Journal of Sedimentary Environments
Published by Universidade do Estado do Rio de Janeiro
4 (1): 72-89. January-March, 2019
doi: 10.12957/jse.2019.39823

JSE
RESEARCH PAPER

Facies analysis applied to Irati Formation in the northern area of the Paraná Basin, Goiás State–A contribution for a depositional model

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Received on 2 December 2018
Received in revised form on 25 January 2019
Accepted on 27 January 2019

Editor: Maria Virginia Alves Martins, Universidade do Estado do Rio de Janeiro, Brazil

Citation:
Oishi, A.A., Pereira, E., Bastos, L.P.H., Fragoso, D.G.C., 2019. Facies analysis applied to Irati Formation in the northern area of the Paraná Basin, Goiás State–A contribution for a depositional model. Journal of Sedimentary Environments, 4 (1): 72-89.

Abstract

The Irati Formation (Lower Permian of Paraná Basin) is a lithostratigraphic unit characterized by the rhythmic alternation between carbonates, shales, and marls, interpreted as low energy deposits with eventual storm deposition. Despite many studies that were developed at Irati Formation in the south and southeast part of Brazil, a better comprehension of the geological processes that took place in the northern portion is still necessary. In this sense, we present a detailed sedimentological analysis coupled with organic carbon content for the Permian rocks of Paraná Basin at Goiás State. Based on sedimentological descriptions, six facies association, including low to high energy facies, were described and interpreted as deposits of an inner to outer ramp domains of a homoclinal ramp system. Our data also indicate a relationship between changes in facies association and organic carbon content variation.

Keywords: Paraná Basin. Irati Formation. Facies analysis. Facies association. Depositional system.

1. Introduction

The huge volume of scientific researches published about Irati Formation (Lower Permian of Paraná Basin) reflects the economic and academic interest in this unit. This fact is due it's evolutive complexity and the high organic carbon content related to the shales and marls characteristics of this formation (up to 30% of organic carbon; Pádula, 1968). Relevant studies have been made over the years to develop the geological knowledge about this unit, including Amaral (1967), Pádula (1968), Hachiro (1991 and 1996), Santos Neto (1993), Araújo (2001) and Alferes et al. (2011).

Despite all this effort, many issues remain open, since most of the researches are carried out in the South and Southeast Brazil region. In the northern portion of Paraná Basin, which covers the Central-Western region of Brazil, studies focusing on sedimentology, geochemistry, and stratigraphy are scarce. The work of Fairchild et al. (1985) was one of the pioneering papers in this area, identifying the occurrence of silicified stromatolites in Goiás and Mato Grosso states. The geological background of Irati Formation in the northern margin is based on previous works performed in this region, including researches about the fossiliferous content (Vieira et al., 1991; Sedor and Silva, 2004), palynological record (Souza et al., 1992; Preamor et al., 2006), the igneous rocks thermal effect (dos Anjos, 2003, 2008; Santos et al., 2009) and the potential for non-conventional energy source (Mabecua, 2018).

The aim of this study is to improve the understanding about the depositional context of the Irati Formation along the northern portion of Paraná Basin, a region that is rarely studied and presents a faciological compartmentalization relevant for the evolutive comprehension of this unit. Based on detailed sedimentological analysis of three localities of Goiás State (Fig. 1), we propose a paleoenvironmental model including the features observed in the study area. We also analyze the relationship between the organic matter content and the facies associations, through geochemical analysis.

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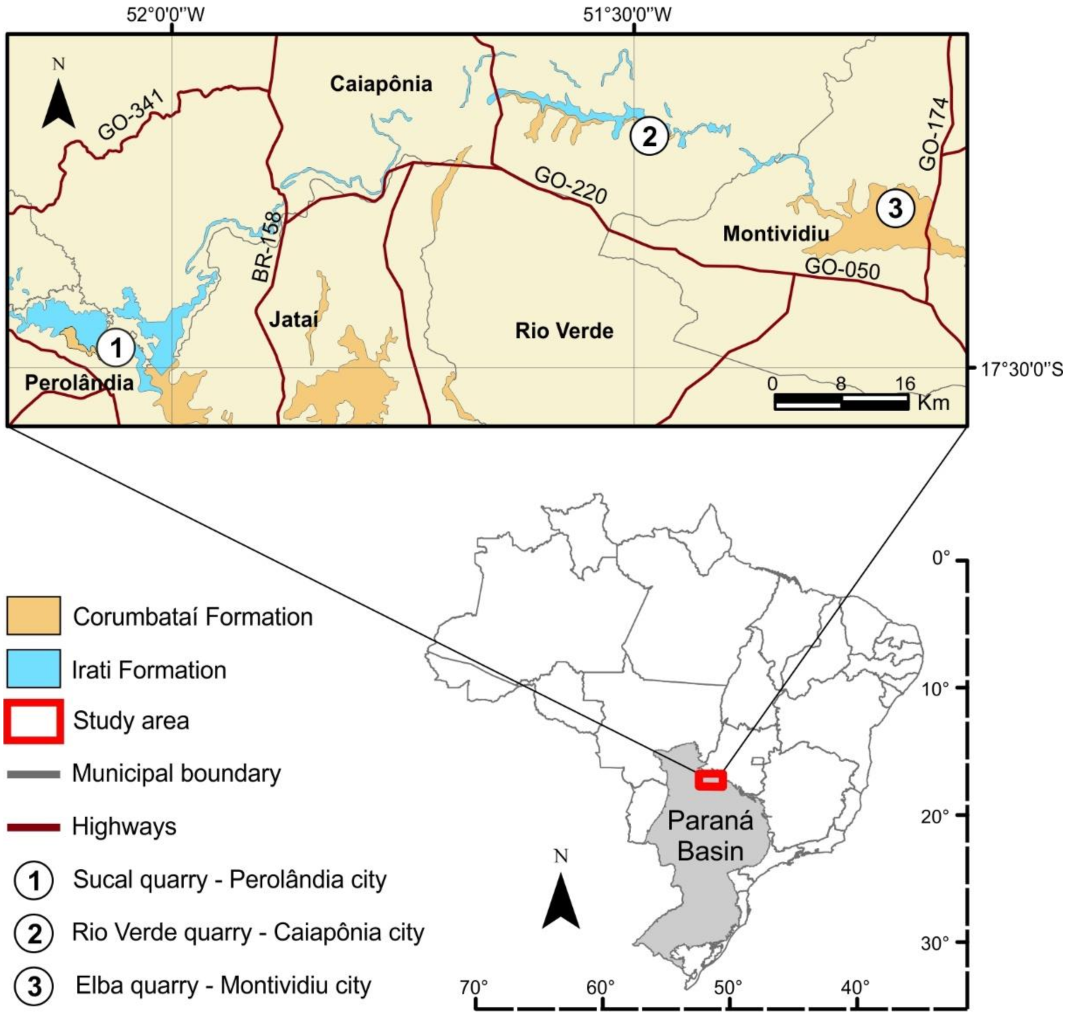

Fig. 1. Location map of the studied localities in Paraná Basin.

2. Geological setting

The Irati Formation is a lithostratigraphic unit of Paraná Basin, deposited during the Permian in an Artinskian age (278.4 ± 2.2 MA; Santos et al., 2006), and is subdivided into Taquaral (lower) and Assistência (upper) members (Barbosa and Gomes, 1958). This unit extends across an area of 1.000.000 km² and comprises the Goiás, Mato Grosso, São Paulo, Paraná, Santa Catarina and Rio Grande do Sul, Brazil states (Hachiro, 1991). Further, the Irati Formation is characterized by the occurrence of Mesosaurus fossils (Araújo, 1976; Oelofsen and Araújo, 1983, 1987; Oelofsen, 1987) besides the high organic matter content related to the deposits of this unit (Pádula, 1968; Araújo, 2001).

The stratigraphic record of Paraná Basin was subdivided into six second-order units (Milani, 1997; Milani et al., 2007). In this context, the Irati Formation is included to a regressive phase of the second-order Gondwana I sequence (Westphalian-Scythian) (Milani, 1997; Milani et al., 2007). Araújo (2001) recognized, in the Lower Permian interval of Paraná Basin, three transgressive-regressive fourth-order sequences. While in the northern portion, Oishi (2017) identified two fourth-order sequences correlated with sequences Irati 1 and 2 of Araújo (2001).

The Irati deposition was developed in a ramp basin physiography with northeast-southeast direction controlled by a mixed carbonatic-siliciclastic sedimentation in a restricted marine setting under hypersalinity conditions (Araújo, 2001; Milani et al., 2007). Araújo (2001) subdivided the depositional system into three facies association: inner ramp, middle ramp, and outer ramp. The inner ramp is characterized by low energy facies where exposition and aridity evidences are identified. Middle ramp consists of low energy deposits associated with tempestites. While pelagic deposition with siliciclastic predominance is characteristic of outer ramp record. Hachiro (1996) interpreted the evolution of the depositional system as an initial terrigenous platform with the predominance of siliciclastic facies in the southern region of the basin and carbonatic sedimentation in the northern area. Then, this system evolved to a semi-restricted carbonatic-siliciclastic platform with tidal plains associated to the basin borders.

In the northern region of Paraná Basin, the scope of this study, the Irati Formation is recognized in mining fronts and

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cores in Goias and Mato Grosso States (dos Anjos, 2003 and 2008; Santos et al., 2009; Mabecua, 2018). Taquaral Member has about 10 to 15 meters of thickness and has its lower contact with Aquidauana Formation (dos Anjos, 2008). While Assistência Member presents a maximum thickness of 30 meters and is characterized by the rhythmic intercalation between shales and dolostones, with the predominance of carbonatic facies at the base and siliciclastic facies at the top (dos Anjos, 2008; Mabecua, 2018). Dos Anjos (2008) identified a major faciological variety in Assistência Member when compared with the southern region of Brazil, including carbonatic dolomitic, lower pelitic, carbonatic oolitic, upper pelitic, stromatolitic and rose-colored carbonatic facies associations.

3. Materials and methods

Five detailed sedimentological sections (Fig. 2) of the Irati Formation were described in three localities of the northern region of Paraná Basin, in the Goiás State (Fig. 1). They include Sucal quarry (17°20'42"S; 52°3'38"W) in Perolândia city, Rio Verde quarry (17°14'57"S; 51°29'0"W) and Rio Verde core (FS-01) in Caiapônia city, besides Elba quarry (17°19'39"S; 51°13'2"W) and Elba core (FS-07) in Montividiu city. Facies descriptions were based on lithology, color, granulometry, texture, sedimentary structures, and bed geometry. Besides the sedimentological features, the insoluble residue was taken into account to differentiate shale and marl. For the compositional differentiation between limestone and dolostone, the Friedman (1959) staining method was used, with red-alizarin solution. The description of 43 thin sections of carbonatic rocks supported the analysis. Classification of carbonatic facies was based on the textural parameter, as suggested by Embry and Klovan (1971).

