limestone (Fig. 4b, 4c); red-yellow sandstone with carbonate cement, with claystone lenses (Fig. 4d), intercalated with layers of evaporite with desert roses and ostracod occurrence (Fig. 4e); layers of pelite; fine red sandstone with carbonate cement, with claystone lenses, intercalated with claystone layers, with ostracod occurrence; black shale, rich in organic matter; green laminated pelite with claystone lenses, intercalated with thin layers of evaporite and mud cracks (Fig. 5f); finely laminated sandstone with clay blades, intercalated with fine red sandstone with carbonate cement; rhythmite, composed by layers of sandstone and layers of pelite, with mud cracks, ostracod and conchostacans occurrence in the top portion (Fig. 5g).

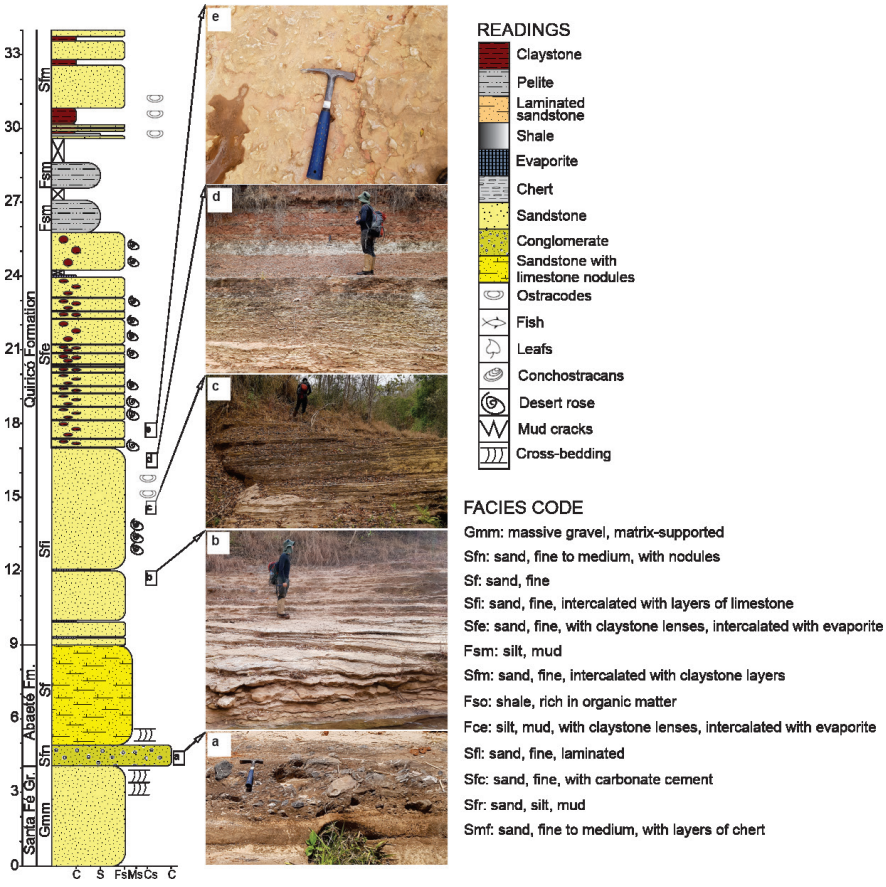


**Figure 4.** Lithostratigraphy of the Areado Group in the stratotype section of the Quiricó Formation, Presidente Olegário County, Minas Gerais State, Brazil. First part of the profile, from 0 m to 34 m. a) conglomerate of the Abaeté Formation. b) layers of fine sandstone intercalated with thin layers of calcite. c) layers of fine sandstone intercalated with thin layers of calcite. d) layers of fine sandstone with claystone lenses. e) surface with desert roses.

