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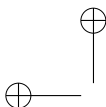
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Marine influence in the Barreiras Formation, State of Alagoas, northeastern Brazil

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ABSTRACT

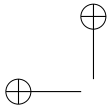
Tidal processes were important for deposition of the Barreiras Formation located in northern Brazil, while correlatable deposits in northeastern Brazil have been traditionally related to continental environments. Facies analysis in southern Alagoas revealed that the Barreiras Formation consists of cross-stratified conglomerates and sandstones (facies Sx and Cgx), compound cross-stratified sandstones (facies Cx), and heterolithic beddings (facies H). A significant portion of these deposits occurs within channel morphologies displaying fining and thinning upward successions. An abundance of sedimentary features is comparable to those from the northern Brazilian counterpart. These include: tidal bundles; herringbone cross-stratification; heterolithic beddings with sandstone and mudstone beds in sharp contact; and ichnofossils mostly consisting of *Ophiomorpha nodosa*, *Skolithos* and *Planolites*. Altogether, these features point to a marginal marine depositional setting dominated by tidal processes, which are related to an estuarine system, an interpretation also provided for the Barreiras Formation in northern Brazil. The widespread occurrence of deposits with unambiguous evidence of tidal processes in the Barreiras Formation of northern Brazil, and now in the State of Alagoas, leads to argue that the early/middle Miocene worldwide marine transgression might have left a much more widespread sedimentary record along the Brazilian coast than currently regarded.

Key words: Miocene, marine transgression, tidal currents, sedimentary structures, northeastern Brazil.

INTRODUCTION

The early/middle Miocene is well known as a period for a worldwide transgression due to a sea level rise. The Barreiras Formation exposed in the States of Pará and Maranhão, northern Brazil, displays an excellent record of this event. In these areas, the Barreiras Formation consists of lower/middle Miocene deposits (Arai et al. 1988, 1994, Arai 1997, Leite 2004, Leite et al. 1997a, b, F.P.R. Leite, unpublished data) that are dominated by an abundance of sedimentary and ichno-

(Rossetti and Truckenbrodt 1989, Rossetti et al. 1999, Rossetti 2000, 2001, 2006a, b, Netto and Rossetti 2004, Rossetti and Santos Jr. 2004). Despite its occurrence in several geological contexts, including different sedimentary basins and platformal areas, the Barreiras Formation shows both faciological and stratigraphic patterns easily reproduced throughout northern Brazil (e.g., Rossetti 2004). Its sedimentary nature is compatible with deposition in a variety of environments, from incised valley estuaries developed under the con-



The Barreiras Formation is widespread along the Brazilian coast, occurring throughout the Northeast and Southeast Regions up to the State of Rio de Janeiro, being particularly well represented along numerous but discontinuous coastal cliffs. In contrast to more inland areas, the sedimentary structures have a higher preservation potential along these cliffs. This is due to the combined effect of wind, waves and tidal currents, which preclude vegetation growth and promote frequent sediment fall. The constant renewal of cliff face provides fresh exposures, which favor sedimentological investigation aiming the reconstruction of sedimentary processes.

There are several works dealing with the Barreiras Formation in northeastern Brazil (e.g., Mabesoone et al. 1972, Bigarella 1975, Suguio et al. 1986, Alheiros et al. 1988, Alheiros and Lima Filho 1991, Vilas Boas et al. 2001, C.C.U. Lima, unpublished data, Lima and Vilas Boas 2004, Araújo et al. 2006, Furrier et al. 2006, Lima et al. 2006). However, in contrast to northern Brazilian areas, these studies have recognized only continental, mostly fluvial and lacustrine deposits within this unit. If these interpretations are correct, then an intriguing question to be answered is why the Miocene transgression is well recorded only in northern Brazil, and not along its northeastern coast, where these deposits are well represented?

Perhaps, there is no need for one to seek answers for this question, as the recognition of marine features might have been under looked. Some authors (Suguio and Nogueira 1999, Arai 2006, Rossetti 2006b) commented that a marine transgression should be also reported in northeastern Brazil, though no data have been provided to sustain this claim. In addition, Salim et al. (1975) and Menezes et al. (1998) documented marine influenced deposits in the Barreiras Formation exposed in the eastern coast of the State of Rio Grande do Norte. Although to the present authors knowledge this represents the only report of this kind, it motivated to look for further evidence that could provide conclusive data for supporting a marine influence in northeastern Brazil.

might be combined with the study of ichnofossils, in order to interpret the sedimentary processes.

This work aims to present the results of a sedimentological investigation undertaken along several cliffs distributed along the southern coast of the State of Alagoas (Fig. 1), where an abundance of sedimentary features in the Barreiras Formation could be characterized in great detail. Based on the data provided herein, it is possible to assure that tidal currents were responsible for the deposition of this unit.

GEOLOGICAL CONTEXT

The study area is located in the Sergipe-Alagoas Basin. This consists of a NNE/SSW elongated asymmetric structure formed along the Brazilian coast during the South Atlantic rifting, initiated in the late Jurassic to early Cretaceous. This basin reaches up to 13,000 km² onland and nearly 35,000 km² offshore. It separates from the Pernambuco-Paraíba Basin by the Maragoji High to the north, and from the Estância Platform and Jacuípe Basin by the Vaza-Barris Fault Zone to the south. The basin is internally sub-divided in two sub-basins by the Jaboatã-Penedo High (Aquino and Lana 1990).

The sedimentary fill of the Sergipe-Alagoas Basin consists of four megasequences representative of the pre-rift, rift, transitional and post-rift phases (Mohriak et al. 1997), with a depocenter located in the Mosqueiro Low, south of Aracajú (SE). The pre-rift megasequence has Mesozoic and Paleozoic ages, and is represented by the Baixo São Francisco Group, which includes the Estância Formation (Precambrian), glacial deposits of the Batinga Formation (Carboniferous), sabkha deposits of the Aracaré Formation (Permian), and fluvio-lacustrine deposits of the Candeeiros, Bananeiras and Serriaria formations (late Jurassic/early Cretaceous). The main rifting took place from Neocomian to Barremian, being represented by the Rio Pitanga, Penedo and Barra de Itiúba formations. The transitional megasequence, formed from Barremian to Aptian, consists of the Poço, Coqueiro Seco and Maceió formations, as well as transitional deposits of the Muribeca Formation (F.J. Feijó, unpublished data). The post-rift megasequence, formed

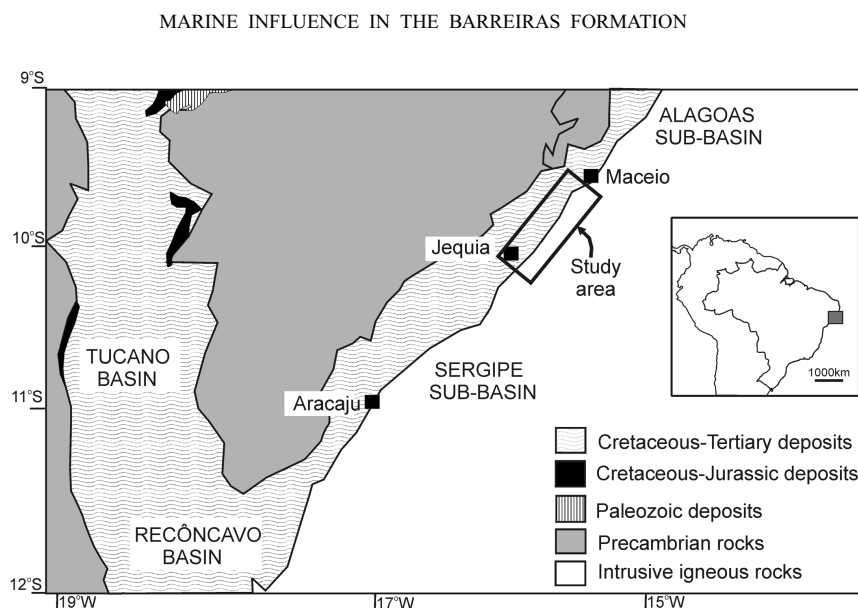


Fig. 1 – Location map of the study area containing exposures of the Barreiras Formation in the southern coast of the State of Alagoas, between the city of Maceió and the locality of Jequiá.

sion, which is represented by the Calumbi, Mosqueiro and Marituba formations.