To explore the variation of the organic matter content inside the facies associations, total organic carbon (TOC) values were obtained based on measurements of 120 rock samples. The most preserved specimen of shales and marls were selected for analysis. The sampling spacing was of 10 centimeters along all the occurrence intervals of these rock types. For the quantification of organic matter content, an elemental analyzer LECO SC-632 (CO_2 infrared detector combustion system) was used following the HCl treatment of rock powders to remove possible inorganic carbon sources. Chemical procedures were performed in the Chemostratigraphy and Organic Geochemistry Laboratory of the Universidade do Estado do Rio de Janeiro (LGQM-UERJ).

4. Results and discussion

4.1 Facies analysis

The facies identified in the northern portion of Irati Formation were combined into six facies associations in a mixed carbonate-siliciclastic ramp depositional system. Facies descriptions and the interpretation of sedimentary processes are summarized in Table 1.

4.1.1 Facies Association 1 (FA1)–Tidal plain

Facies Association 1 is recognized in Elba (FS-07) and Rio Verde (FS-01) core sections (Fig. 2). Characterized by the alternation of low-energy facies, including massive mudstones (Mm) and thick shale (Sh) levels. Intraformational breccias also occur, composed by mudstone (B_{mud}) or peloidal packstone (B_{pack}) clasts.

Massive mudstones (Mm) consists of fine-grained limestones and may present an incipient horizontal lamination. Locally, calcite veins and stylolites are observed.

Thick shale (Sh) levels (11 to 166 cm) occur throughout the interval. They consist of laminated to fissile fine-grained siliciclastic rock with dark-gray to black color.

Intraformational breccias with mudstone clasts (B_{mud}) are limestones clast-supported by mudstone clasts (Fig. 3A). They are highly cemented by calcite spar (Fig. 3C) and present a syndepositional deformation associated. The bed thickness varies from 20 to 60 centimeters.

The breccia with peloidal packstone clasts (B_{pack}) consists of a limestone supported by peloidal packstone clasts (Fig. 3D). A centimeter-scale vuggy porosity occurs (Fig. 3B, 3D). Silicified levels are observed. The interparticle area is partially filled by spar calcite cement (Fig. 3D).

4.1.1.1 Interpretation of sedimentary processes

Carbonate mud can be generated by several processes, including abrasion, microorganisms accumulation and biogeochemical precipitation (Scholle and Ulmer Scholle, 2003; Terra et al., 2010). It can be transported by tidal currents or storms and deposited by suspension in low energy setting (Flügel, 2004). Siliciclastic fine sediments are are brought to the basin by drainages in wet periods and deposited in low energy environments.

Intraclastic breccias (B_{mud}, B_{pack}) indicates subaerial exposure in the intertidal to the supratidal environment, generating dissection cracks (Tucker and Wright, 1990; Scholle and Ulmer Scholle, 2003; Flügel, 2004). High carbonate concentration in this setting induces an early cementation (Wright, 1984). The vuggy porosity may be formed by dissolution of evaporitic levels, common in supratidal domains under arid conditions (Walker and James, 1992).

Facies Association 1 represents low energy facies with eventual subaerial exposure, interpreted as tidal plain deposits in the inner ramp, over the low tide level, including the intertidal and supratidal domains.

4.1.2 Facies association 2 (FA2)–Lagoon

Facies Association 2 is recognized in Elba core (FS-07) section (Fig. 2). Basically, formed by low energy facies, including laminated mudstones (Mh), crenulated laminites

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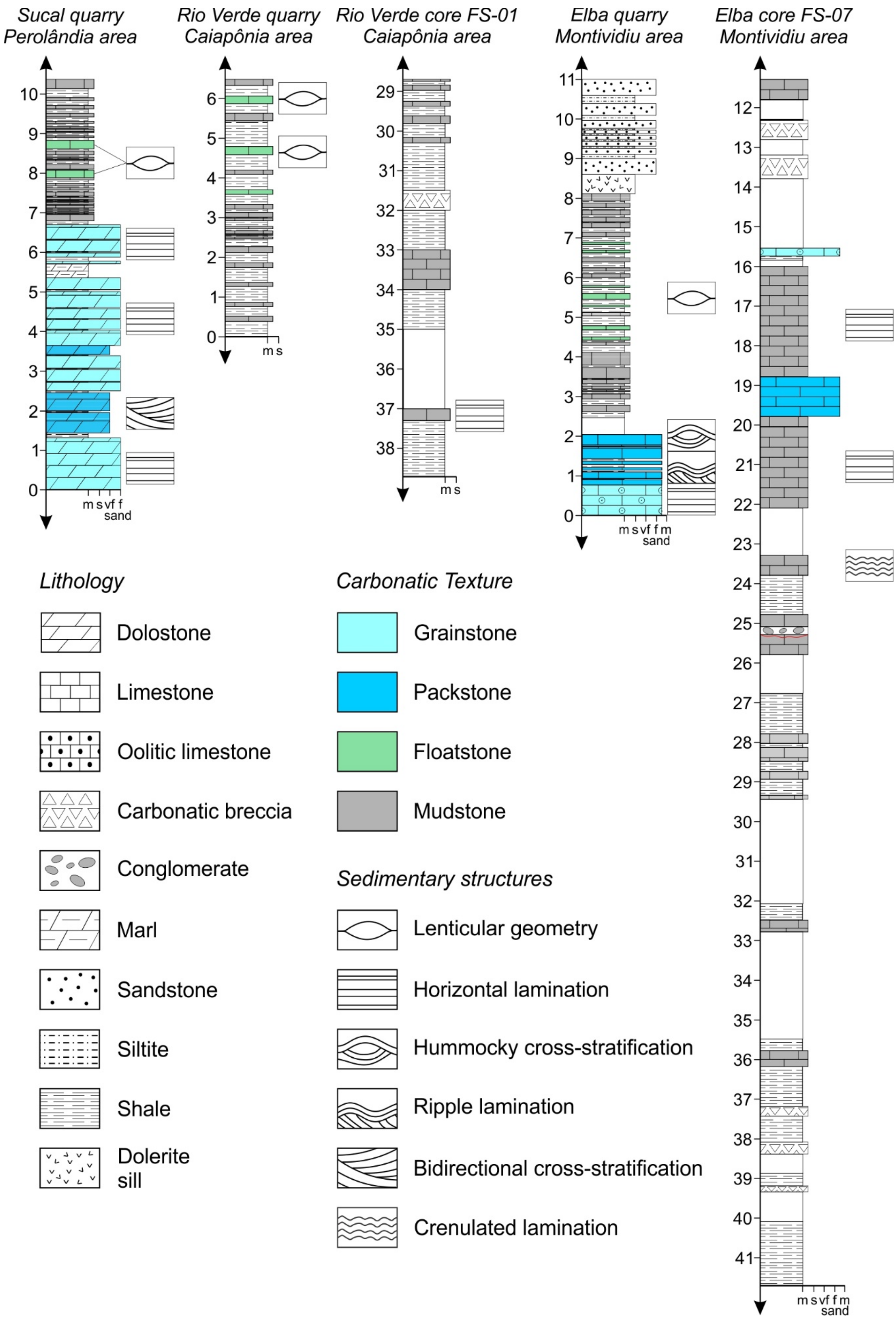

Fig. 2. Studied sedimentological sections.

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Tab. 1. Irati Formation facies description and interpretation of sedimentary processes.

Facies type	Code	Thickness	Color - texture - sedimentary structure - geometry - contacts	Carbonate grains	Sedimentary processes	Sedimentary environment
Intraformational breccia - mudstone clasts	B_{mud}	20-60 cm	Gray - breccia - massive	Mudstone intraclasts	Desiccation crack and penecontemporaneous deformation in a low energy environment	FA1
Intraformational breccia - packstone clasts	B_{pack}	45 cm	Beige/gray - breccia - massive	Peloidal packstone intraclasts	Subaerial exposition in arid, low energy environment	FA1
Massive mudstone	Mm	5-25 cm	Gray - mudstone - massive - tabular - sharp		Deposition from suspension in a low energy setting (proximal or distal)	FA1, FA2, FA6
Laminated mudstone	Mh	80-150 cm	Beige - mudstone - horizontal lamination	Organic matter filaments	Bottom remobilization by tidal flows and deposition from suspension in a proximal low energy setting	FA2
Crenulated laminite	Mcr	50 cm	Gray - mudstone - crenulated lamination		Deposition by bioinduced precipitation (microbialites)	FA2
Conglomerate	C_i	8 cm	Gray - floatstone - massive - erosive base	Mudstone intraclasts	Erosion and resedimentation–transgressive *lag*	FA2
Laminated peloidal grainstone	G_ph	7-60 cm	Beige - grainstone - horizontal lamination - tabular - sharp	Peloids and bivalve bioclasts	Tidal currents in a low to moderate energy setting	FA3
Cross-stratified peloidal packstone	P_pc	10-40 cm	Beige - packstone - cross-stratification - wavy - sharp	Peloids	Action of tidal currents in tidal channels	FA3
Laminated oolitc grainstone	$G_{ol}h$	7-22 cm	Beige - grainstone - low angle cross-stratification - tabular - sharp	Oolites, oncolites and bivalve bioclasts	High energy barriers (oolitic barries) deposited from traction flow in a high energy setting, within the winnowing zone. High concentration of calcium carbonate, inducing sin-depositional cementation	FA4, (FA2)
Ripple laminated oncolytic packstone	$P_{on}r$	7-30 cm	Beige - packstone - wave ripples - wavy - erosive	Oncolites and bivalve bioclasts	Storm-generated combined flow (oscillatory and unidirectional) in a high energy setting	FA5, (FA2)
HCS peloidal packstone	P_pHCS	30 cm	Gray - packstone - hummocky cross-stratification - concave - erosive base (sole marks and rip-up clasts)	Peloids, oncolites, bivalve bioclasts, and intraclasts	Storm-generated combined flow (oscilatory and unidirectional) in a high energy setting	FA5
Intraclastic floatstone	F_im	5-20 cm	Gray - floatstone - massive - lentiform - erosive	Intraclasts	Bottom remobilization and resedimentation by storm-generated turbidity flow in a moderate to high energy setting	FA6
Shale	Sh	2-160 cm	Dark gray/black - horizontal lamination - tabular - sharp - IR>35%		Deposition from suspension in a low energy setting (proximal or distal)	FA1, FA2, FA3, FA5, FA6
Marl	Ml	18 cm	Dark gray/black - horizontal lamination - tabular - sharp - IR<35%		Deposition from suspension in a low energy setting (proximal)	FA3

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(Mcr) and shales (Sh). High energy facies occur singly, represented by oncolytic packstone and oolitic grainstone. A conglomerate level (C_i) composes the base of this facies association.

The conglomerate (C_i) is matrix-supported and is formed by rounded centimeter-scale mudstone clasts. The matrix is micritic. The interval of this facies has 8 centimeters thick and is marked by an erosive base.

The laminated mudstones (Mh) consist of fine-grained limestones with elongated organic matter fragments marking the planar lamination (Fig. 4C, 4D). The bed thickness varies from 80 to 150 centimeters with millimeter-scale lamination.