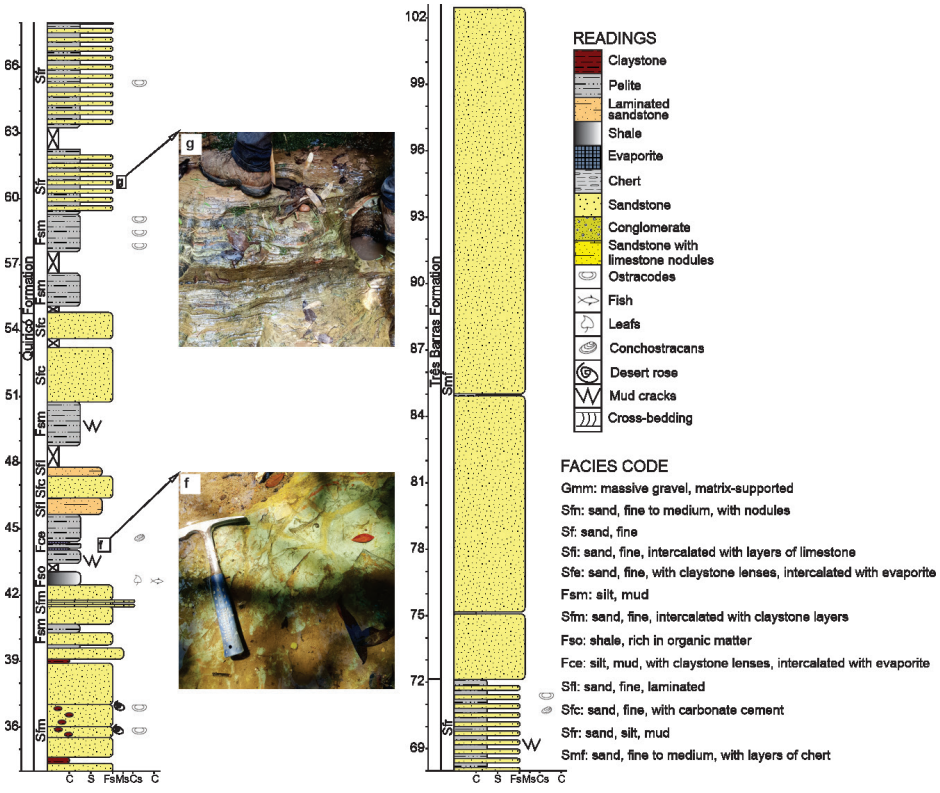


**Figure 5.** Lithostratigraphy of the Areado Group in the stratotype of the Quiricó Formation, Presidente Olegário County, Minas Gerais State, Brazil Second part of the profile, from 34 m to 102 m. f) layer with mud cracks. g) rhythmite package.

## Description hypostratotype section from the tereza farm

The hypostratotype section of the Tereza Farm is located near the Santa Luzia da Serra community, João Pinheiro County, Minas Gerais State, southeastern Brazil (Fig. 1). The coordinates of the section (UTM), Datum WGS84, are: 23K, 403859.00mE, 8050999.00mN. The three formations of the Areado Group – Abaeté, Quiricó and Três Barras –, as well as the Serra da Saudade Formation, Bambuí Group, outcrop in this locality (Fig. 6).

In this area, the Quiricó Formation rests conformably over matrix-supported conglomerates of the Abaeté Formation, a few centimeters thick, which in turn is in erosional contact (disconformity) with grey micaceous metasiltite of the Neoproterozoic Serra da Saudade Formation, with thickness undefined. In the upper portion of the outcrop, the Quiricó Formation, about 29 m thick, is in conformable contact with poorly selected, coarse/very coarse kaolinitic sandstones, of the Três Barras Formation (Fig. 6d).

