FOSSOCYTHERIDEA SWAIN & BROWN AND PERISSOCYTHERIDEA STEPHENSON (OSTRACODA): INSIGHTS INTO PALEOSALINITY GRADIENTS OF LATE CRETACEOUS DEPOSITS FROM BRAZIL AND PORTUGAL

ENELISE KATIA PIOVESAN

Departamento de Geologia, Centro de Tecnologia, UFPE, Cidade Universitária, 50670-901, Recife, PE, Brasil.
katiapiovesan@gmail.com

MARIA CRISTINA CABRAL, ELBA ASSIS BOAVIDA, JEAN-PAUL COLIN†

Departamento de Geologia e Centro de Geologia, Faculdade de Ciências, Universidade de Lisboa, C6, 4º, 1749-016, Lisboa, Portugal. *mccabral@fc.ul.pt*

GERSON FAUTH

Instituto Tecnológico de Micropaleontologia, UNISINOS, Av. Unisinos, 950, 93.022-000, São Leopoldo, RS, Brasil.
gersonf@unisinos.br

ABSTRACT – *Fossocytheridea* Swain & Brown and *Perissocytheridea* Stephenson are genera characteristic of brackish water environments. In 51 samples from the Santonian-Campanian, from the well 9-MO-13-RN, Potiguar Basin, Brazil, *Fossocytheridea potiguarensis* Piovesan, Cabral & Colin, *Fossocytheridea* POT 1 Piovesan, Cabral & Colin and *Perissocytheridea jandairensis* Piovesan, Cabral & Colin have been identified. In the São João das Lampas section (middle Cenomanian), Lusitanian Basin, Portugal, 25 samples were studied and *Fossocytheridea merlensis* (Babinot & Colin) and *Perissocytheridea estribeirensis* Andreu have been recognized. The distributional pattern of the *Fossocytheridea*-*Perissocytheridea* assemblage, combined with analysis of the abundance and diversity of marine ostracodes, suggests that in the Late Cretaceous *Fossocytheridea* and *Perissocytheridea* were euryhaline genera, and that the tolerance to salinity gradients is related to the ecology of each species and not strictly to that of the genus.

Key words: ostracodes, brackish environment, Late Cretaceous, Brazil, Portugal.

RESUMO – *Fossocytheridea* Swain & Brown e *Perissocytheridea* Stephenson são gêneros característicos de ambientes mixohalinos. Nas 51 amostras do Santoniano-Campaniano, provenientes do testemunho 9-MO-13-RN, bacia Potiguar, Brasil, foram identificadas *Fossocytheridea potiguarensis* Piovesan, Cabral & Colin, *Fossocytheridea* POT 1 Piovesan, Cabral & Colin e *Perissocytheridea jandairensis* Piovesan, Cabral & Colin. No afloramento de São João das Lampas (Cenomaniano médio), bacia Lusitânica, Portugal, foram estudadas 25 amostras e identificadas *Fossocytheridea merlensis* (Babinot & Colin) e *Perissocytheridea estribeirensis* Andreu. A observação do comportamento da associação *Fossocytheridea*-*Perissocytheridea* estudada, aliada à análise da abundância e diversidade de ostracodes marinhos permite sugerir que, no Neocretáceo, tanto *Fossocytheridea* quanto *Perissocytheridea* são gêneros eurihalinos, sendo a tolerância a gradientes de salinidade relacionada à ecologia de cada espécie e não necessariamente ao gênero.

Palavras-chave: ostracodes, ambiente mixohalino, Cretáceo Superior, Brasil, Portugal.

INTRODUCTION

The cytherideids *Fossocytheridea* Swain & Brown, 1964 and *Perissocytheridea* Stephenson, 1938 are mixohaline genera typical of marginal marine environments from the Late Cretaceous onwards. The marginal marine zones might comprise many types of environments (*e.g.* estuaries, deltas, open or closed lagoons, lakes, temporary or permanent ponds) subject to highly variable hydrodynamic processes (tides, currents, storms, sea level variation/time of subaerial exposure) and climatic (precipitation/evaporation rate) factors

(Frenzel & Boomer, 2005). Important changes on physical and chemical parameters of water (*e.g.* salinity, temperature, pH, dissolved oxygen), the inflow of sediment and the presence of high organic productivity are characteristic of these zones.