Crenulated laminites (Mcr) are fine-grained limestones with crenulated lamination (Fig. 4E). The bed thickness is about 50 centimeters. Locally the trapping of intraclasts is observed associated with this lamination (Fig. 4F). Silicified nodules also occur.

The oolitic grainstone (Fig. 4A, 4B) is a well-sorted limestone composed basically by medium-grained oolites, oncolites and bivalves bioclasts (Fig. 4A, 4B). While the oncolytic packstone is a meter-thick layer of medium-grained limestone composed by oncolites. Bivalve bioclasts also occur.

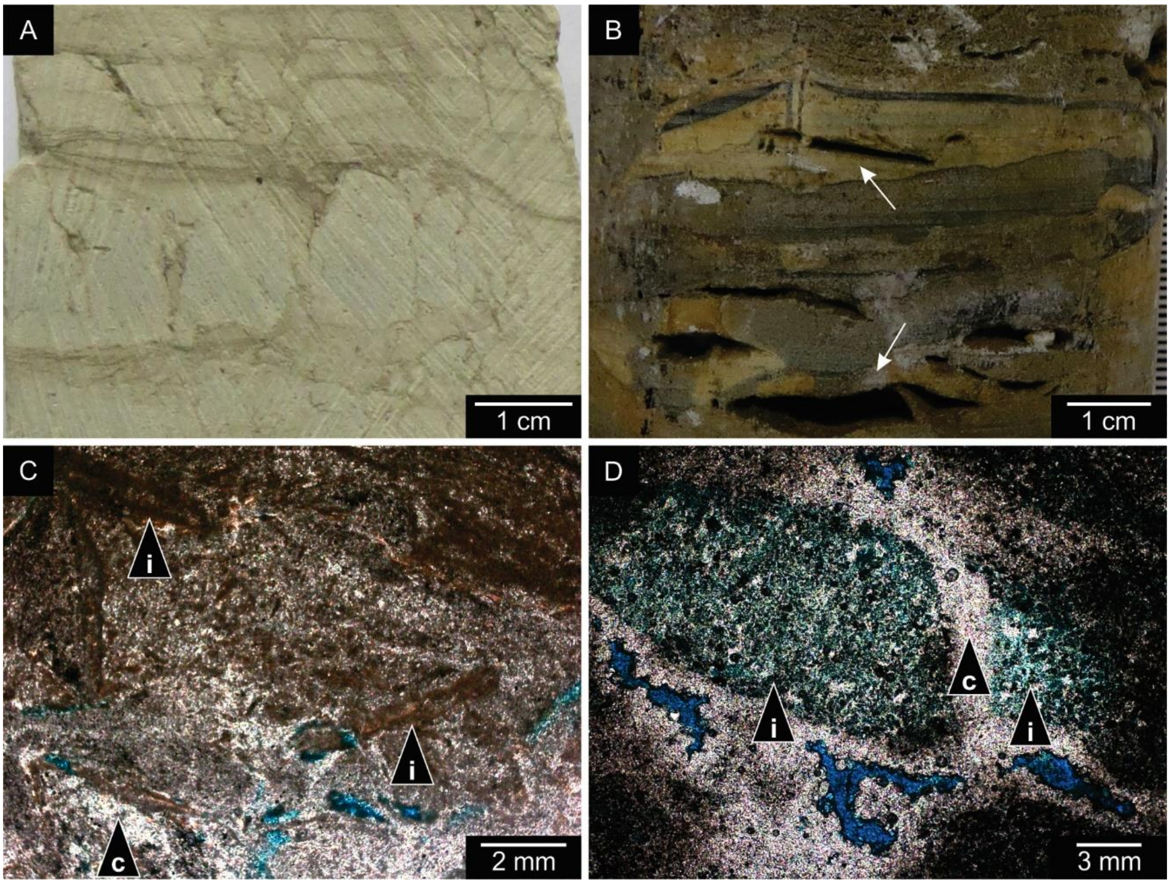

Fig. 3. A) Core sample of intraformational breccia with mudstone clasts (B_{mud}). B) Core sample of intraformational breccia with peloidal packstone clasts (B_{pack}), the vuggy porosity is indicated by arrows. C) Thin-section of intraformational breccia with mudstone clasts, notice the high cementation rate. D) Detail of peloidal packstone grains in the intraformational breccias, the porosity is marked in blue color. Legend: (i) intraclasts; (c) calcitic cement.

4.1.2.1 Interpretation of sedimentary processes

The lamination in the mudstone (Mh) is marked by compositional change (Suguio, 2003) and can be formed by the reworking of microbial mats, probably by tides and deposition in low energy setting. They also can represent microbial mats characteristic of intertidal to supratidal settings (Fairchild et al., 2015). More detailed investigations should be done to improve this interpretation. Lagoonal deposits generally are bioturbated (Davis Jr. and Dalrymple, 2012), then the preservation of the laminated structures is indicative of a lack of benthic fauna variety. The hypersalinity setting of the “Irati sea” can explain this low biodiversity, since most of the organisms are sensitive to extreme environmental conditions. Only a small number of organisms that are resistant and can proliferate in such adverse conditions. The crenulated laminites (Mcr) are interpreted as ancient microbial mats (Terra et al., 2010).

Although they can develop in many environments, during the Phanerozoic they generally represent paleoenvironmental stressful conditions (Fairchild et al., 2015), and they still colonize hypersalinity settings in the current environments (Iespa et al., 2012; Rocha and Borghi, 2017).

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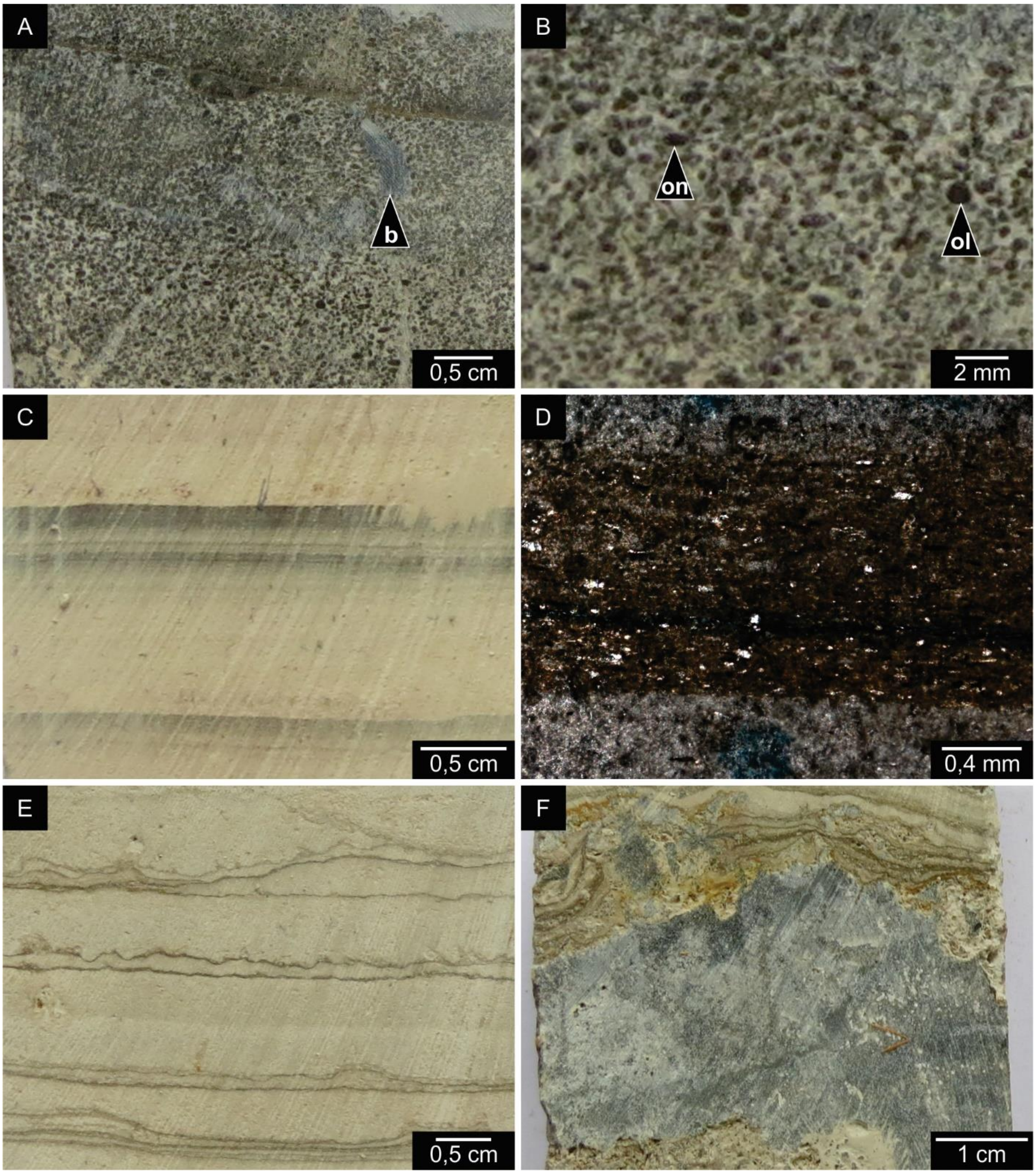

Fig. 4. A-B) Oolitic grainstone core sample: (b) Bivalve bioclasts, (on) oncolites, (ol) oolites. C) Laminated mudstone sample, the planar lamination is millimeter to centimeter scale. D) Laminated mudstone thin section with detail to the laminae, in brown, is observed the organic filaments. E) Crenulated lamination in the mudstone. F) Calcarenite trapping in the crenulated laminite.

High energy facies, including oolitic grainstone and oncolytic packstone, can occur in this low energy system during major storm events as washover deposits, characterized by calcarenite deposits inside the subtidal deposits (mudstones/wackestones) protected by barriers (Sedgwick and Davis Jr., 2003; Hudock et al., 2014). The occurrence of conglomerates (C_i) in shallow marine environments can indicate transgressive lags, generated by the erosion of subjacent deposits during the sea level rise (Flügel, 2004).

Facies Association 2 is interpreted as the inner ramp lagoonal deposits, protected by a barrier system and affected by major storms.

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4.1.3 Facies Association 3 (FA3)–Tidal channel

Facies Association 3 (Fig. 5A) is represented in Sucal quarry section (Fig. 2) and is characterized by laminated peloidal grainstones (G_ph) and cross-stratified peloidal packstones (P_pcs) interbedded with shales (Sh). A marl (Mr) interval occurs on the top of this succession.

Peloidal grainstones (G_ph) consists of a dolostone with fine sand size peloid grains (Fig. 5F) presenting a horizontal lamination developed in a tabular geometry with sharp contact (Fig. 5E). Bivalve bioclasts are also observed (Fig. 5F). Pyrite occurs locally. Cementation by calcite spar is well developed in this facies (Fig. 5F). A wackestone texture occurs subordinately, associated with levels holding organic matter fragments and microfractures.