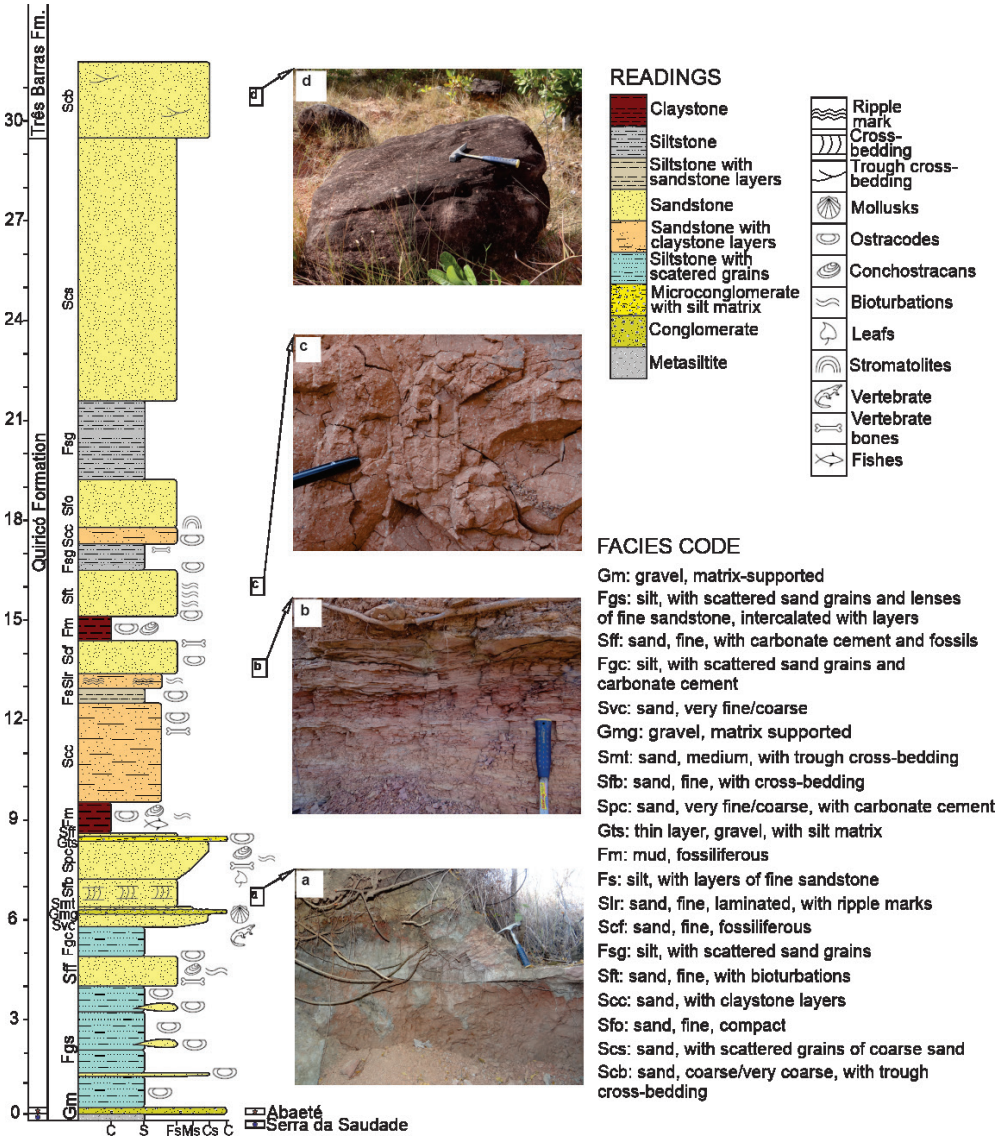


**Figure 6. Lithology of the Areado Group in the hypostratotype section of the Tereza Farm, João Pinheiro County, Minas Gerais State, Brazil. a) microconglomerate overlaid by sandstone. b) very fine sandstone intercalated with laminated siltstone. c) bioturbation. d) sandstone with cross-bedding.**