The Barreiras Formation overlies the above described megasequences in the onland portion of the Sergipe-Alagoas Basin. This unit has not been dated in this study area yet, but studies of correlatable deposits in northern Brazil have indicated a Miocene age for these deposits (Arai et al. 1988, 1994, Arai 1997, F.P.R. Leite, unpublished data, Leite et al. 1997a, b).

THE BARREIRAS FORMATION IN THE STUDY AREA

Deposits of the Barreiras Formation studied herein occur in several cliffs along the southern coast of the State of Alagoas, particularly between the city of Maceió and the locality of Jequiá (Fig. 1). Cliffs are up to 25 m high, several hundreds of meters long (Fig. 2A), and display strata with a variety of well preserved sedimentary features that can be used for the reconstruction of the depositional processes. Likewise many other places in northeastern Brazil, the Barreiras Formation in this study area consists of quartzose conglomerates, fine to coarse-grained sandstones, heterolithic deposits

In general, the base of the Barreiras Formation is not exposed in the study area, but in a few places marked by a discontinuity surface mantled by a cemented conglomeratic lag (Fig. 2B) displaying abundant root marks (Fig. 2C). In addition, this unit is distinguished from overlying sandy deposits, which herein designated informally as the Post-Barreiras sediments (*sense* Rossetti 2001), with basis on the presence of an unconformity. This unconformity, observed on remote sensing image (Fig. 2D), is similar to the unconformity that occurs at the top of the Barreiras Formation in northern Brazil. Likewise that region, the unconformity atop the Barreiras Formation in the study area is characterized by an irregular, erosional discontinuity surface. This is marked by a lateritic paleosol profile including a ferruginous concretionary horizon up to 3 m thick (Fig. 2D-E). The thickness of the Barreiras Formation below this unconformity averages 15 m along the studied cliffs.

Analysis of the studied exposures reveals the abundance of strata with channel morphologies characterized by shallow (3 to 5 m thick), but laterally

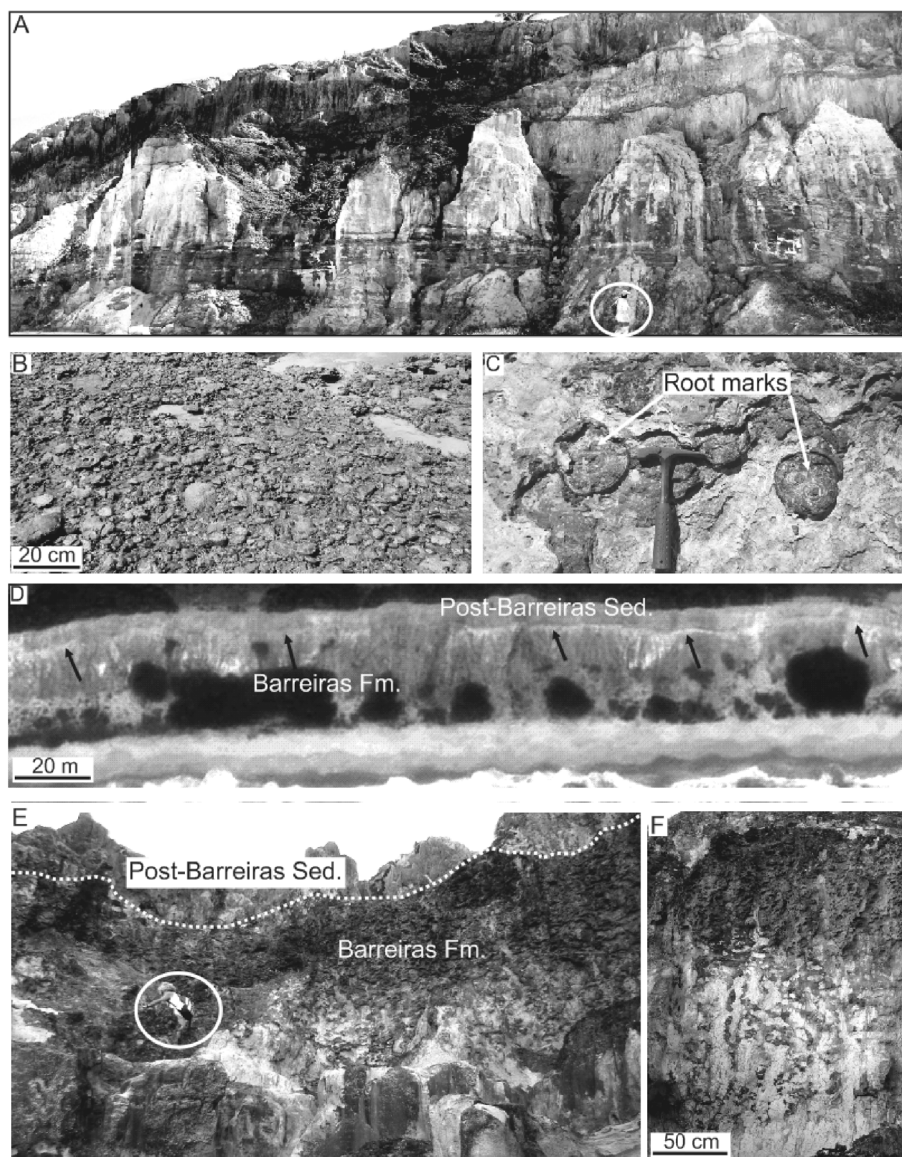
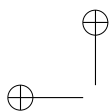
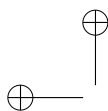


Fig. 2 – A) General view of a cliff consisting of exposures of the Barreiras Formation (person for scale indicated in the inside circle is 1.75 m tall). B-E) Characterization of discontinuity surfaces that bound the Barreiras Formation, illustrating: the iron-cemented conglomeratic lag (B) and the root marks (C) associated with the basal discontinuity surface; a spatial view of the upper unconformity, which separates the Barreiras Formation from the overlying Post-Barreiras Sediments (D; *Image 2007-Digital Globe*); general view of the upper unconformity, which is marked by lateritic paleosol (E; person for scale indicated in the inside circle is 1.75 m tall); and a close-up of the concretionary horizon of this paleosol (F).

However, the sandstones might grade both laterally and downward into conglomerates. Additionally, channel fills dominated by heterolithic deposits are also com-

channel and the flat lying deposits, are internally organized into fining and thinning upward successions.