Cross-stratified peloidal packstones (P_pcs) are formed by very fine sand size peloids, showing a wavy to lenticular geometry (Fig. 5C, 5D). The cross stratification has a bidirectional trend (Fig. 5C), with dip directions to north and south. The internal lamination is marked by a color alternation, characterizing more argillaceous levels inside the strata. Silicified levels are common. Subordinated wackestone texture also occurs. In the microscopic analysis, peloids grains are very obliterated, probably due to diagenetic processes, making the interpretation of grain size difficult. Disseminated organic matter filaments occur.

Mesosaurus articulated skeletons (Fig. 5B) and isolated bones and fragments (Class I and III - Soares, 2003) occur related to this facies association.

4.1.3.1 Interpretation of sedimentary processes

Tidal currents are characterized by reversal flow with dominant and subordinated current directions (Davis Jr. and Dalrymple, 2012). The movement of subaqueous dunes by these currents generates tidal bars (Reesink and Bridge, 2007) characterized by the bidirectional trend, as observed in the cross-stratified peloidal packstone (P_pcs). If fine-grained siliciclastic sediments are available in the setting, shales (Sh) can be deposited during the slack water periods between the tides, forming mud drapes (Longhitano et al., 2012). The horizontal lamination in peloidal grainstones (G_ph) can be formed by traction in low flow regime, indicating a low energy current (Suguio, 2003; Boggs Jr., 2009). Peloids, identified in this facies association, generally are formed and preserved in subtidal to intertidal domains (Scholle and Ulmer Scholle, 2003; Flügel, 2004). The deposition of marls (Ml) on the top of this succession indicates a restriction of siliciclastic sedimentation.

Dolomitization is a predominant process in present tidal domain environments (Tucker and Wright, 1990) and can be an indicator of similar processes in these paleoenvironments.

Based on the characteristics described above, Facies Association 3 is interpreted as tidal channel deposits in the subtidal inner ramp domain.

4.1.4 Facies Association 4 (FA4)–Oolitic barriers

Facies Association 4 (Fig. 6) is represented in Elba quarry section (Fig. 2). Characterized by a high energy succession of laminated oolitic grainstones ($G_{ol}h$).

Laminated oolitic grainstones ($G_{ol}h$) consists of fine to medium sand size laminated (Fig. 6A, 6B) limestones composed by tabular centimeter-scale beds decreasing in thickness towards the top, with low-angle cross-stratification (Fig. 6A). Silicified levels occur near the bed's contact.

Well selected grains, including oolites, oncolites, and bivalves bioclasts support the rock framework (Fig. 6C, 6D, 6E, 6F). Elongated particles are oriented according to the lamination. Moldic porosity is highly developed in this facies. Interparticle porosity also occurs. Fringe calcite spar is cemented in the grain borders (Fig. 6F). Granular cementation is also common (Fig. 6F). Locally is observed a micritization process inside the grain molds.

4.1.4.1 Interpretation of sedimentary processes

Oolites generally are formed in high-energy shallow environments, saturated/supersaturated in calcium carbonate (Tucker and Wright, 1990; Scholle and Ulmer-Scholle, 2003; Flügel, 2004; Schlager, 2005). The planar lamination can be generated by high-velocity hydrodynamics traction processes in the upper flow regime (Tucker, 2001; Suguio, 2003; Boggs Jr., 2009) and is also an indicator of high-energy setting. The low angle cross-stratification may indicate the association between the body geometry and the depositional substrate.

The oolitic grainstones ($G_{ol}h$) are interpreted as high-energy barriers or oolitic shoals. The constant reworking by waves wash the fine-sized sediments forming the grainstone texture. This sandy bodies represented by the oolitic grainstones ($G_{ol}h$) have a barrier behavior due to the high sediment productivity and the syn-depositional lithification (Schlager, 2005). According to Burchette and Wright (1992), these barrier deposits generally are sandy and have a laminar feature due to their fast migration.

This kind of structures is common in ramp physiography (Tucker and Dias-Brito, 2017). In stressful environments, like the “Irati sea”, they can develop better since reef-building organisms are sensitive to extreme conditions and they compete for energy with the oolitic barriers (Scholle and Ulmer-Scholle, 2003).

Facies Association 4 is interpreted as oolitic barriers deposits in a high energy inner ramp.

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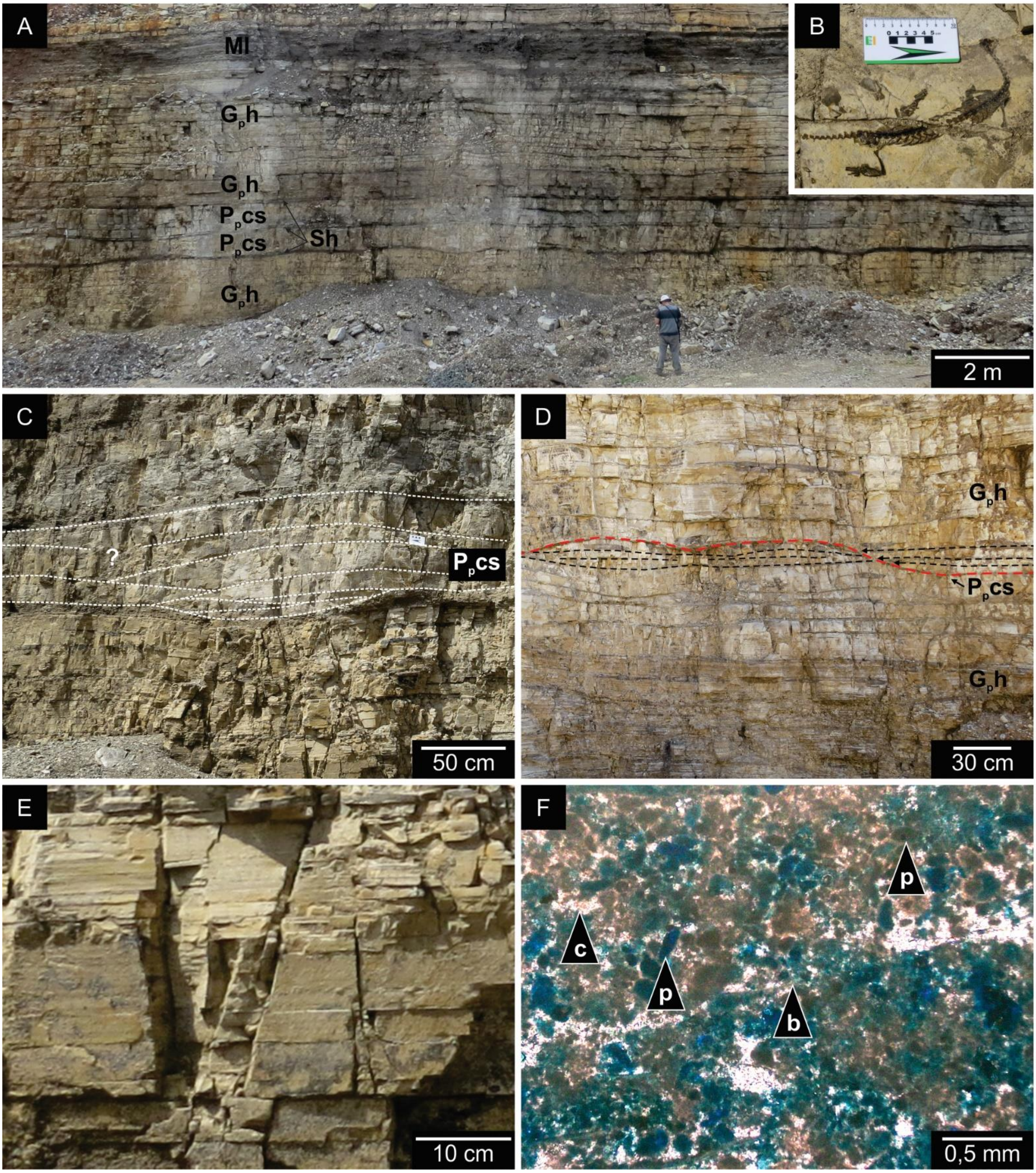

Fig. 5. A) Facies Association 3 in Sucal quarry section. B) Mesosaurus articulated fossil observed in the field. C) Cross-stratified peloidal packstone (P_pcs) interpreted with the apparent bidirectional trend. D) Multi-channel feature. Arrows mark the channel filling. E) Horizontal lamination in laminated peloidal grainstone (G_ph). F) Thin-section of laminated peloidal grainstone. Legend: (c) cement; (p) peloids; (b) bivalve bioclasts.

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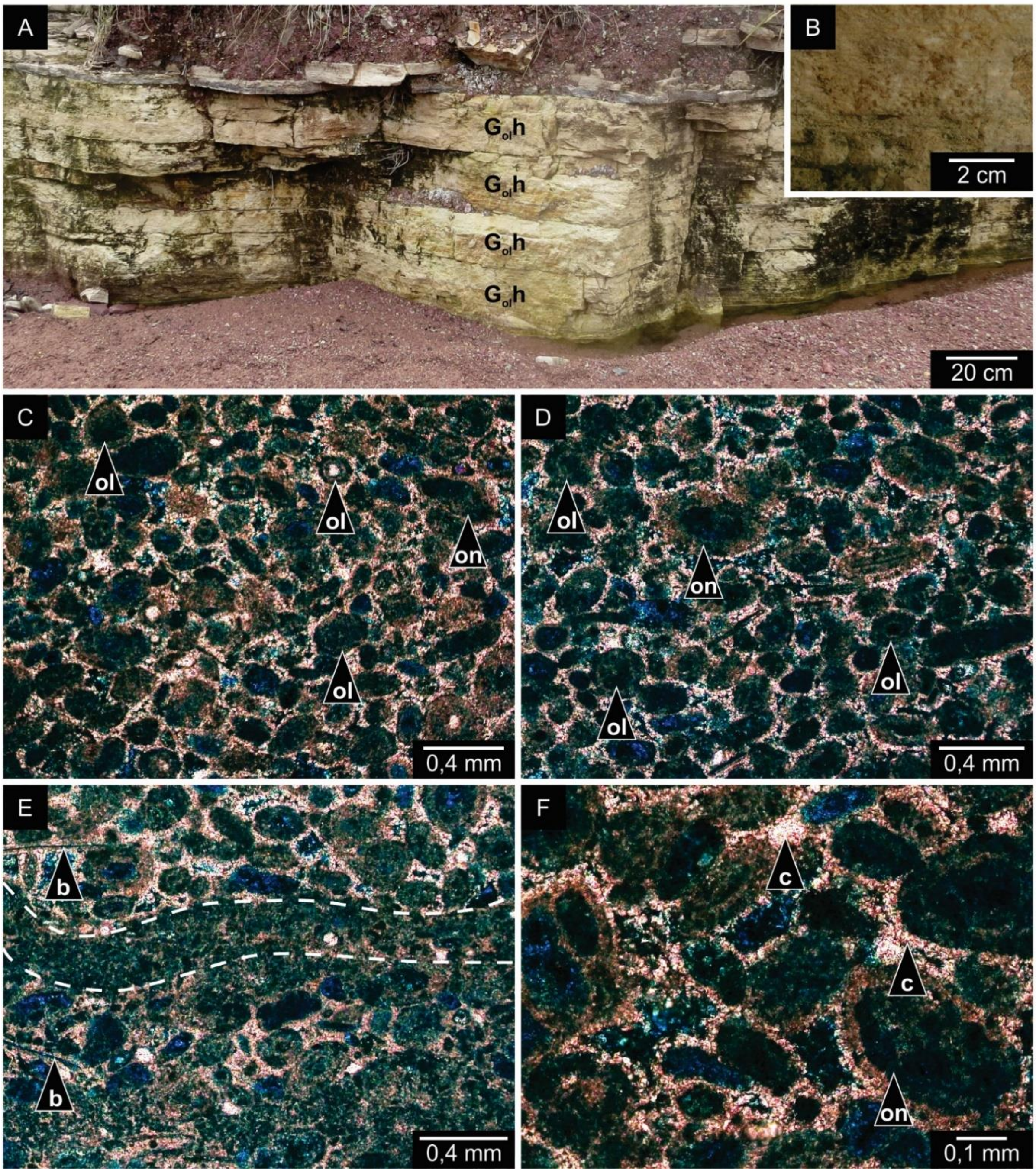