One of the most important population controlling factors in these zones is the salinity. Regarding it, ecologically, ostracodes may be divided into marine, brackish (mixohaline) and freshwater faunas. The ostracodes are further divided into euryhaline, *i.e.*, the ones which tolerate a wide salinity variation, and stenohaline, which are restricted to environments with a limited salinity variation.

Fossocytheridea is a genus widely distributed in marginal marine facies from the Aptian to the Maastrichtian of America, Europe, China, Africa and Middle East (Swain & Brown, 1964; Babinot & Colin, 1976; Tibert *et al.*, 2003; Bergue *et al.*, 2011). Previous works have already highlighted its application in the characterization of marginal marine environments (*e.g.* Colin *et al.*, 1990; Tibert *et al.*, 2002, 2003, 2009). The descendant of this genus is the cosmopolitan and euryhaline *Cyprideis* Jones, 1857 which is one of the most utilized Ostracoda genera in paleoecological studies in current marginal marine environments (*e.g.* Sandberg, 1964; Rosenfeld & Vesper, 1977; Boomer & Eisenhauer, 2002; Medley *et al.*, 2007).

Perissocytheridea, in its turn, is also a mixohaline genus, typically lagoon-dwelling, which disappears almost completely from the present Gulf of Mexico bays when the salinity level reaches 30‰ (Colin *et al.*, 1996). According to Keyser (1977), in Florida this genus is currently euryhaline, with one species preferring either mesohaline or polyhaline waters. Its origin is generally considered to have taken place on the Gondwana, and it occurs in Africa, South America, the Middle East and the south of Europe (Andreu, 1981, 1996; Babinot, 1988 a,b; Szczechura *et al.*, 1991; Colin *et al.*, 1996; Viviers *et al.*, 2000; Mebrouk *et al.*, 2011). In America this genus is recorded since the Cenomanian up to the present. Since its appearance, *Perissocytheridea* seems to be a mixohaline genus (*e.g.* Keiser, 1977; Babinot, 1988b; Nicolaidis & Coimbra, 2008), which can be found associated both to freshwater or marine species, though in some cases the non mixohaline species are considered to be allochthonous (*e.g.* Coimbra *et al.*, 2006).

The *Fossocytheridea*-*Perissocytheridea* association in the Late Cretaceous is considered as the fossil equivalent of the *Cyprideis*-*Perissocytheridea* one observed from the Neogene to present. Previous studies have shown that these two associations may occur with both marine ostracodes (Garbett & Maddocks, 1979; Cronin, 1988; Andreu, 1996; Morsi & Wendler, 2010) and non-marine ostracodes (Uliana & Musacchio, 1978; Colin *et al.*, 1996; Gross *et al.*, 2013). The *Cyprideis*-*Perissocytheridea* genera, associated with marine ostracodes, have also been found in hyperhaline environments (Neale, 1988). Studies based on the modern living genera *Cyprideis* and *Perissocytheridea* show their potential in ecological studies. One example of this ecological approach is the work of Dias-Brito *et al.* (1988) at Sepetiba Bay (Rio de Janeiro State, Brazil), where they proposed distinct biofacies, within a lagoon ecosystem, based on ostracodes and foraminifers. *Cyprideis* and *Perissocytheridea* were associated in most of those biofacies, but *Perissocytheridea* occurred in all of them, including the ones with more marine influence.

In this work an analysis of the paleoecological response of *Fossocytheridea* and *Perissocytheridea* was carried out in Upper Cretaceous formations from Brazil and Portugal, and although occurring together the two genera seem to present different salinity tolerances.

STUDY AREAS

Potiguar Basin, Brazil

The Potiguar Basin is located in the intersection of the Equatorial Margin with the East Continental Margin, comprising an area of approximately 48,000 km², being 21,500 km² of emerged area and 26,500 km² of submerged area (Figure 1). The Potiguar Basin is the easternmost of the Equatorial Margin basins, being, however, genetically related to a series of intracontinental basins of the Lower Cretaceous that represent the rift system of the Brazilian Northeast (Bertani *et al.*, 1990).