In the following, a detailed facies description of



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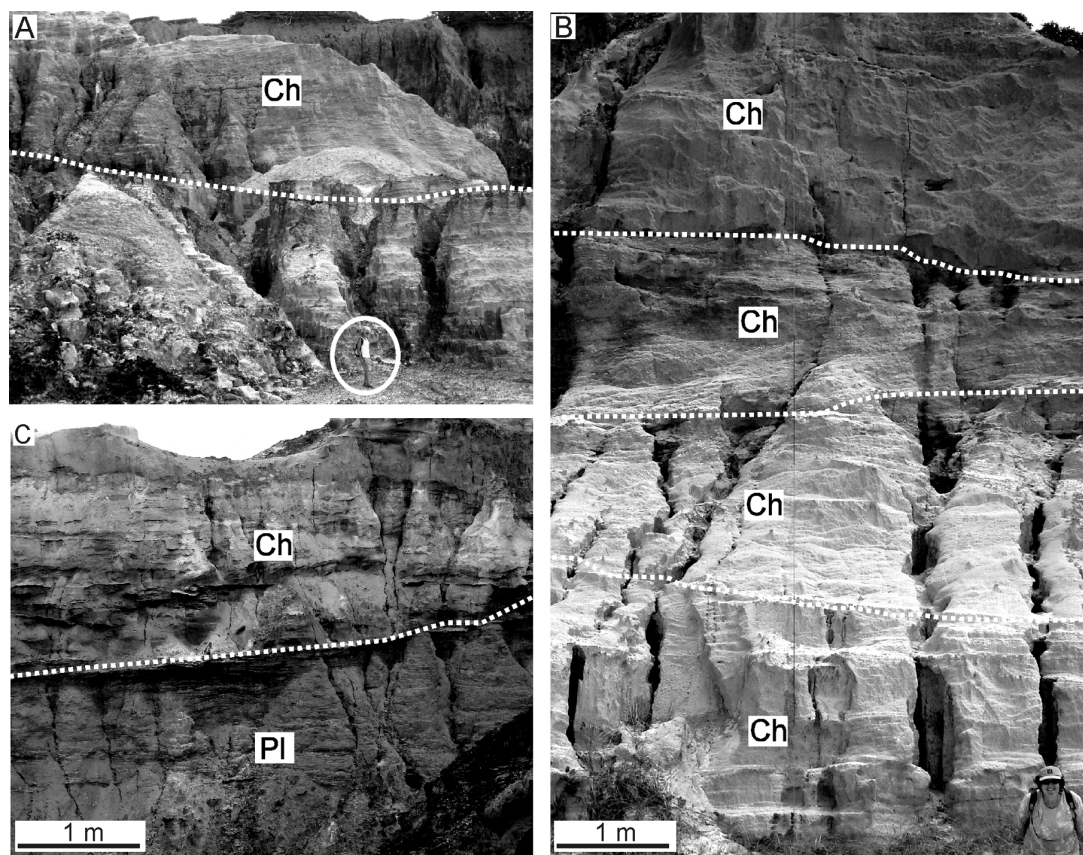


Fig. 3 – Typical channel morphologies of the Barreiras Formation. A) General view of a channel shape (person for scale indicated by inset; person is 1.65 m tall). B) Amalgamation of several channel deposits (Ch) that cut down into each other. C) A channel deposit (Ch) that cuts down into laterally continuous flat lying heterolithic deposits (Pl).

FACIES DESCRIPTION

For the purpose of this work, the studied deposits can be described in terms of four main sedimentary facies: cross-stratified conglomerates (facies Cgx), cross-stratified sandstones (facies Sx), compound cross-stratified sandstone (facies SCx), and heterolithic deposits (H).

CROSS-STRATIFIED CONGLOMERATE (FACIES CGX)

This facies (Fig. 4A-D) consists of poorly- to moderately-sorted, sub-rounded to rounded pebbles of quartz and intraformational mudstones, which are bounded by a matrix of coarse- to medium-grained sandstones. The mud clasts occur in sizes commonly larger than the

tabular cross-stratifications. Despite the coarse-grained nature, thin mud drapes highlight internal reactivation surfaces (Fig. 4). Laminated mud layers averaging 1 cm thick are also present along set boundaries. These deposits are topped by either symmetric or asymmetric ripple marks. A striking feature of this sedimentary facies is the abundance of trace fossils dominated by *morpha* and *Skolithos* (Fig. 4B-D).

CROSS-STRATIFIED SANDSTONE (FACIES SX)

Cross-stratified sandstones (Fig. 5A-H) show, in general, poorly- to well-sorted, fine- to coarse-grained and small to medium scale, tabular and trough cross-stratifications. Not rarely, large scale cross-stratifications

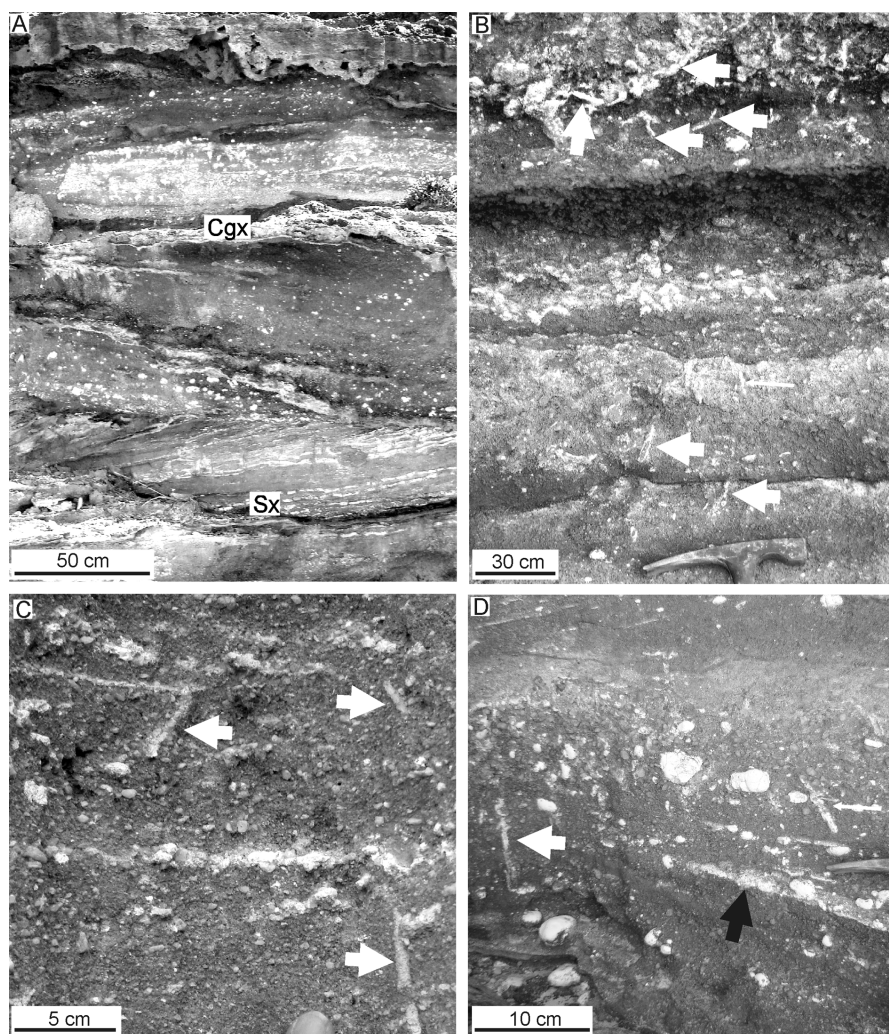
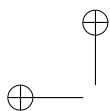


Fig. 4 – Cross-stratified conglomerates (facies Cgx). A) General view of several sets of cross-stratified conglomerates that grade downward into cross-stratified sandstones (facies Sx). B-D) Details of the cross sets with abundant (B) and disperse trace fossils (C-D) (white arrows), mostly consisting of *Ophiomorpha* and *Skolithos*. The white rounded clasts in all figures are mudstone intraclasts.