Fig. 6. A) Field exposure of Facies Association 4–oolitic barrier. B) Detail of horizontal lamination in the sample. C-F) Thin sections of laminated oolitic grainstone ($G_{ol}h$), notice the moldic porosity and fringe cementation. The lamination in microscopic view is marked by wackestone levels and indicated by traces in Figure 6E. Legend: (c) cement; (b) bivalve bioclasts; (on) oncolites; (ol) oolites.

4.1.5 Facies Association 5 (FA5)–Proximal middle ramp

Facies Association 5 (Fig. 7) is represented in Elba quarry section (Fig. 2). Composed basically by a succession of ripple laminated oncolytic packstones ($P_{on}r$) interbedded with shales (Sh). A single bed of hummocky cross-stratified (HCS) peloidal packstone (P_pHCS) occurs at the top of this section.

Ripple laminated oncolytic packstones ($P_{on}r$) consist of fine to medium sand size limestones with wavy to wave-ripple laminations (Fig. 7C), which occurs at the top of low-angle cross-stratified intervals. A centimeter-scale lamination with erosive base and normal graded is observed in detailed analysis (Fig. 7D). Wackestone texture occurs subordinated. The carbonatic grains are represented by oncolites and bivalve bioclasts presenting a preferential orientation (Fig. 7F). Intraclasts occur locally. Moldic porosity is well developed. The recrystallization of the micritic matrix forming sparry calcite crystals is common. The bed thickness varies from 7 and 30 centimeters.

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HCS peloidal packstone (P_pHCS) consists of a limestone with erosive base marked by sole marks and rip up clasts (Fig. 7B), large symmetrical concave features occur over the bed top (Fig. 7A). Despite this facies being characterized by a normal graded structure, incipient planar lamination is also observed. Carbonatic grains include peloids and intraclasts (Fig. 7E). Bivalves bioclasts and oncolites also occur. Other diagnostic features are absent, probably due to diagenetic effects. The bed thickness is about 30 cm. Silicified nodules are locally observed.

4.1.5.1 Interpretation of sedimentary processes

Low-angle laminations topped by wave-ripples ($P_{on}r$) represent high energy facies deposited by a combined flow (Aigner, 1985) characteristic of proximal tempestites in a transition zone (Reineck et al., 1967, 1968).

According to Aigner (1985), the barometric effect related to the wind action in the coastal region can generate an offshore bottom flow, named gradient current. This current can be characterized by a turbiditic flow (Myrow and Southard, 1996), that associated to the oscillatory wave effect generates a combined flow. The features observed in the HCS peloidal packstones (P_pHCS) are characteristic of this storm-induced flow. The incipient horizontal lamination, normal-graded feature, rip up clasts and sole marks are structures indicative of deposition by density currents in laminar flow conditions (Mutti et al., 1999; Tucker and Dias-Brito, 2017). The symmetrical concave geometry at the top represents the predominance of oscillatory turbiditic flow (Tucker and Wright, 1990). Although some internal characteristics are obliterated, probably by diagenesis, the characteristics analyzed in this facies are interpreted as hummocky deposits. Araújo (2001) also identified this kind of structures as hummocky. Shales (Sh) can be transported by tidal or storm currents to distal areas and deposited during fair-weather periods. The preservation rate of shales is low because of the bottom reworking during storms.

According to the Aigner (1985) model of storms proximity trends, this facies association cannot be preserved in shallow areas due to the constant reworking, neither in deep water where the waves do not affect the bottom. In this context, Facies Association 5 is interpreted as storm deposits generated in a proximal middle ramp, between the fair-weather base level and storm base level.

4.1.6 Facies Association 6 (FA6)–Distal middle ramp to proximal outer ramp

Facies Association 6 (Fig. 8A) is represented in Sucal, Rio Verde and Elba quarries (Fig. 2). This succession is characterized by a rhythmic alternation between massive mudstones (Mm) and shales (Sh). Floatstone (F_i) levels occur isolated.

Massive mudstones (Mm) consist of grey fine-grained limestones, composed by micrite matrix. The mudstone beds are centimeter-scale and present a tabular geometry with sharp contact. The general structure is massive, but incipient planar lamination occurs locally. Silicified lens or levels are observed.

The floatstones (F_i) are fine-grained limestones with disseminated shale elongated intraclasts. The intraclasts can present a preferential orientation (Fig. 8C). The beds of this facies have a discontinuous lenticular geometry (Fig. 8B). The general aspect is massive (Fig. 8B).

Shales (Sh) occur alternated with these facies and consist of black to dark-gray fine-grained siliciclastic rock with fissile to a laminar structure. In field exposure, is possible to observe a sharp contact with the massive mudstones (Mm) and a general deformation (Fig. 8B) of the layers around the floatstones (Fi) beds.

4.1.6.1 Interpretation of sedimentary processes

Both shales (Sh) and massive mudstones (Mm) are deposited from suspended material in low energy settings. In Irati Formation, the general increase of siliciclastic facies is indicative of distality (Hachiro, 1991; Araújo, 2001).

The density currents generated in storm events can be characterized as turbiditic flow (Myrow and Southard, 1996) that can carry the sediments for long distances towards the basin (Mutti et al., 1999). The reworking of the depositional bottom by storm waves generates intraclasts (Aigner, 1985), which are then incorporated into the flow (Mutti et al., 1999). These deposits are represented in the sedimentary record as the floatstones (F_i).

The increase of shales associated with mudstones and distal storm deposits (floatstones) indicates a deposition in deeper waters in relation to the previous facies associations. Despite the pelagic sedimentation, characteristic of distal settings (outer ramp to basin), the evidence of storms influence limits the sedimentation to a more proximal domain inside this context.

Facies Association 6 is interpreted as deposits of a distal middle ramp to proximal outer ramp.

4.2 Organic matter content

Based on the TOC data acquired from shales (Sh) and marls (Ml), in samples collected throughout the sections, a comparison between facies association and total organic matter content was made in order to understand the relationship of organic matter content and environmental conditions (Fig. 9).

Facies association 1 and 2 have TOC values varying between 0.5% and 2%. The analyzed maximum TOC values are related to Facies Association 3, reaching 6% at the base and decreasing towards the top of this interval, where a marl level occurs.

Due to the constant reworking during the deposition of Facies Association 4, the fine-grained siliciclastic facies were not preserved.

Journal of Sedimentary Environments
Published by Universidade do Estado do Rio de Janeiro
4 (1): 72-89. January-March, 2019
doi: 10.12957/jse.2019.39823

Facies Association 5 and 6, representing open sea environments, have TOC values ranging from about 1% to 3%.

The low TOC contents observed in Rio Verde quarry are probably a consequence of organic matter degradation by the thermal effect of a huge dolerite sill in the area. This interference of the heat in organic matter measurements is also seen in other regions of Goiás State (Santos et al., 2009).

4.3 Sedimentary environment

Facies associations analyzed in the present work are characteristic of a mixed carbonatic-siliciclastic sedimentation developed in a ramp physiography in a marine context.

The carbonate ramp is a gently sloping surface subdivided into four domains according to the waves influence: inner ramp, middle ramp, outer ramp and basin (Tucker and Wright, 1990; Burchette and Wright, 1992; Flügel, 2004). Barrier-lagoon complexes associated with tidal features are common in carbonate ramp proximal settings (Tucker and Dias-Brito, 2017).

Facies Association 1 to 4, including tidal plain (FA1), lagoon (FA2), tidal channel (FA3) and oolitic barriers (FA4), are subdomains of an inner ramp, developed above the fair-weather base level. They include low to high energy settings.