As for the description of the Quiricó Formation, the lithostratigraphic sequence, from base to top, is: red-brown siltstones with grains of medium sand scattered on the matrix and lenses of fine sandstone, intercalated with a thin layer of poorly selected very fine/coarse sandstone, with ostracod occurrence; fine red sandstone with carbonate cement, with milimetric layers of grey sandstone, with conchostracans, ostracods, vertebrate bones and bioturbation; siltstone with carbonate cement, with scattered grains of sand; poorly selected, very fine/coarse sandstone, with vertebrate bones and mollusks, in erosive contact with a gray conglomerate; compact sandstone with trough cross-bedding; fine sandstone with cross-bedding (Fig. 6a); poorly selected, very fine/coarse sandstone, with carbonate cement, vertebrate bones, leaves, bioturbations and ostracods; microconglomerate with carbonate cement, with matrix of silt size, and pebbles, and a thin layer of fine gray fossiliferous sandstone with carbonate cement; red claystone, with conchostracans, ostracods, bioturbations and impressions of fish scales; finely laminated sandstone with carbonate cement, with milimetric layers of claystone, and very thin layers of very fine sandstone at the top, with ostracods and vertebrate bones; finely laminated siltstone, with milimetric to centimetric layers of fine sandstone, with ostracod occurrence; laminated sandstone with carbonate cement, with ripple marks (Fig. 6b); fine yellow sandstone with carbonate cement, with vertebrate bones and ostracods; red claystone with carbonate cement, rich in ostracods and bioturbations; fine red sandstone with carbonate cement, with centimetric calcite-filled bioturbations (Fig. 6c); compact yellow siltstone with carbonate cement, with sand grains scattered in the base and ostracod occurrence; finely laminated sandstone, with thin claystone layers, with stromatolites at the top; fine compact sandstone; siltstone with sand grains scattered; laminated sandstone with grains of coarse sand.

## CONCLUSIONS

The stratotype section of the Quiricó Formation is herein formally described for the first time, along with a description of hypostratotype section, located in the Minas Gerais State, southeast Brazil: 1. Stratotype section located at the banks of the Quiricó and São José creeks, Presidente Olegário County; 2. hypostratotype section from the Tereza Farm, João Pinheiro County. The designation of the Tereza Farm section as hypostratotype section complements the lithostratigraphic and chronostratigraphic definition of the stratotype section, due to the abundant fossiliferous occurrence and well exposed and complete sedimentary sequence. With the biostratigraphic framework illustrated in Tables I and II, the description of the stratotype section originally designated by Barbosa (1965) and the formal proposal of a hypostratotype section, the complete characterization of the Quiricó Formation is achieved. The dating of the Quiricó Formation is based on biostratigraphy, and although fish and ostracod occurrences in the Tereza Farm seem to indicate a Valanginian age for the base of the section, due to controversies regarding ostracod taxonomy, the age of the Quiricó Formation remains to be reevaluated considering new fossil record and isotopic dating.