forming herringbone cross sets (Fig. 5A). The dominant type is tabular cross-stratification, which is usually highly tangential to set bottoms (Fig. 5C-D). Sigmoidal cross-stratification was also observed locally. A particular feature of this lithofacies is the presence of abundant reactivation surfaces and mud drapes (Fig. 5B-D) locally organized into laterally alternating thicker/thinner

have barely been displaced from the mud drapes that separate the foreset packages. In addition, trace fossils are pervasive in this facies, mostly consisting of *Ophiomorpha nodosa* (Fig. 5F-G) and, subordinately, *Skolithos* and *Planolites*. The first occurs in large sizes, i.e., burrow galleries averaging 10 cm in diameter and up to 40 cm, and locally forms monospecific

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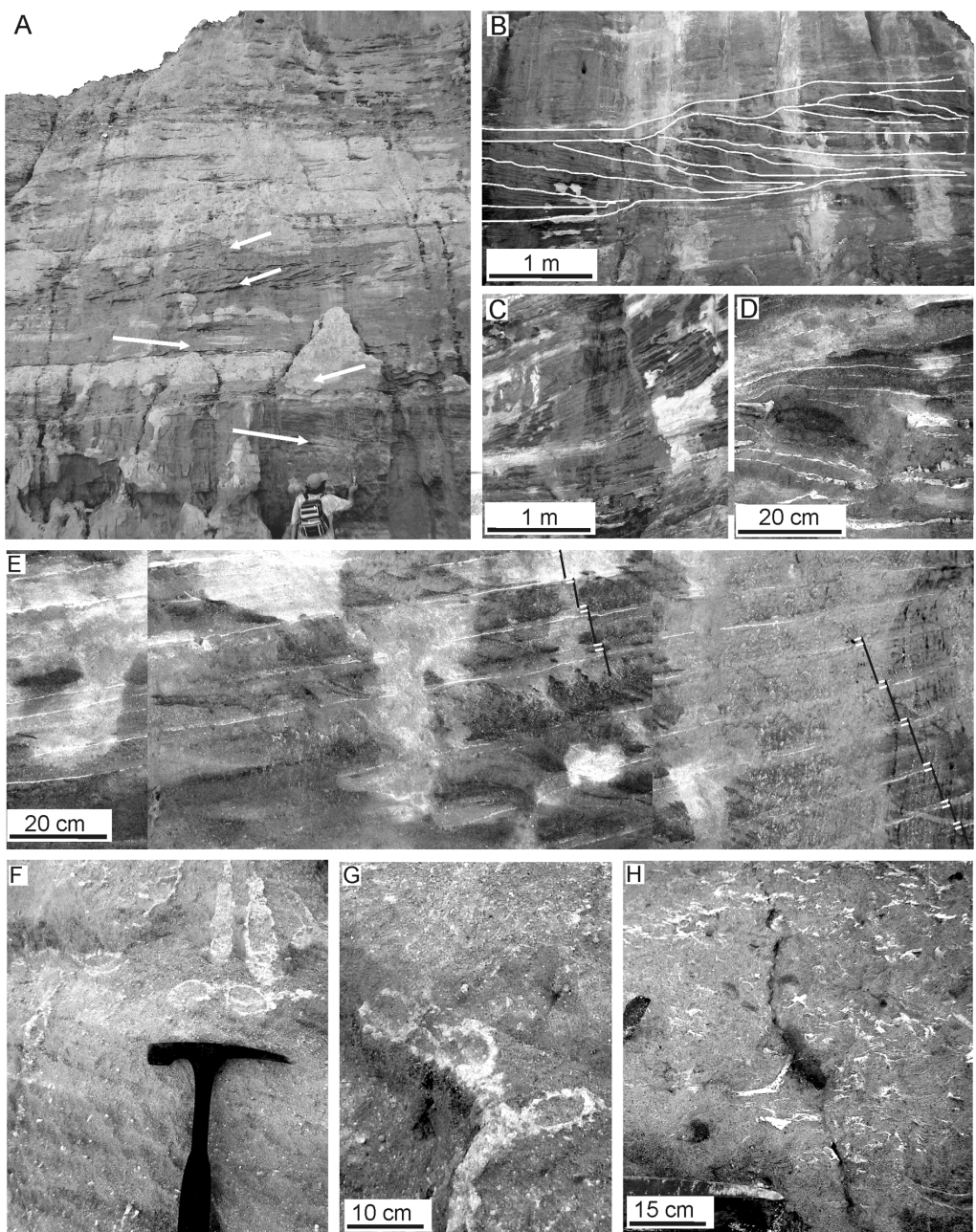


Fig. 5 – Cross-stratified sandstones (facies Sx). A) General view of several sets of cross-stratified sandstones displaying opposed foreset packages. B) Large scale cross sets with packages of foresets marked by reactivation surfaces and/or mud drapes, highlighted by white lines in B and C. C) Large scale cross sets with packages of foresets marked by reactivation surfaces and/or mud drapes, highlighted by white lines in B and C. D) Close up of the cross-stratified sets with abundant, either continuous or discontinuous, mud drapes (white color). E) Close up of a cross set with abundant, alternating thicker and thinner foreset packages (black lines), defined by mud couplets (white lines), a feature characteristic of the Sx facies.



COMPOUND CROSS-STRATIFIED SANDSTONE (FACIES SCX)

Compound cross-stratified sandstones (Fig. 6) are characterized by low angle ($< 15^\circ$) dipping, large scale (up to 5 m thick) cross sets internally showing superimposed, medium scale, either tabular or trough cross beds. Sand grain sizes vary from fine to coarse, and the sorting is usually moderate. Mud clasts are dispersed throughout these beds, particularly in association with coarser grain sizes. The superimposed cross sets usually ascend (climb) upon the large scale foresets, though descending cross sets are also present. Foresets within the superimposed cross sets also dip at low angle ($< 20^\circ$, on average). Facies SCx is most common at the base of channel deposits, or it can fill up the entire channel. Likewise facies Sx, climbing cross sets display abundant reactivation surfaces, but mud drapes are rare. Master beddings, however, are marked by mud layers. Trace fossils similar to those found in facies Sx are dispersed throughout these deposits, though they are much less abundant than in that facies.

HETEROLITHIC DEPOSITS (H)

This facies (Fig. 7A-D) consists of interbedded sandstones and mudstones with layers in sharp contacts. The proportion between these lithologies varies, resulting in several types of heterolithic beddings. Thinly-laminated (pinstripe) beddings are formed where mudstones are dominant, with only minor sandstone stripes forming thin lenses or continuous laminae less than 1 mm thick. Lenticular/wavy bedding is characterized by alternating sandstone and mudstone layers commonly 1-2 cm thick (Fig. 7A). Flaser bedding consists of sandstone layers internally displaying discontinuous mud laminae. Additional features are vertically accreting sandstone units up to 5 cm thick that are separated by either planar or slightly undulatory, laterally continuous mudstone layers a few mm thick (Fig. 7B). Sandstone layers are mainly parallel laminated and, less commonly, cross laminated. Interestingly is the internal organization of these lithologies, which form alternating thicker/thinner successions of sandstones separated by mud couplets (Fig.

the sandy components. In addition to the types of traces described above, there are several smaller-scale, undetermined burrows.

INTERPRETATION OF SEDIMENTARY PROCESSES

In the lack of fossil bodies, the best criteria to recognize deposits formed under influence of marine flows in the sedimentary record are based on the presence of sedimentary structures diagnostic of tidal processes. The sedimentological imprint of tidal currents relies chiefly on their cyclic nature, which results from diurnal/semi-diurnal ebb and flood tide and monthly neap and spring tide fluctuations. Earlier workers focusing on the recognition of tidal deposits had to rely their interpretation basically on the presence of bipolar or bidirectional herringbone cross-stratification (Yagishita 1997). However, the action of tidal currents on sediments does not necessarily produce this structure. This is because many tidal settings display asymmetrical tidal currents, when reduced deposition or even no deposition is expected during weak, subordinate tides (Kreisa and Moiola 1986), as observed in many ancient and modern settings (Dalrymple et al. 1978, de Boer et al. 1989, Nio and Yang 1991).