Geologically, it is limited, to the south, east and west by the crystalline basement and it extends to the North up to the isobath of 2,000 m. It is distributed mostly through the Rio Grande do Norte State and partially through the Ceará State (Mohriak, 2003; Pessoa Neto *et al.*, 2007). The Potiguar Basin was formed by extensional processes during the Early Cretaceous associated with the rifting which culminated in the separation of the South-American and African plates.

Pessoa Neto *et al.* (2007) have divided the stratigraphical record of the Potiguar Basin into three supersequences: rift, deposited in the Early Cretaceous (Berriasian-early Aptian) and represented by fluvial-deltaic and lacustrine deposits of the Pendência and Pescada formations; post-rift, deposited during the Alagoas Stage (late Aptian-early Albian) and characterized by fluvial-deltaic deposits, with the first records of marine ingression (Alagamar Formation); and drift comprising the whole marine sedimentation occurring since the early Albian up to the Recent (including Açú, Ponta do Mel, Quebradas, Jandaíra, Ubarana, Guamaré, Macau, Tibau and Barreiras formations).

The Jandaíra Formation results from the first great marine ingression which originated from the north (Brito, 1976). This unit is mainly represented by calcarenites and bioclastic calcilutites, deposited in environments ranging from tidal flat to shallow platform (Monteiro & Faria, 1988; Araripe & Feijó, 1994). Rocks of this formation crop out in almost the whole emerged portion of the basin and dip at a low angle towards the Atlantic Ocean. Its thickness varies from a few dozens to 600 m (Pessoa Neto *et al.*, 2007). Araripe & Feijó (1994), re-examining some Petrobras reports, have attributed a Turonian-Campanian age to the formation, which was later corroborated by Pessoa Neto *et al.* (2007).

Lusitanian Basin

The Lusitanian Basin (Figure 2) is a sedimentary basin which has developed in the Western Iberian Margin during the Mesozoic, occupying an area of over 20,000 km², from which about 2/3 are emerged in the continental area (Kullberg *et al.*, 2013). The basin is limited to the north and to the east by the Hesperian Massif (Porto-Tomar Fault), to the west by basement horsts of which one crops out at the Berlengas Islands and to the south by the Arrábida fault. Based on facies variations, thickness of the lithostratigraphic units and tectonic characteristics, the basin is divided into three sectors: northern, central and southern (Ribeiro *et al.*, 1996; Kullberg *et al.*, 2000).

Figure 1. Map of the Potiguar Basin, onshore part, with location of the well 9-MO-13-RN (modified from Monteiro & Faria, 1988).

Figure 2. Onshore part of the Lusitanian Basin with its three sectors (adapted from Kullberg *et al.*, 2013).

The evolution of this basin was conditioned by the late Variscan faulting about 300-280 Myr ago (Ribeiro *et al.*, 1979) and by the Mesozoic extension related to the opening of the Northern Atlantic (*e.g.* Kullberg *et al.*, 2013). During this extension period many rifting episodes occurred, which have been divided by some authors in four main events, since the Triassic up to the upper Aptian (Kullberg *et al.*, 2013).

In the Cenomanian, the Lusitanian Basin was in a post-rift stage in which there was carbonate sedimentation and extension of the carbonate platform to the north and east and retraction of the clastic adjacent systems. Two formations in the Lisbon-Sintra region are part of this stage (Rey *et al.*, 2006), being described as Belasian (old terminology) of Choffat (1885): the Caneças Formation, at the base, corresponding to the two upper levels of the Belasian, represented mainly by oyster-rich marls and marly limestones bearing many ostracodes, characteristic of marginal-lagoonal environments; and the Bica Formation, at the top (upper Cenomanian) corresponding to the “*Neolobites vibrayeanus* Level” (Choffat, 1885), associated with the rudist limestones from a more open subtidal marine environment.

The sedimentary sequence at São João das Lampas is stratigraphically correlated with the Lousa sequence (Cabral *et al.*, 2008) and corresponds to the Caneças Formation (Rey *et al.*, 2006). Being about 30 m thick, this sequence is represented, as many others of the same age in the Lisbon/Sintra region (*e.g.* Cacém and Carenque), by massive limestone, marly limestones and marl and black clays from the lower? and middle Cenomanian (Berthou, 1984).