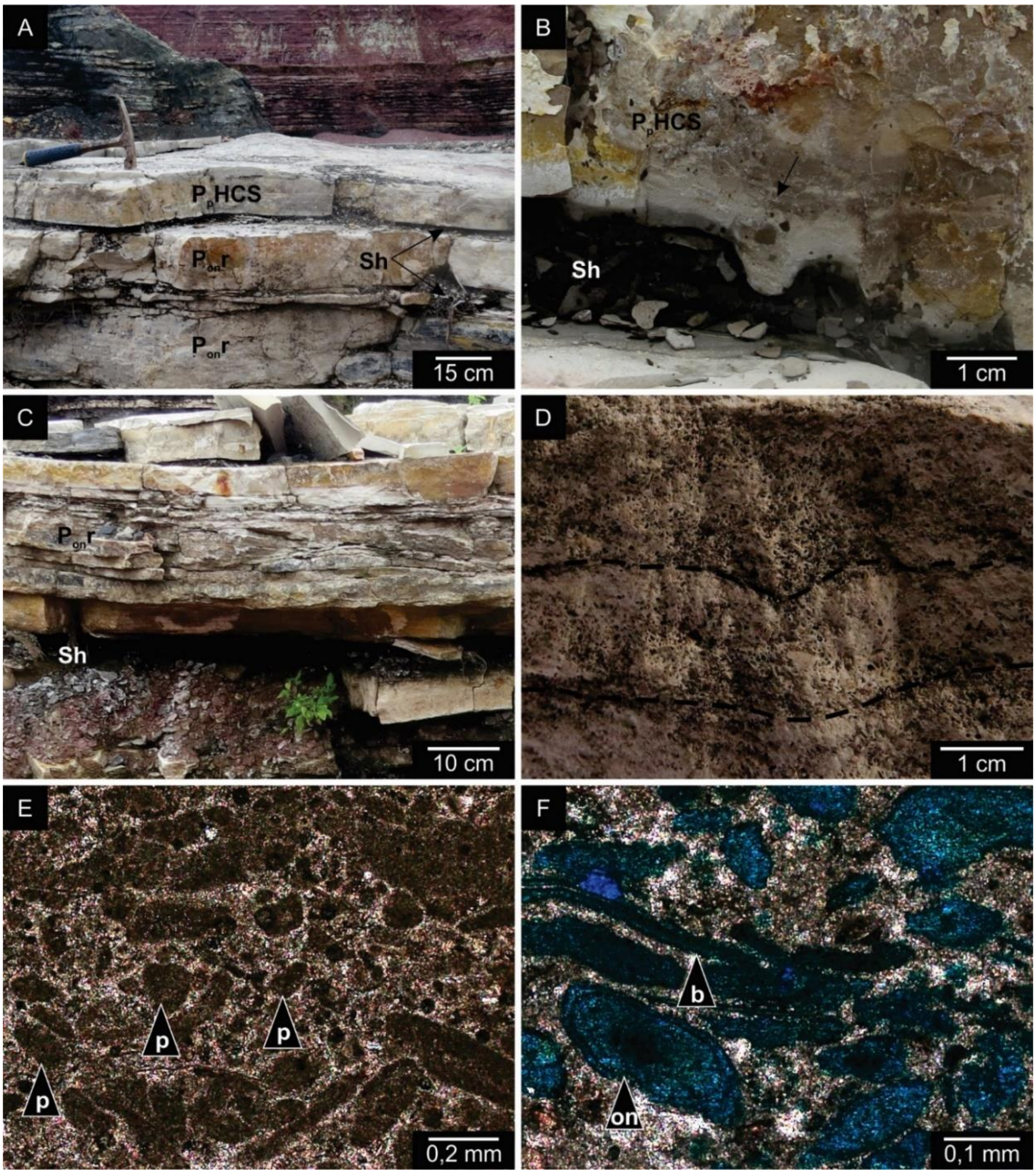

Fig. 7. A) Field exposure of Facies Association 5 focusing the HCS peloidal packstone (P_pHCS). Note the concave feature in the top. B) The erosive base of HCS peloidal packstone with sole marks and rip-up clasts. C) Wave ripple structures of ripple laminated oncolytic packstone (P_{on}r). D) Lamination with erosive base and normal graded feature. Oncolytic molds are visible. E-F) Thin sections of HCS peloidal packstone and ripple laminated oncolytic packstone, respectively. Legend: (p) peloids; (on) oncolites; (b) bivalve bioclasts.

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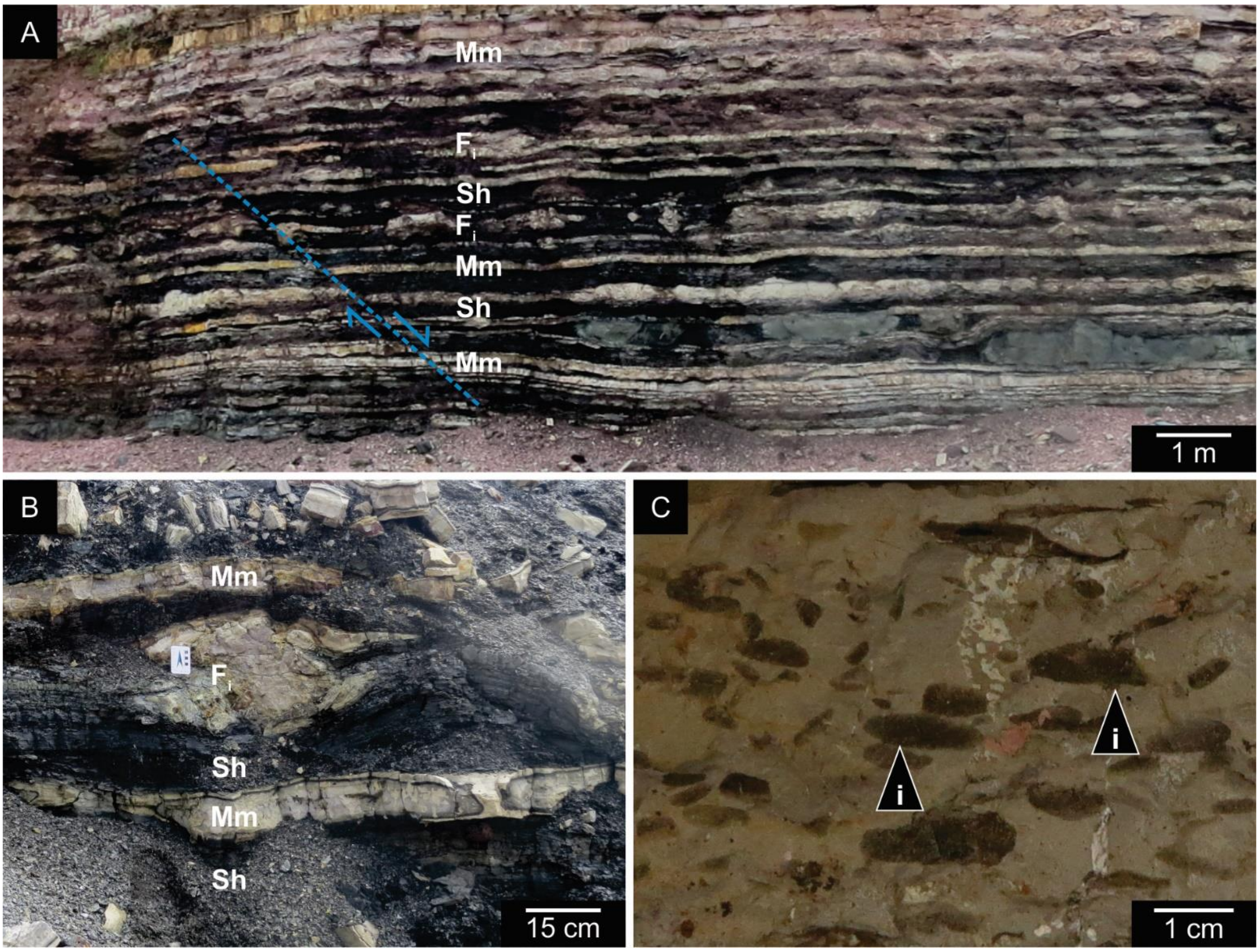

Fig. 8. A) Field exposure of Facies Association 6, showing the rhythmic pattern of the carbonatic-siliciclastic facies. B) Floatstone lenticular geometry in comparison with the mudstone tabular one. The lamination of shales (Sh) is deformed. C) Shale elongated intraclasts in the intraclastic floatstone (F_i).

The barriers can act as attenuators of the energy of the waves, allowing the formation of protected subenvironments (i.e. lagoon), where it has the predominance of low energy sedimentation.

Tides control the deposition in tidal channels (FA3) and tidal plain (FA1).

The middle ramp is characterized by the action of storm waves (Burchette and Wright, 1992) represented by the proximal tempestites of Facies Association 5. Storm-generated features are identified in Facies Association 6 combined with the pelagic sedimentation, reflecting a middle to outer ramp domain.

The analyzed main features are summarized in the depositional system model developed for the study region (Fig. 10).

5. Stratigraphy of the study area in the context of Paraná Basin

Based on the stacking pattern of the facies and facies association inside the depositional system coupled with the geochemical organic parameters in the stratigraphic record, it was possible to subdivide the stratigraphic framework into two fourth-order sequences, correlated with the Sequences Irati 2 and 3 of Araújo (2001) (Oishi, 2017). The predominance of carbonatic deposition in the Facies Association 3 and 4, described in this study, is related to the regressive phase of Sequence Irati 2 of Araújo (2001), while the siliciclastic domain of Facies Association 6 represents the transgressive period of Sequence Irati 3 of Araújo (2001).

Journal of Sedimentary Environments
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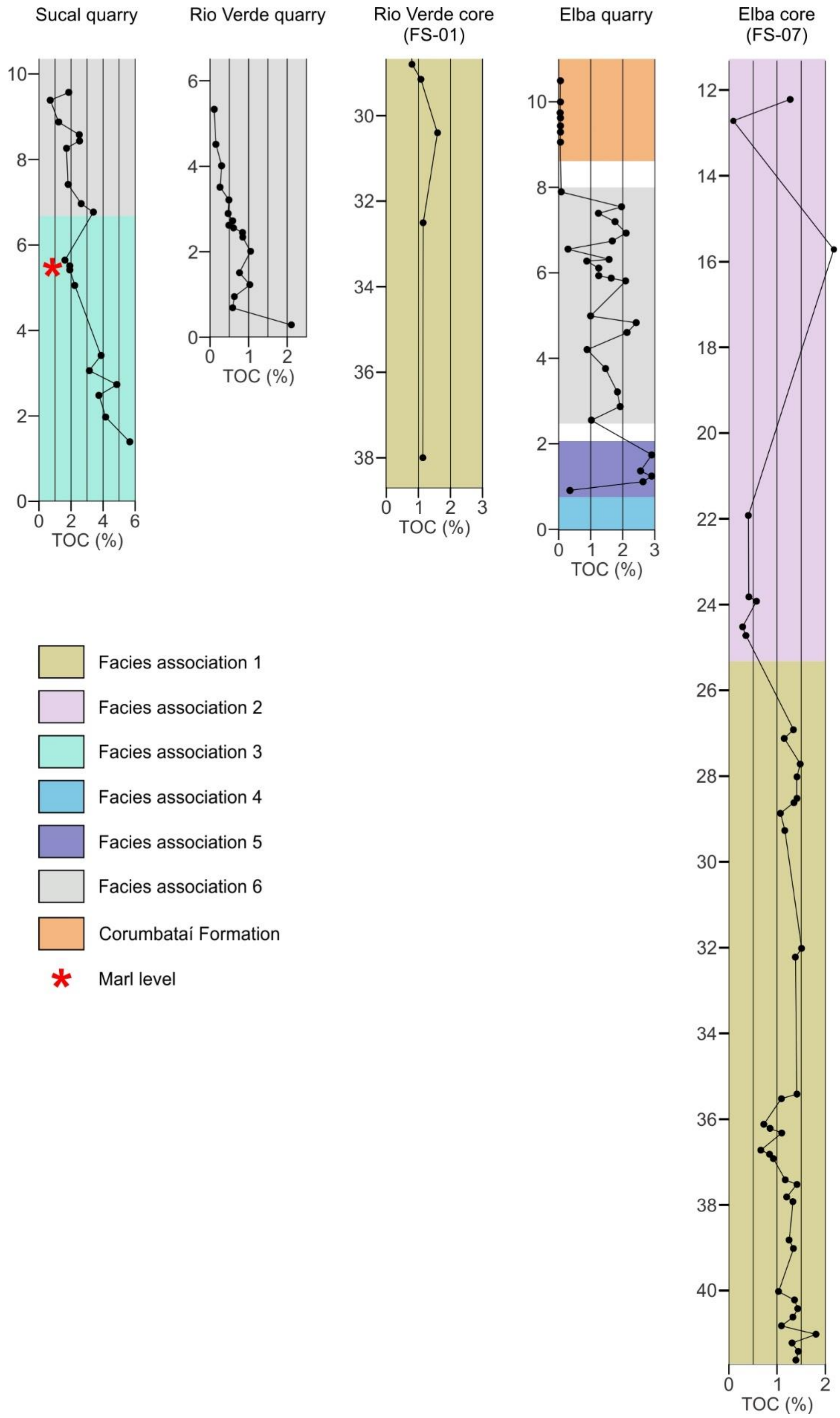

Fig. 9. Total organic carbon values for the studied sections subdivided into facies association.