The advance of studies on tidal settings resulted in several additional criteria that can be used to identify tidal rhythmites (see Nio and Yang 1991 for a review). These are imprinted in the sedimentary deposits as tidal beddings (Reineck and Wunderlich 1968, Visser 1980, Terwindt 1981). Tidal bundles were first identified by Boersma (1969) as being deposited by dominant tidal currents, and thin mud layer were ascribed by Terwindt (1971) to slack water deposition during tidal reversals. The thickness variation of tidal bundles was shown to correspond to neap/spring tidal cycles by Visser (1980). Based on these works, many deposits previously ascribed as entirely continental in origin were reinterpreted as primarily formed by tidal processes.

The main feature diagnostic of tidal bundles is the repetitive thick-thin pairing of strata marked by reactivation surfaces and/or mud drapes, which are related to ebb/flood tidal periodicities (e.g., Mowbray and Visser



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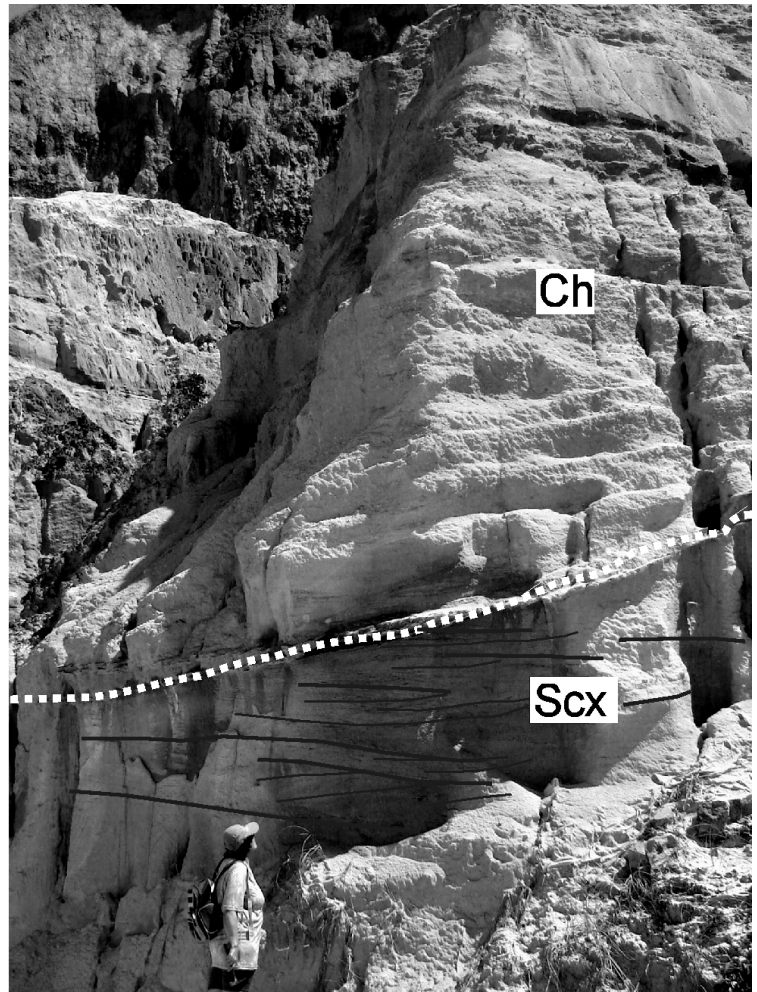


Fig. 6 – Compound cross-stratified sandstone (facies SCx) with large scale cross sets defined by low angle dipping master bedding separating internal, medium scale, ascending cross sets. Note that this facies is sharply overlain by a concave up deposit related to a tidal channel (Ch) (the dotted white line highlights the base of the channel deposit).

In the study area, there are several features assuring that deposition took place chiefly in a marine influenced setting under the action of tidal currents. The common occurrence of opposed dipping cross sets forming herringbone cross-stratification is consistent with highly fluctuating flow conditions, as occurs in marine settings. However, the most convincing evidence is the abundance of sedimentary structures diagnostic of tidal pe-

recorded in both modern and ancient tidal-ge deposits (e.g., Visser 1980, Allen 1981a, b, B and Terwindt 1981, Nio et al. 1983, Allen and wood 1984, Mowbray and Visser 1984, Tessi Gigot 1989, Nio and Yang 1991, Archer et al. Shanley et al. 1992). Sandstones with lateral sions of tidal bundles are related to megaripple tion under fluctuating asymmetric flood and eb

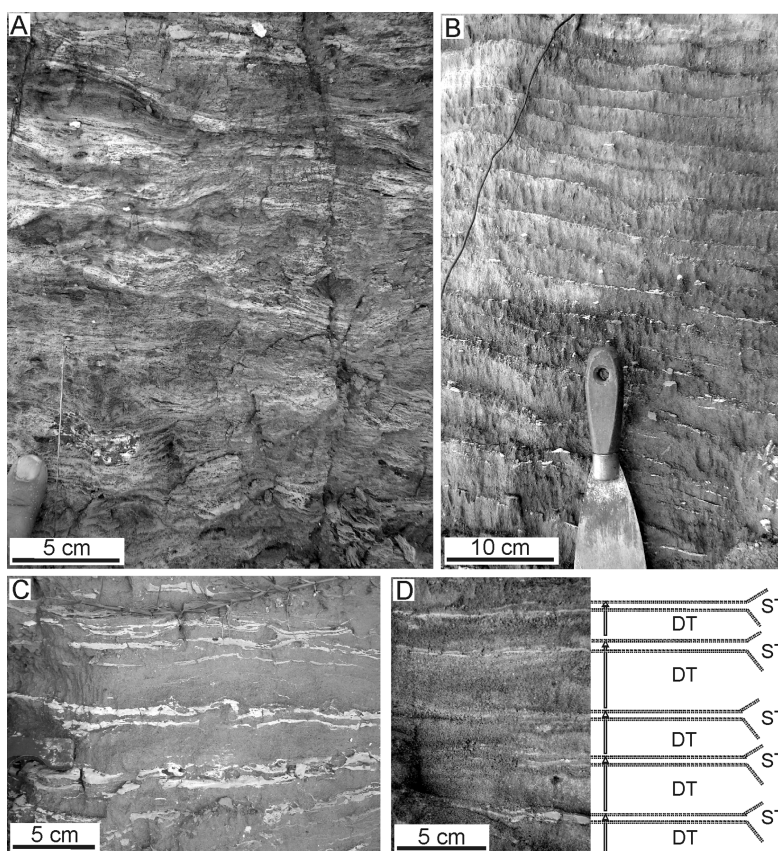
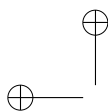
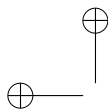


Fig. 7 – Heterolithic bedding (facies H). A) Lenticular/wavy heterolithic bedding. B) Heterolithic bedding consisting of vertically accreting sandstone packages defined by either planar or slightly undulating, laterally continuous mudstone layers. C-D) Internal organization of the vertically accreting sandstones, forming alternating thicker/thinner successions separated by mud couplets related to dominant (DT)/subordinated (ST) daily tidal cycles.

of slack water that occur just before flow inversions. The sigmoidal cross strata present in facies Sx are also attributed to tidal processes, as similar structures have been recorded in many tidal-influenced settings (e.g., Kreisa and Moiola 1986, Nio and Yang 1991). Sigmoidal beddings reflect progressive acceleration from full vortex to deceleration flow conditions within a single ebb-flood tide (Boersma and Terwindt 1981, Allen and Homewood 1984, Uhlir et al. 1988).