MATERIAL AND METHODS

The well 9-MO-13-RN was drilled in 1979 and cored a thick section of carbonates deposited in tidal flat, lagoon and bioclastic bar systems. For this study, a 20 m interval was analyzed, from where 51 samples were selected, covering the Santonian-Campanian interval of the Potiguar Basin. This well is located on the Mossoró town, Rio Grande do Norte State (Monteiro & Faria, 1988; Viviers *et al.*, 2000). The samples were weighed (approximately 60 g), disaggregated with hydrogen peroxide (35% concentration), washed through 0.250 mm, 0.180 mm and 0.063 mm mesh sieves and dried in an oven at 60°C. The ostracode fauna varies its diversity, abundance and preservation through the sampling of the well 9-MO-13-RN. The dominant marine species *Protocosta babinoti* Piovesan, Cabral & Colin, 2014, *Cophinia ovalis* Piovesan, Cabral & Colin, 2014, *Semicytherura musachioi* Piovesan, Cabral & Colin, 2014, *Ovocytheridea anterocompressa* Piovesan, Cabral & Colin, 2014 and *Ovocytheridea triangularis* Piovesan, Cabral & Colin, 2014 are well preserved, represented by different ontogenetic stages in many samples, indicating low reworking of the material. The *Perissocytheridea* and *Fossocytheridea* species are very well preserved and with a large number of instars, highlighting that they are probably *in situ*. All studied specimens of the well 9-MO-13-RN are housed at Museum of Paleontology of Universidade do Vale do Rio dos Sinos, Brazil.

From the Lusitanian Basin 25 marly samples from the upper part of the São João das Lampas (middle Cenomanian) section were selected for ostracode studies. This section was studied and sampled for the first time in 1999 by M.C. Cabral and A.C. Azerêdo (University of Lisbon) and locally re-sampled in 2012 (only few samples from the upper part, 12 m, 22 lithologically distinct levels). Each sample (~300 g) was dried and treated during 24 h, at room temperature, with commercial pink oil (used for illumination) to disaggregate the marl. Then, it was washed through 2 mm, 0.5 mm, 0.150 mm and 0.063 mm mesh sieves and dried in an oven at 50°C. The ostracodes were very abundant but not well preserved, frequently recrystallized and worn, especially the transported marine forms (generally rare). It is also possible that the lagoonal forms themselves were reworked by storm currents. A large number of instars of the mixohaline *Fossocytheridea merlensis* and the marine *Paracaudites* (*Dumontina*) aff. *grekoffi* (Babinot, 1971) were found; *Perissocytheridea estribeirensis* is well represented, with both adults and juveniles, in one sample only. The ostracodes of the Lusitanian Basin are housed at Cabral Collection, Departamento de Geologia, Faculdade de Ciências, Universidade de Lisboa, Portugal.

The *Fossocytheridea* and *Perissocytheridea* species of the Potiguar and Lusitanian Basins were analyzed, as well as the abundance (number of individuals) and the diversity (number of species) of ostracodes associated to them. For the calculation of these two parameters it was considered that one individual (specimen) = one carapace or one valve.

The graphic presented was elaborated using C2 software (available at <http://www.staff.ncl.ac.uk/staff/stephen.juggins/software/C2Home.htm>). The abundance was grouped according to the classes: 1-4, 5-20, 21-100, 101-200, ≥201 (specimens).

RESULTS AND DISCUSSION

In the material from the well 9-MO-13-RN, Potiguar Basin (Piovesan *et al.*, 2014b), were identified *Fossocytheridea potiguarensis* Piovesan, Cabral & Colin, 2014, *Fossocytheridea* POT 1 Piovesan, Cabral & Colin, 2014 (Figures 3A-F) and *Perissocytheridea jandairensis* Piovesan, Cabral & Colin, 2014 (Figures 3G-I). At the São João das Lampas section the species *Fossocytheridea merlensis* (Babinot & Colin, 1976) (Figures 3J-L) and *Perissocytheridea estribeirensis* Andreu, 1981 (Figures 3M-O) were registered.