**Table II. Geographic and stratigraphic distribution of ostracod species from the Quiricó Formation.**

| Specimen | Geographic distribution | Stratigraphic distribution |
|---|---|---|
| ***Harbinia* sp. 1** | São Francisco basin, Quiricó Formation (Do Carmo et al. 2004) | Barremian |
| ***Harbinia* sp. 2** | Africa, Gabon basin, Mediéla Formation (Grosdidier 1979)<br>São Francisco basin, Quiricó Formation (Do Carmo et al. 2004) | Upper Aptian<br>Barremian |
| ***Harbinia aff. Harbinia angulata* (Krömmelbein & Weber 1971)** | Sergipe-Alagoas basin, Riachuelo Formation (Krömmelbein & Weber 1971)<br>Araripe basin, Santana Formation, Romualdo Formation (Poropat & Colin 2012)<br>Cedro basin, in strata correlated to the Crato Formation (Tomé 2007)<br>Jatobá basin, Serra Negra (Tomé et al. 2014)<br>São Francisco basin, Quiricó Formation (Leite et al. 2018) | Upper Aptian<br>Aptian<br>Aptian<br>Upper Aptian<br>Barremian-Aptian |
| ***Harbinia symmetrica* (Krömmelbein & Weber 1971)** | Parnaíba basin, Codó Formation (Krömmelbein & Weber 1971, Ramos et al. 2006)<br>Araripe basin, Santana Formation, Crato, Ipubi and Romualdo members, and Rio da Batateira Formation (Coimbra et al. 2002, Ramos et al. 2006, Antonietto 2010)<br>África, Congo, Gabão and Angola basins (Bate 1999)<br>São Francisco basin, Quiricó Formation (Leite et al. 2018) | Upper Aptian<br>Aptian<br>Barremian<br>Aptian |
| ***Harbinia aff. Harbinia salitrensis* (Krömmelbein & Weber 1971)** | Araripe basin, Santana Formation, Romualdo Member (Krömmelbein & Weber 1971, Antonietto et al. 2012, Poropat & Colin 2012, Tomé et al. 2014)<br>Grajaú basin, Codó Formation (Do Carmo et al. 2008)<br>São Francisco basin, Quiricó Formation (Leite et al. 2018) | Aptian<br>Aptian<br>Aptian |
| ***Harbinia alta* Antonietto et al. 2012** | Grajaú basin, Codó Formation (Ramos et al. 2006, Do Carmo et al. 2008)<br>Araripe basin, Santana Formation, Crato e Romualdo members (Viana et al. 1989, Silva-Telles Jr. & Viana 1990)<br>Potiguar basin, Alagamar Formation (Do Carmo et al. 2013)<br>Jatobá basin, Serra Negra (Tomé et al. 2014)<br>São Francisco basin, Quiricó Formation (Leite et al. 2018) | Upper Aptian<br>Aptian-Albian<br>Medium-Upper Aptian<br>Upper Aptian<br>Aptian |

**Table II.** Continuation

| | | |
|---|---|---|
| ***Harbinia aff. Harbinia crepata* Do Carmo et al. 2013** | Araripe basin, Santana Formation, Crato Member (Silva-Telles Jr. & Viana 1990)<br>Potiguar basin, Alagamar Formation (Do Carmo et al. 2013)<br>São Francisco basin, Quiricó Formation (Leite et al. 2018) | Aptian<br>Medium-upper Aptian<br>Barremian-Aptian |
| ***Brasacypris* sp. 1** | São Francisco basin, Quiricó Formation (Do Carmo et al. 2004) | Barremian |
| ***Brasacypris ovum* Krömmelbein 1965b emend. Leite et al. 2018** | Tucano basin, Itaparica and Candeias Formation (Krömmelbein 1965)<br>São Francisco basin, Quiricó Formation (Leite et al. 2018) | Lower Cretaceous, Berriasian<br>Lower Cretaceous, Valanginian to Aptian |
| ***Brasacypris fulfaroi* Dias-Brito et al. 2001** | Paraná basin, Bauru Group, Adamantina Formation (Dias-Brito et al. 2001)<br>São Francisco basin, Quiricó Formation (Leite et al. 2018) | Upper Cretaceous<br>Lower Cretaceous, Valanginian to Barremian? |
| ***Ilyocypris* sp. 1** | São Francisco basin, Quiricó Formation (Do Carmo et al. 2004) | Barremian |
| ***Cypridea hystrix* Krömmelbein 1962 emend. Leite et al. 2018** | Recôncavo basin, Ilhas Formation, Rio da Serra Stage (Krömmelbein 1962, Poropat & Colin 2012)<br>São Francisco basin, Quiricó Formation (Leite et al. 2018) | Lower Cretaceous, Berriasian to Valanginian<br>Lower Cretaceous, Valanginian |
| ***Cypridea conjugata* Krömmelbein & Weber 1971 emend. Leite et al. 2018** | Recôncavo basin, São Sebastião Formation (Krömmelbein & Weber 1971, Poropat & Colin 2012)<br>São Francisco basin, Quiricó Formation (Leite et al. 2018) | Lower Cretaceous, Barremian<br>Lower Cretaceous, Valanginian |
| ***Cypridea infima* Krömmelbein & Weber, 1971 emend. Leite et al. 2018** | Recôncavo basin, Formação Candeias, porção média e inferior (Krömmelbein & Weber 1971, Poropat & Colin 2012)<br>São Francisco basin, Formação Quiricó (Leite et al. 2018) | Lower Cretaceous, Berriasian<br>Lower Cretaceous, Valanginian to Aptian? |
| ***Cypridea jequiensis* Krömmelbein & Weber, 1971** | Sergipe-Alagoas basin, Jiquiá Formation, Post Bahia Series (Krömmelbein & Weber 1971, Poropat & Colin 2012, Antonietto 2015)<br>São Francisco basin, Quiricó Formation (Leite et al. 2018) | Lower Cretaceous, Barremian-Aptian<br>Lower Cretaceous, Valanginian |
| ***Cypridea* sp. 1** | São Francisco basin, Quiricó Formation (Do Carmo et al. 2004) | Barremian |