Facies H is also related to tidal processes, as revealed by several lines of evidence. First, this facies is commonly intergraded with facies Sx. Second, the

favored under the time velocity asymmetry of tidal currents (e.g., Reineck and Wunderlich 1968, Reineck and Singh 1986, Terwindt 1971, Terwindt and Breusers 1972, Howley 1981, Mowbray 1983). Third, the sharp contacts between sandstone and mudstone layers, though not exclusive, are typical of tidal processes, indicating rapid changes between periods of quiescence (mud settling) and periods with relative increase in flow strength (sand deposition). Finally, the tidal influence on the genesis of facies H is particularly shown by the vertically accreting sandstone beds that are separated by either planar or slightly undulatory, laterally continuous



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reflects periodic vertical sand accumulation due to tidal currents affecting flat areas (tidal flats and shoals) with high sediment rates. Shallow waters under this environmental condition would have momentarily enhanced tidal flows, promoting upper flow regime sand deposition, as recorded by the abundance of parallel laminated sandstones.

The high volume of features characteristic of tidal bundles in facies Sx and H is consistent with formation of tidal bundles under subtidal conditions. The preservation of subordinate, slack water mud drapes is not favored in the intertidal zone (Clifton 1983, Terwindt 1988, Nio and Yang 1991).

Given the genetic relationship of facies Sx and H, the compound cross-stratified sandstones are related to migration of large-scale bedforms, mostly within channels, during alternating dominant and subordinate tidal currents (e.g., Houbodt 1968, Allen 1980, Dalrymple 1984, Mowbray and Visser 1984, Chakraborty and Bose 1990, Simpson and Eriksson 1991). The large scale bedforms were superimposed by smaller scale bedforms that migrated mostly upstream during subordinate tides, producing the ascending cross sets. Deeper waters within tidal channel settings would have favored the development of this facies, as indicated by its frequent occurrence within channelized deposits.

Facies Cgx was also formed by tidal currents, as indicated by its transition to facies Sx. The coarse-grained nature of these deposits, added to the abundance of large mud clasts, record high energy tidal flow conditions. However, the reactivation surfaces with mud drapes record punctuated episodes of low flow conditions, which are naturally developed in tidal settings.

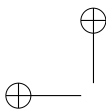
In addition to the abundance of sedimentary structures diagnostic and/or suggestive of tidal processes, the types of trace fossils recorded in the studied strata support deposition in marginal marine settings. A further specific ichnological investigation is still needed in order to fully characterize the entire assemblage of trace fossils present in these deposits. However, the overall prevalence of *Ophiomorpha nodosa* and *Skolithos*, with subordinate occurrence of *Planolites*, attests a low

Ophiomorpha nodosa records dwelling/feeding of organisms reworking marine settings. Its occurrence as large burrows forming monospecific ichnofauna reflects an opportunistic behavior of marine organisms which was also recorded frequently in the Barreiras Formation in northern Brazil (Netto and Rossetti 1992). *Skolithos* is a dwelling trace that occurs in marine, brackish and freshwater environments, but is more common in high energy settings, being particularly common in tidal settings (Bromley and Ager 1979, Pemberton et al. 1992a, b, Buatois et al. 1992, Gibert and Martinell 1998). *Planolites* is a feeding structure that occurs in a variety of depositional settings (Pemberton and Frey, 1982). Together, these traces characterize the *Skolithos* ichnofacies developed in high energy marine influenced settings.

CONCLUSION

This work records the first unequivocal evidence of marine influence in the Barreiras Formation of eastern Brazil. Combination of sedimentary structural and ichnological data led to the conclusion that the Barreiras Formation that occurs in the southern coast of the State of Alagoas is definitely related to sedimentation in a marine, tidal dominated depositional setting.

The studied deposits display a variety of sedimentary features that resemble those documented in marginal marine deposits of the Barreiras Formation located in northern Brazil. In particular, the dominance of tidal bundles, though not exclusive to, is typical of estuarine settings. The complex sedimentary record consisting of the abundance of channel fills, characterized by widespread extensive concave up deposits with fining/thinning upward successions, is common in estuarine successions, as are heterolithic beddings. This environmental interpretation is further sustained by the ichnological assemblage suggestive of stressed waters with constant salinity fluctuations. However, future detailed facies mapping should be undertaken in this area in order to determine the lateral (i.e., lateral and vertical) distribution of facies associations, which is crucial to reconstruct the paleoenvironments and better characterize the depositional



of northeastern Brazil. The pervasive occurrence of deposits with unambiguous evidence of tidal processes in the Barreiras Formation of northern Brazil, and now in the State of Alagoas, leads to argue that the early/middle Miocene period of worldwide marine transgression might have left a much more widespread sedimentary record along the Brazilian coast than currently regarded.

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RESUMO

Processos de maré foram importantes na deposição da Formação Barreiras localizada no norte do Brasil, enquanto depósitos correlatos do nordeste brasileiro têm sido tradicionalmente relacionados a ambientes continentais. Análise de fácies no sul de Alagoas revelou que a Formação Barreiras consiste em conglomerados e arenitos com estratificações cruzadas (facies Sx e Cgx), arenitos com estratificação cruzada composta (facies Cx), e acamamentos heterolíticos (facies H). Uma porção significativa desses depósitos ocorre inserida em morfologias de canal, internamente contendo sucessões de granocrescência e adelgaçamento ascendentes. A abundância de feições sedimentares é comparável àquelas documentadas em depósitos correlatos do norte do Brasil. Estas incluem: bandamentos de maré; estratificações cruzadas espinha-de-peixe; acamamentos heterolíticos contendo camadas de arenitos e argilitos em contato brusco; e icnofósseis consistindo principalmente em *Ophiomorpha nodosa*, *Skolithos* e *Planolites*. Estas feições apontam para ambiente deposicional marinho marginal dominado por processos de maré, possivelmente relacionado a sistema estuarino. Esta interpretação é similar à atribuída para a Formação Barreiras no norte do Brasil. A ampla ocorrência de depósitos contendo evidência inequívoca de processos de maré na Formação Barreiras no norte do Brasil, e agora também no Estado de Alagoas, leva a propor que o período de transgressão marinha registrada globalmente no eo/meso Mioceno pode ter deixado um registro sedimentar muito mais amplo ao