Journal of Sedimentary Environments
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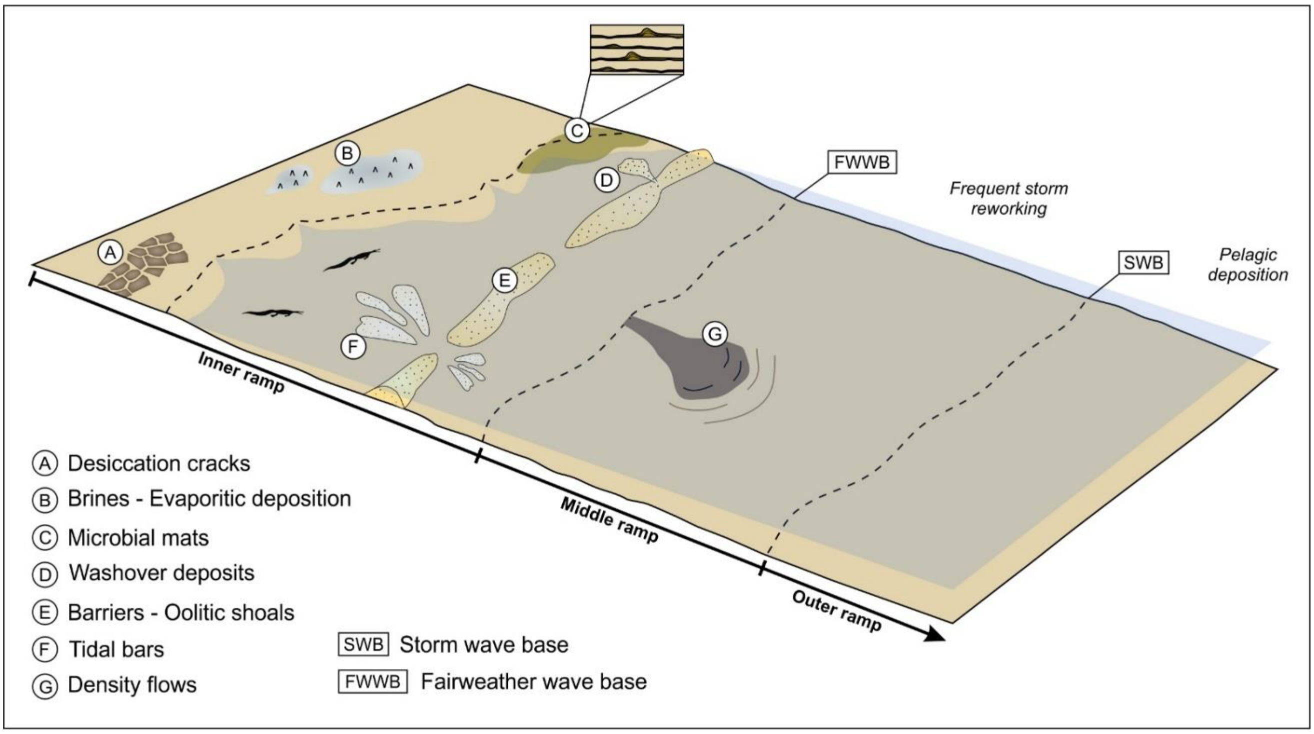

Fig. 10. Irati Formation depositional system model for the northern area of Paraná Basin. The main features analyzed in this study are represented in this illustration

Facies Association 1, defined in this study, is identified in the lower portion of Assistência Member in all the northeast and northern border of the basin. It is characterized by the events of subaerial exposure and the evidence of evaporitic precipitation as discussed by Hachiro (1991, 1996) and Araújo (2001).

According to Hachiro (1996) the dolomitic interval, recognized in Facies Association 3, is continuous from São Paulo to Mato Grosso states. However, in São Paulo (northeast border) there is evidence of subaerial exposure, indicating a more proximal position.

The attenuation of waves due the morphology of the basin justifies the predominance of low energy deposition in the inner ramp facies association of Araújo (2001), based mainly on the northeast portion of the Paraná Basin.

In the northern portion of the basin, in Goiás State, high energy facies associated to the inner ramp domain were identified. Due to the border position and a different physiographic compartmentalization, the oolitic barriers (Facies Association 4) worked as energy attenuators. This feature allowed the formation of a low energy subenvironment in the inner ramp.

Some morphological features of Mesosaurus fossils indicate an adaptation to aquatic and to semi-aquatic habits (Oelofsen and Araújo, 1983). In the northern portion of Paraná Basin, *Brazilosaurus sanpauloensis* Shikama and Ozaki 1966 were identified (Araújo-Barberena et al., 2002) representing a shallow water environment, since this species does not present significant adaptation to the deep aquatic setting and is associated to shallow deposits (Oleofsen and Araújo, 1983). Specific studies should be done to analyse the species of the Mesosaurus fossil reported in this study in order to characterize better its depositional environment.

Mabecua (2018) found TOC values varying between 0.04% and 3.52% for this region. The higher TOC contents identified in this work, reaching about 6%, was recognized in Sucal quarry section (Fig. 2). The organic geochemical analysis of this section, based on the hydrogen and oxygen indexes of the kerogen, indicates an association to organic matter of type I and II in this interval (Oishi, 2017). Type I is mainly composed of algae, especially from lacustrine source, while type II is mostly related to a marine planktonic source (Tissot and Welte, 1984).

The high TOC values, associated with the Facies Association 3–a tidal channel, was developed in shallow environmental conditions. In this context, the preservation of organic matter can be related to the environmental lagoonal restriction associated with high productivity, probably of microbial origin but not provided only from algal sources which is a common feature in Irati Formation.

Specific studies of the organic matter content and quality should be done in this region to improve the understanding of the paleoenvironmental context.

The barrier-lagoon complex has been studied for oil system analysis (Burchette et al., 1990) where can be

Journal of Sedimentary Environments
Published by Universidade do Estado do Rio de Janeiro
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found sediments with high organic content. Therefore, lagoons and oolitic barriers can be considered good reservoirs when second porosity is developed.

More detailed studies should be done in the northern region of Paraná Basin in order to characterize a potential analog.

6. Conclusion

The detailed facies analysis presented in this work contributes to the knowledge of the depositional context of Irati Formation in the northern region of Paraná Basin, where this kind of research is scarce. The identification of 14 sedimentary facies shows the faciological complexity inherent to this paleomargin. They were subdivided into 6 facies associations, including tidal plain, lagoon, tidal channel, oolitic barriers and middle to outer ramp deposits.

The Irati Formation in the northern area of Paraná Basin is interpreted as a homoclinal ramp developed in a marine environment, characterized by the coexistence of low to high energy subenvironments. The record of high energy features in Irati Formation is scarce in literature, thus we included it in this depositional model to improve the understanding of the paleoenvironmental context of this unit. This marginal high energy interval can be correlated with the distal low energy record of Brazil south region.

The organic matter content varies around 1% to 3% in this region, except in the Sucal quarry where the TOC values reached 6%. This high preservation rate is related to the environmental restriction of Facies Association 3.

The barrier-lagoon association identified in the Elba area can be studied as an oil system analog. Further research should be done to characterize this interval.

Acknowledgment

The authors are grateful for the support provided by the coordinators and technicians of the Chemostratigraphy and Organic Geochemistry Laboratory of the Universidade do Estado do Rio de Janeiro (LGQM-UERJ) and all the technical and physical infrastructure offered by the Universidade do Estado do Rio de Janeiro. The authors also would like to thank the Financiadora de Estudos e Projetos - FINEP (Rede Gasbras) and Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro–FAPERJ for the financial support that enables the progress of this research.

References

Aigner, T., 1985. Storm Depositional Systems: Dynamic Stratigraphy in Modern and Ancient Shallow Marine Sequences. *In*: Friedman, G.M. et al. (Eds.), Lecture Notes in the Earth Sciences 3. Springer Verlag Berlin Heildelberg. Printed in Germany, pp. 1–174.

Alferes, C., Rodrigues, R., Pereira, E., 2011. Geoquímica orgânica aplicada à Formação Irati, na área de São Mateus do Sul (PR), Brasil. Geochimica Brasilienses 25 (1), 47-54. http://dx.doi.org/10.21715/gb.v25i1.331

Amaral, S.E., 1967. Contribuição ao conhecimento geológico, petrográfico e sedimentológico da Formação Irati, no Estado de São Paulo. Habilitation Thesis, Universidade de São Paulo, São Paulo, 136 p.

Araújo, D.C., 1976. Taxonomia e Relações dos Proganosauria da Bacia do Paraná. Anais da Academia Brasileira de Ciências 48 (1), 91–116.

Araújo, L.M., 2001. Análise da expressão estratigráfica dos parâmetros de geoquímica orgânica e inorgânica nas Sequências deposicionais Irati. PhD Thesis, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, 307 p.

Araújo-Barberena, D.C., Lacerda Filho, J.V., Timm, L.L., 2002. Mesossauro da Serra do Caiapó (Montividiu), GO: Um vertebrado fóssil típico do Paleozóico Superior, importante na história da Deriva Continental. *In*: Chobbenhaus, C., Campos, D.A., Queiroz, E.T., Winge, M., Berbert-Born, M. (Eds.), Sítios Geológicos e Paleontológicos do Brasil, DNPM/CPRM - Comissão Brasileira de Sítios Geológicos e Paleobiológicos (SIGEP), Brasília, pp. 81–85.

Barbosa, O., Gomes, F.A., 1958. Pesquisa de petróleo na Bacia do Rio Corumbataí, Estado de São Paulo. Boletim da Divisão de Geologia e Mineralogia–DNPM, n.º 171, 40 p.

Boggs Jr., S., 2009. Petrology of Sedimentary Rocks. 2 ed. Cambrige Universisty Press, New York, 720 p. https://doi.org/10.1017/CBO9780511626487

Burchette, T.P., Wright, V.P., 1992. Carbonate ramp depositional systems. Sedimentary Geology 79, 3–57. https://doi.org/10.1016/0037-0738(92)90003-A

Burchette, T.P., Wright, V.P., Faulkner, T.J., 1990. Oolitic sand body depositional models and geometries, Mississipian of southwest Britain: implications for petroleum exploration in carbonate ramp settings. Sedimentary Geology 68, 87–115.

Davis Jr., R.A., Dalrymple, R.W., 2012. Principles of Tidal Sedimentology. Springer, Berlin, 621 p.

Dos Anjos, C.W.D., 2003. A influência térmica de intrusões ígneas sobre pelitos e rochas carbonáticas da Formação Irati, em Goiás. MsD thesis, Universidade de Brasília, Brasília, Brazil, 101 p.