**Table II.** Continuation

| | | |
|---|---|---|
| ***Bisulcocypridea*? sp. 1** | São Francisco basin, Quiricó Formation (Do Carmo et al. 2004) | Barremian |
| ***Neuquenocypris* (*Protoneuquenocypris*) *antiqua* Musacchio & Simeoni 1991** | D-129 Formation, Chenques hill, Chubut Province (Musacchio & Simeoni 1991, Ballent et al. 2011)<br>Austral basin, Piedra Clavada Formation, Santa Cruz (Ballent et al. 2011)<br>São Francisco basin, Quiricó Formation (Leite et al. 2018) | Aptian<br>Lower-upper Albian<br>Valanginian |
| ***Darwinula* sp. 1** | Argentina, Chubut Group, Fortím hill Formation, Barcino hill Member (Musacchio & Chebli 1975)<br>São Francisco basin, Quiricó Formation (Do Carmo et al. 2004) | Lower Cretaceous (Aptian?)<br>Barremian |
| ***Darwinula* sp. 2** | São Francisco basin, Quiricó Formation (Do Carmo et al. 2004) | Barremian |
| ***Darwinula* sp. 3** | São Francisco basin, Quiricó Formation (Do Carmo et al. 2004) | Barremian |
| ***Penthesilenula martinsi* (Silva 1978) *emend.* Do Carmo et al. 2004** | Araripe basin, Santana Formation, Crato Member and base of the Ipubi Member (Silva 1978, Silva-Telles Jr. & Viana 1990, Colin & Dépêche 1997)<br>Potiguar basin, Alagamar Formation (Do Carmo et al. 2013)<br>São Francisco basin, Quiricó Formation (Leite et al. 2018) | Aptian<br>Medium to upper Aptian<br>Lower Cretaceous, Valanginian-Barremian |
| ***Penthesilenula pintoi* Leite et al. 2018** | São Francisco basin, Quiricó Formation (Leite et al. 2018) | Lower Cretaceous, Valanginian-Aptian |
| ***Alicenula longiformis* Leite et al. 2018** | São Francisco basin, Formação Quiricó (Leite et al. 2018) | Lower Cretaceous, Valanginian-Barremian? |
| ***Timiriasevia sanfranciscanensis Leite et al. 2018*** | São Francisco basin, Quiricó Formation (Leite et al. 2018) | Lower Cretaceous, Valanginian |
| ***Wolburgiopsis plastica* (Musacchio 1970)** | Argentina, Neuquén Province, La Amarga Formation (Musacchio 1970)<br>São Francisco basin, Quiricó Formation (Do Carmo et al. 2004) | Barremian<br>Barremian |
| ***Wolburgiopsis chinamuertensis* (Musacchio 1970)** | Argentina, Neuquén Province, La Amarga Formation, "Margas y Calizas" Member (Musacchio 1970)<br>São Francisco basin, Quiricó Formation (Do Carmo et al. 2004) | Barremian<br>Barremian |

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## Author contributions

Both authors of the present article did all field campaigns together, aiming the description of the stratotype section and hypostratotype section. The first author, Amanda Moreira Leite, was responsible for the organization and interpretation of data, lithostratigraphic log elaboration and writing the article. The second author, Dermeval A. Do Carmo, was responsible for orienting the interpretation of data and the writing of the article.