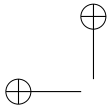
REFERENCES

- ALHEIROS MM AND LIMA FILHO MF. 1991. A Formação Barreiras. Revisão Geológica da Faixa Sedimentar Costeira de Pernambuco, Paraíba e Rio Grande do Norte. *Est Geol – Ser B, Est Pesq* 10: 77–88.
- ALHEIROS MM, LIMA FILHO MF, MONTEIRO FAJ AND OLIVEIRA FILHO JS. 1988. Sistemas deposicionais na Formação Barreiras no Nordeste Oriental. In: ANAIS DO CONGRESSO BRASILEIRO DE GEOLOGIA, 35, Belém, PA, Brasil 2: 753–760.
- ALLEN JRL. 1980. Sand waves: a model of origin and internal structure. *Sed Geol* 26: 281–328.
- ALLEN JRL. 1981a. Lower Cretaceous tides revealed by cross-bedded sets with mud drapes. *Nature* 289: 579–581.
- ALLEN JRL. 1981b. Paleotidal speeds and ranges estimation from cross-bedding sets with mud drapes. *Nature* 293: 394–396.
- ALLEN PA AND HOMEWOOD P. 1984. Evolution and mechanics of a Miocene tidal sandwave. *Sedimentology* 31: 63–81.
- AQUINO GS AND LANA MC. 1990. Exploração na Bacia de Sergipe-Alagoas: O “estado da arte”. *Bol Geoc Petrob* 4: 3–11.
- ARAI M. 1997. Dinoflagelados (Dinophyceae) miocênicos do Grupo Barreiras do nordeste do Estado do Pará (Brasil). *Univ Guar, Geoc* 2: 98–106.
- ARAI M. 2006. A grande elevação eustática do Mioceno e sua influência na origem do Grupo Barreiras. *Geologia USP, Ser Cient* 6: 1–6.
- ARAI M, UESUGUI N, ROSSETTI DF AND GÓES AM. 1988. Considerações sobre a idade do Grupo Barreiras no nordeste do Estado do Pará. In: ANAIS DO CONGRESSO BRASILEIRO DE GEOLOGIA, 35, Belém, PA, Brasil 2: 738–752.
- ARAI M, TRUCKENBRODT W, NOGUEIRA ACR, GÓES AM AND ROSSETTI DF. 1994. Novos dados sobre a estratigrafia e ambiente deposicional dos sedimentos Barreiras, NE do Pará. In: BOLETIM DE RESUMOS EXPANDIDOS DO SIMPÓSIO DE GEOLOGIA DA AMAZÔNIA, 4, Belém, PA, Brasil 1: 185–187.
- ARAÚJO VD, REYES-PERES YA, LIMA RO, PELOSI APM, MENEZES L, CÓRDOBA VC AND LIMA-FILHO FB. 2006. Fácies e ambientes deposicionais da Formação

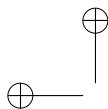


MARINE INFLUENCE IN THE BARREIRAS FORMATION

- ARCHER AW, KUECHER GJ AND KVALE EP. 1995. The role of tidal-velocity asymmetries in the deposition of silty tidal rhythmites (Carboniferous, Eastern Interior Coal Basin, USA). *J Sed Res* 65: 408–416.
- BIGARELLA JJ. 1975. The Barreiras Group in Northeastern Brazil. *An Acad Bras Cienc* 47 (Suppl): 366–392.
- BOERSMA JR. 1969. Internal structures of some tidal megaripples on a shoal in the Westerschelde Estuary, The Netherlands, Report of a preliminary investigation. *Geol Mij* 48: 409–414.
- BOERSMA JR AND TERWINDT JHJ. 1981. Neap-spring tide sequences of intertidal shoal deposits in a mesotidal estuary. *Sedimentology* 28: 151–170.
- BROMLEY RG AND ASGAARD U. 1979. Triassic freshwater ichnocoenosis from Carlberg Fjord, East Greenland. *Palaeo Palaeo Palaeo* 28: 39–80.
- BUATOIS LA, MÁNGANO MG, GENISE JF AND TAYLOR TN. 1998. The ichnologic record of the continental invertebrate invasion: evolutionary trends in environmental expansion, eco-space utilization, and behavioral complexity. *Palaio* 13: 217–240.
- CHAKRABORTY C AND BOSE PK. 1990. Internal structures of sandwaves in a tide-storm interactive system: Proterozoic Lower Quartzite Formation, India. *Sed Geol* 67: 133–142.
- CLIFTON HE. 1983. Discrimination between subtidal and intertidal facies in Pleistocene deposits, Willapa Bay, Washington. *J Sed Petrol* 53: 353–369.
- DALRYMPLE RW. 1984. Morphology and internal structures of sandwaves in the Bay of Fundy. *Sedimentology* 31: 365–382.
- DALRYMPLE RW, KNIGHT RJ AND CAMBIASE JJ. 1978. Bedforms and their hydraulic stability in the tidal environment, Bay of Fundy, Canada. *Nature* 275: 100–104.
- DE BOER PL, OOST AP AND VISSER MJ. 1989. The diurnal inequality of the tide as a parameter for recognizing tidal influences. *J Sed Petrol* 59: 912–921.
- FURRIER M, ARAUJO ME AND MENESES LF. 2006. Geomorfologia e tectônica da formação barreiras no estado da Paraíba. *Geologia USP, Ser Cient* 6: 61–70.
- GIBERT JM AND MARTINELL J. 1998. El modelo de icnofácies, 30 años después. *Rev Esp Pal* 13: 167–174.
- HOUBODT JHC. 1968. Recent sediments in the southern KREISA RD AND MOIOLA RJ. 1986. Sigmoidal tidal ridges and other tide-generated sedimentary structures in the Curtis Formation, Utah, USA. *Geol Soc Am Bull* 97: 381–387.
- LECKIE DA AND SINGH C. 1991. Estuarine deposits of the Albian Paddy Member (Peace River Formation), and the Edmonton Shaftesbury Formation, Alberta, Canada. *Geol Soc Am Bull* 102: 825–849.
- LEITE FPR. 2004. Palinologia. In: ROSSETTI D, GÓES AM (Eds), *O Mioceno na Amazônia Oriental*. Mus Paraens Em Goeldi, p. 55–90.
- LEITE FPR, OLIVEIRA MEB, OLIVEIRA PE, SILVA JF, CAPELATO MS, ARAI M AND TRUCKENBRODT W. 1997a. Palinofloras miocenas da Formação Barreiras, na Região Bragantina, Estado do Pará, Brasil. *Rev Univ Guar, Geoc* 2: 128–140.
- LEITE FPR, OLIVEIRA MEB, ARAI M AND TRUCKENBRODT W. 1997b. Palinoestratigrafia da Formação Barreiras, Mioceno do nordeste do estado do Pará, Brasil. *Rev Univ Guar, Geoc* 2: 141–147.
- LIMA CCU AND VILAS BOAS GS. 2004. Morphological analysis in the Barreiras Group, south coast of the state of Bahia, based on the square over radar image approach. *Rev Cienc e Nat, Edição Especial*, p. 101–115.
- LIMA CCU, VILAS BOAS GS AND BEZERRA FHF. 2005. Faciologia e análise tectônica Preliminar da Formação Barreiras no litoral sul do Estado da Bahia. *Geologia USP, Ser Cient* 6: 71–80.
- MABESOONE JM, CAMPOS-SILVA A AND BUENOS AIRES. 1972. Estratigrafia e origem do Grupo Barreiras, Paraíba e Rio Grande do Norte. *Rev Bras Geol* 2: 173–188.
- MENEZES MRF, SOUZA FILHO LV AND BARROSO. 1998. Discordâncias e inundações no Grupo Barreiras, litoral leste do Rio Grande do Norte. In: ANAIS DO CONGRESSO BRASILEIRO DE GEOLOGIA, 50, Belo Horizonte, MG, Brasil 1: 75.
- MOHRIAK WU, BASSETTO M AND VIEIRA IS. 1999. Observações sobre a carta estratigráfica e a evolução sedimentar das bacias de Sergipe e Alagoas. *Bol Bras Geol* 11: 84–115.
- MOWBRAY T. 1983. The genesis of lateral accretion in recent intertidal mudflat channels, Solway Firth, Scotland. *Sedimentology* 30: 425–435.