Dos Anjos, C.W.D., 2008. Fatores condicionantes na gênese dos argilominerais dos folhelhos negros e pelitos associados da Formação Irati no norte da Bacia do Paraná. PhD thesis, Instituto de Geociências, Universidade de Brasília, Brasília, Brazil, 101 p.

Embry, A F., Klovan, J.E., 1971. A Late Devonian reef tract on northeastern Banks Island, Northwest Territories. Bulletin of Canadian Petroleum Geology 19, 730–781.

Fairchild, T.R., Coimbra, A.M., Boggiani, P.C., 1985. Ocorrência de estromatólitos silicificados na Formação Irati (Permiano) na borda setentrional da Bacia do Paraná (MT, GO). Anais da Academia Brasileira de Ciências, 57 (1), 117 p.

Fairchild, T.R., Rosemarie, R., Dimas, D.B., 2015. Microbialitos do Brasil do Pré-Cambriano ao Recente: um atlas. UNESpetro, Rio Claro, 392 p.

Journal of Sedimentary Environments
Published by Universidade do Estado do Rio de Janeiro
4 (1): 72-89. January-March, 2019
doi: 10.12957/jse.2019.39823

RESEARCH PAPER

Flügel, E., 2004. Microfacies of Carbonate Rocks: Analysis, Interpretation and Application. Springer, Berlin, 976 p. https://doi.org/10.1017/S0016756806221940

Friedman, G.M., 1959. Identification of carbonate minerals by staining methods. Journal of Sedimentary Petrology 29, 87–97.

Hachiro, J., 1991. Litotipos, associações faciológicas sistemas deposicionais da Formação Irati no estado de São Paulo. MsD thesis, Universidade de São Paulo, São Paulo, 175 p.

Hachiro, J., 1996. O subgrupo Irati (Neopermiano) da Bacia do Paraná.PhD Thesis, Universidade de São Paulo, São Paulo, Brazil, 196 p.

Hudock, J. W., Flaig, P.P., Wood, L., 2014. Washover fans: A modern geomorphologic analysis and proposed classification scheme to improve reservoir models. Journal of Sedimentary Research 84 (10), 854–865. https://doi.org/10.2110/jsr.2014.64

Iespa, A.A.C., Iespa, C.M.D., Borghi, L., 2012. Evolução paleoambiental da Lagoa Salgada utilizando microbialitos, com ênfase em microfácies carbonáticas. Geociências 31 (3), 371–380.

Longhitano, S.G., Mellere, D., Steel, R.J., Ainsworth, B., 2012. Tidal depositional systems in the rock record: A review and new insights. Sedimentary Geology 279, 2–22. https://doi.org/10.1016/j.sedgeo.2012.03.024

Mabecua, F.J., 2018. Avaliação do potencial para *Shale Gas* e Shale Oil dos folhelhos negros da Formação Irati na região de Goiás e Mato Grosso, Centro-Oeste do Brasil. MsD thesis, Universidade de São Paulo, São Paulo, Brazil, 180 p.

Milani, E.J., 1977. Evolução tectono-estratigráfica da Bacia do Paraná e seu relacionamento com a geodinâmica Fanerozóica do Gondwana sul-ocidental. PhD Thesis, Universidade Federal do Rio do Grande do Sul, Porto Alegre, Brazil, 283 p.

Milani, E.J., Melo, J.H.G., Souza, P.A., Fernandes, L.A., França, A.B., 2007. Bacia do Paraná. Boletim de Geociências da PETROBRÁS, 15(2), 265–287.

Mutti, E., Tinterri, R., Remacha, E., Mavilla, N., Angella, S., Fava, L., 1999. An Introduction to the analysis of ancient turbidite basins from an outcrop perspective. A.A.P.G. Continuing Education Course Note Series 39, Oklahoma, 61 p.

Myrow, P.M., Southard, J.B., 1996. Tempestite deposition. Journal of Sedimentary Research 66(5), 875–887. https://doi.org/10.1306/D426842D-2B26-11D7-8648000102C1865D

Oelofsen, B., 1987. The biostratigraphy and fossils of the Whitehill and Irati shale formations of the Karoo and Paraná Basins. *In*: McKenzie, G D. (Ed.), Gondwana Six: stratigraphy, sedimentology, and paleontology, Washington D.C., pp. 131-138.

Oelofsen, B., Araújo, D.C., 1987. *Mesosaurus tenuidens* and *Stereosternum tumidium* from the Permian Gondwana of both Southern Africa and South America. South African Journal of Sciences 83(6), 370–372.

Oelofsen, B, Araújo, D.C., 1983. Paleoecological implications of the distribution of Mesosaurid reptiles in the Permian Irati Sea (Paraná Basin), South America. Revista Brasileira de Geociências 13(1), 1–6.

Oishi, A.A., 2017. Análise estratigráfica de alta resolução aplicada à Formação Irati, Permiano da Bacia do Paraná, no estado de Goiás. Undergraduate thesis, Faculdade de Geologia, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil, 91 p.

Pádula, V.T., 1968. Estudos geológicos da Formação Irati, sul do Brasil. Boletim Técnico da PETROBRAS 11(3), 407–430.

Preamor, E., Fischer T.V., de Souza, P.A., 2006. Palinologia da Formação Irati (Permiano Inferior da Bacia do Paraná), em Montividiu, Goiás, Brasil. Revista del Museo Argentino de Ciencias Naturales 8 (2), 221–230.

Reesink, A.J.H., Bridge, J.S., 2007. Influence of superimposed bedforms and flow unsteadiness on formation of cross strata in dunes and unit bars. Sedimentary Geology 202, 281–296. https://doi.org/10.1016/j.sedgeo.2007.02.005

Reineck, H. E., Dörjes, J., Gadow, S., Hertweck, G., 1968. Sedimentologie, Faunenzonierung und Faziesabfolge vor der Ostküste der inneren Deutschen Bucht. Senckenbergiana Lethaea 49, 261–309.

Reineck, H.-E., Gutmann, W.F., Hertweck, G., 1967. Das Schlickgebiet südlich Helgoland als Beispiel rezenter Schelfablagerungen. Senckenbergiana Lethaea 48, 219–275.

Rocha, L., Borghi, L., 2017. Análise de microbiofácies das esteiras microbianas na Lagoa Pitanguinha (Região dos Lagos, RJ, Brasil). Anuário do Instituto de Geociências–UFRJ, 40, 191–205. https://doi.org/10.11137/2017_1_191_205

Santos Neto, E.V., 1993. Caracterização geoquímica e paleoambiente deposicional da sequência carbonato-pelítica superior do Membro Assistência, Formação Irati no estado de São Paulo, Bacia do Paraná. MsD thesis, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil, 103 p.

Santos, R.V., Dantas, E.L., Oliveira, C.G., Alvarenga, C.J.S., dos Anjos, C.W.D., Guimarães, E.M., Oliveira, F.B., 2009. Geochemical and thermal effects of a basic sill on black shales and limestones of the Permian Irati Formation. Journal of South America Earth Sciences 28, 14–24. https://doi.org/10.1016/j.jsames.2008.12.002

Santos, R.V., Souza, P.A., Alvarenga, J.S., Dantas, E.L., Pimentel, M.M., Oliveira, C.G., Araújo, L.M., 2006. Shrimp U-Pb zircon dating and palynology of bentonitic layers from the Permian Irati Formation, Paraná Basin, Brazil. Gondwana Research 9, 456–463. https://doi.org/10.1016/j.gr.2005.12.001

Schlager, W., 2005. Carbonate sedimentology and sequence stratigraphy. Society for Sedimentary Geology, Oklahoma, 200 p. https://doi.org/10.2110/csp.05.08

Scholle, P.A., Ulmer-Scholle, D.S., 2003. Petrography of Carbonate Rocks: Grains, texture, porosity, diagenesis, AAPG Memoir 77. American Association of Petroleum Geologists, Oklahoma, 474 p.

Sedgwick, P. E., Davis Jr., R. A., 2003. Stratigraphy of washover deposits in Florida: Implication for recognition in the stratigraphic record. Marine Geology 200 (1-4), 31–48. https://doi.org/10.1016/S0025-3227(03)00163-4

Sedor, F.A., Silva, R.C., 2004. Primeiro registro de pegadas de Mesosauridae (Aminota, Sauropsida) na Formação Irati (Permiano Superior da Bacia do Paraná) no estado de Goiás, Brasil. Revista Brasileira de Paleontologia 7(2), 269–274. https://doi.org/10.4072/rbp.2004.2.21

Soares, M.B., 2003. A taphonomic model for the Mesosauridae assemblage of the Irati Formation (Paraná Basin, Brazil). Geologica Acta 1(4), 349–361.

Journal of Sedimentary Environments
Published by Universidade do Estado do Rio de Janeiro
4 (1): 72-89. January-March, 2019
doi: 10.12957/jse.2019.39823

Souza, P.A., Santos, P.R. dos, Lima, M.R. de, 1992. Contribuição à palinologia da Formação Irati no Estado de Goiás. 37º Congresso Brasileiro de Geologia (São Paulo). Boletim de Resumos, pp. 485–486.

Suguio, K., 2003. Geologia Sedimentar. Blucher Ltda, São Paulo, 416 p.

Terra, G.J.S., Spadini, A.R., França, A.B., Sombra, C.L., Zambonato, E.E., Juschaks, L.C.S., Arienti, L.M., Erthal, M.M., Blauth, M., Franco, M.P., Matsuda, N.S., da Silva, N.G.C., Moretti Junior, P.A., D'Avila, R.S.F., de Souza, R.S., Tonietto, S.N., dos Anjos, S.M.C., Campinho, V.S., Winter, W.R., 2010. Classificação de rochas carbonáticas aplicável às bacias sedimentares brasileiras. Boletim de Geociências da Petrobrás 18, 9–29.

Tissot, B.P., Welte, D.H., 1984. Petroleum formation and occurrence. Springer-Verlag, Berlin, 699 p.

Tucker, M.E., Dias-Brito, D., 2017. Petrologia sedimentar carbonática: iniciação com base no registro geológico do Brasil. UNESpetro, São Paulo, 208 p.

Tucker, M., 2001. Sedimentary Petrology: An Introduction to the Origin of Sedimentary Rocks. Blackwell Science, Oxford, 272 p.

Tucker, M.E., Wright, V.P., 1990. Carbonate sedimentology. Blackwell Science, Oxford, 482 p. http://dx.doi.org/10.1002/9781444314175

Vieira, P.C., Mezzalira, S., Ferreira, F.J.F., 1991. Mesossaurídeo (*Stereosternun tumidum*) e Crustáceo (*Liocaris huenei*) no Membro Assistência da Formação Irati (P) nos municípios de Jataí e Montividiu, Estado de Goiás. Revista Brasileira de Geociências 21 (3), 224–235. https://doi.org/10.25249/0375-7536.1991224235

Walker, R.G., James, N.P., 1992. Facies Models: Response to sea level changes. Geological Association of Canada, Ontario, 409 p.

Wright, V.P., 1984. Peritidal carbonate facies models: A review. Geological Journal 19, 309–325. https://doi.org/10.1002/gj.3350190402