- NIO SD AND YANG CS. 1991. Diagnostic attributes of clastic tidal deposits: a review. In: SMITH DG, REISON GE, ZAITLIN BA AND RAHMANI RA (Eds), *Clastic Tidal Sedimentology*: CSPG Memoir 16: 3–28.
- NIO SD, SIEGENTHALER C AND YANG CS. 1983. Megaripple cross-bedding as a tool for the reconstruction of the paleo-hydraulics in a Holocene subtidal environment, S.W. Netherlands. *Geol Mij* 62: 499–510.
- NETTO RG AND ROSSETTI DF. 2003. Ichnology and salinity fluctuations: a case study in the Early Miocene (Lower Barreiras Succession) of São Luís Basin, Maranhão, Brazil. *Rev Bras Pal* 6: 5–18.
- PATTISON SAJ. 1992. Recognition and interpretation of estuarine mudstones (central basin mudstones) in the tripartite valley fill deposits of the Viking Formation, Central Alberta. In: PEMBERTON SG (Org), *Applications of Ichnology to Petroleum Exploration – A Core Workshop*: SEPM Core Workshop 17: 223–249.
- PEMBERTON SG AND FREY RW. 1982. Trace fossil nomenclature and the Planolites-Palaephycus dilemma. *J Pal* 56: 843–871.
- PEMBERTON SG AND WIGHTMAN DM. 1992. Ichnological characteristics of brackish water deposits. In: PEMBERTON SG (Org), *Applications of Ichnology to Petroleum Exploration: A Core Workshop*: SEPM Core Workshop 17: 141–167.
- PEMBERTON SG, MACEachern J AND FREY RW. 1992a. Trace fossils facies models, environmental and allostratigraphic significance. In: WALKER RRG AND JAMES NP (Eds), *Facies Models – Response to Sea Level Change*: *Geol Assoc Can*, p. 47–72.
- PEMBERTON SG, REINSON GE AND MACEachern JA. 1992b. Comparative ichnological analysis of Late Albian estuarine valley-fill and shelf-shoreface deposits, Crystal Viking Field, Alberta. In: PEMBERTON SG (Org), *Applications of Ichnology to Petroleum Exploration: A Core Workshop*: SEPM Core Workshop 17: 291–317.
- REINECK HE AND SINGH IB. 1986. *Depositional sedimentary environments (with reference to terrigenous clastics)*. Germany, Springer-Verlag, 551 p.
- REINECK HE AND WUNDERLICH F. 1968. Classification and origin of flaser and lenticular bedding. *Sedimentology* 11: 99–104.
- ROSSETTI DF. 2000. Influence of low amplitude/high frequency tidal oscillations on the development of clastic tidal deposits: a review. In: SMITH DG, REISON GE AND RAHMANI RA (Eds), *Clastic Tidal Sedimentology*: CSPG Memoir 16: 29–48.
- ROSSETTI DF. 2001. Late Cenozoic sedimentary evolution in northeastern Pará, Brazil, within the context of sea level changes. *J South Am Earth Sci* 14: 77–89.
- ROSSETTI DF. 2004. Paleosurfaces from northeastern Amazonia as a key for reconstructing paleolandscapes and understanding weathering products. *Sed Geol* 169: 151–174.
- ROSSETTI DF. 2006a. The role of tectonics on the preservation of estuarine valleys in areas with low accommodation rates: examples from Upper Cretaceous and Miocene Successions in Northern Brazil. In: DALRYMPLE RW, LECKIE DA AND TILLMAN RW (Eds), *Incised Valley in Time and Space*: SEPM Spec Publ 85: 199–218.
- ROSSETTI DF. 2006b. Evolução sedimentar miocênica nos estados do Pará e Maranhão. *Geologia USP – Ser Cient* 6: 7–18.
- ROSSETTI DF AND SANTOS JR AEA. 2004. Facies architecture in a tectonically-influenced estuarine incised valley fill of Miocene age, Northern Brazil. *J South Am Earth Sci* 17: 267–284.
- ROSSETTI DF AND SANTOS JR AEA. 2006. Analysing the origin of the upper Cretaceous–?lower Tertiary Rio Capim semi flint (Pará State, Brazil) under a sedimentologic perspective. *Sed Geol* 186: 133–144.
- ROSSETTI DF AND TRUCKENBRODT W. 1989. Estudo paleoambiental e estratigráfico dos sedimentos Barreiras e Pós-Barreiras na região Bragantina, nordeste do Pará. *Bol Mus Par Emílio Goeldi, Ser Cienc Terra* 1: 25–74.
- ROSSETTI DF, GÓES AM AND TRUCKENBRODT W. 1990. A influência marinha nos Sedimentos Barreiras. *Bol Mus Par Emílio Goeldi, Ser Cienc Terra* 2: 17–29.
- SALIM J, SOUZA CJ, MUNIZ GCB AND LIMA MR. 1975. Novos subsídios para elucidação do episódio “Barreiras” no Rio Grande do Norte. In: ACTAS DO SIMPÓSIO DE GEOGRAFIA, 7, Fortaleza, CE, Brasil 1: 149–158.
- SHANLEY KW, MCCABE PJ AND HETTINGER RD. 1992. Tidal influence in Cretaceous fluvial strata from Utah: a key to sequence stratigraphic interpretation. *Sedimentology* 39: 905–930.
- SIMPSON EL AND ERIKSSON KA. 1991. Depositional facies and controls on parasequence development in siliciclastic tidal deposits from the Lower Proterozoic, Upper Mount Guide Quartzite, Mount Isa Inlier, Australia. In: SMITH DG, REINSON GE AND RAHMANI RA (Eds), *Clastic Tidal Sedimentology*: CSPG Memoir 16: 49–68.



MARINE INFLUENCE IN THE BARREIRAS FORMATION

- Barreiras do Neógeno e o seu possível significado como testemunho de alguns eventos geológicos mundiais. *Geociências* 2: 461–479.
- SUGUIO K, BIDEKAN JC AND MORNER NA. 1986. Dados preliminares sobre as idades paleomagnéticas do Grupo Barreiras e da Formação São Paulo. *Rev Bras Geoc* 16: 171–175.
- TERWINDT JHJ. 1971. Lithofacies of inshore estuarine and tidal inlet deposits. *Geol Mij* 50: 515–526.
- TERWINDT JHJ. 1981. Origin and sequences of sedimentary structures in inshore mesotidal deposits of the North Sea. In: NIO SD, SHUTTENHELM RJE AND VAN VEERING TCE (Eds), *Holocene Marine Sedimentation in the North Sea Basin*: Int Assoc Sed Spec Publ 5: 4–26.
- TERWINDT JHJ. 1988. Paleotidal reconstruction of inshore tidal depositional environments and facies. In: DE BOER PL, VAN GELDER A AND NIO SD (Eds), *Tide-influenced Sedimentary Environments and Facies*: Reidel Publishing Company, p. 233–264.
- TERWINDT JHJ AND BREUSERS NHC. 1972. Experiments on the origin of flaser, lenticular, and sand-clay alternating bedding. *Sedimentology* 19: 85–98.
- TESSIER B AND GIGOT P. 1989. A vertical record of recent tidal cyclicities: an example from the Miocene Molasse of Digne (Haute Provence, France). *Sedimentology* 36: 767–776.
- UHLIR DM, AKERS A AND VONDRA CF. 1988. Tidal sequence, Sundance Formation (Upper Jurassic) in central Wyoming. *Sedimentology* 5: 739–752.
- VILAS BOAS GS, SAMPAIO FJ AND PEREIRA AM. 1985. The Barreiras Group in the Northeastern coast of the State of Bahia, Brazil: depositional mechanisms and processes. *An Acad Bras Cienc* 73: 417–427.
- VISSER MJ. 1980. Neap-spring cycles reflected in Holocene subtidal large-scale bedforms deposits: a preliminary note. *Geology* 8: 543–546.
- YAGISHITA K. 1997. Preservation of herringbone cross-bedding in a transgressive sequence of the Santoku Formation, northeast Japan. *Mem Geol Soc Japan* 48: 76–84.
- YANG CS AND NIO SD. 1985. The estimation of paleohydrodynamic processes from subtidal deposits using series analysis methods. *Sedimentology* 32: 41–51.