In Potiguar Basin, *Fossocytheridea* is the most abundant mixohaline genus (sample 33.80 m), while *Perissocytheridea* occurs most frequently (number of samples). The analysis of the studied species distribution (Figure 4) along the well 9-MO-13-RN, shows that *Perissocytheridea jandairensis* occurs associated in many levels with the marine ostracode fauna, which generally presents low diversity and abundance. In rare samples, *P. jandairensis* occurs alone (40.90 m; 35.60-35.00 m). Furthermore, the species is most abundant in levels in which it occurs associated with *Fossocytheridea potiguarensis*. A similar pattern has been observed in *Perissocytheridea cretacea* (Piovesan *et al.*, 2010) recorded

Figure 3. A-C, *Fossocytheridea potiguarensis* Piovesan, Cabral & Colin, 2014. A, f, C, RV, sample 33.80 m; B, f, C, DV, sample 33.80 m; C, m, C, RV, sample 33.80 m. D-F, *Fossocytheridea* POT 1 Piovesan, Cabral & Colin, 2014. D, f, C, RV, sample 38.00 m; E, m, C, RV, sample 39.60 m; F, f, C, DV, sample 33.00 m. G-I, *Perissocytheridea jandairensis* Piovesan, Cabral & Colin, 2014. G, f, C, RV, sample 34.00 m; H, f, C, DV, sample 46.05 m; I, m, C, RV, sample 33.80 m. J-L, *Fossocytheridea merlensis* (Babinot & Colin, 1976). J, f, C, RV, sample LAP-4; K, m, RV, sample LAP-8; L, f, C, DV, sample LAP-4. M-O, *Perissocytheridea estribeirensis* Andreu, 1981. M, f, C, RV, sample LAP-16; N, f, C, DV, sample LAP-16; O, m, C, RV, sample LAP-16. **Abbreviations:** C, carapace; DV, dorsal view; RV, right view; f, female; m, male. Scale bars = 100 μm.

Figure 4. Species distribution of *Fossocytheridea*, *Perissocytheridea* and associated marine ostracodes in the Santonian-Campanian from the well 9-13-MO-RN, Potiguar Basin, Brazil and in the middle Cenomanian section of São João das Lampas, Lusitanian Basin, Portugal. The vertical scales in both sections represent sample levels. For the Potiguar Basin the interval sampled was 26.60 to 46.60 m below the surface, and in the Lusitanian Basin the samples LAP-1 to LAP-22 were collected over a section interval of 12 m.

in the Santonian-Campanian of the Santos Basin, Brazil. *P. cretacea* occurs associated with *Fossocytheridea* spp., when it is most abundant, but it is also found associated with typically marine species (Piovesan *et al.*, 2010; Bergue *et al.*, 2011). These data demonstrate the euryhaline character of the *Perissocytheridea* species which occurs in the Brazilian Santonian-Campanian.

The two species of the genus *Fossocytheridea* from the Potiguar Basin do not occur associated, which seems to indicate that they possess a different tolerance to salinity. *Fossocytheridea* POT 1 occurs always in association with *Perissocytheridea jandairensis* and in levels with the presence of the marine genera *Ovocytheridea* Grékoff, 1951, *Cophinia* Apostolescu, 1961, *Protocosta* Bertels, 1969, *Cytherella* Jones, 1849 and *Soudanella* Apostolescu, 1961. In the levels 34.05 to 33.80 m, *Fossocytheridea potiguarensis* is very abundant and is associated with only one species from the marine genus *Ovocytheridea*.

In the Santonian-Campanian interval of the Santos Basin, *Fossocytheridea* is the mixohaline genus most diversified and abundant (Bergue *et al.*, 2011; Fauth *et al.*, 2012), especially in a mesohaline environment, in association with *Perissocytheridea* spp. On the other hand, *Fossocytheridea posterodentata* Bergue *et al.*, 2011 occurs in an oligohaline environment in association with the non-marine genera *Cyprois* Zenker, 1854 and *Ilyocypris* Brady & Norman, 1889 and charophytes.

At the São João das Lampas section (Figure 4), among the mixohaline species recorded, *Fossocytheridea merlensis* is significantly the most abundant and frequently species, sometimes forming monospecific associations with over a thousand individuals. *F. merlensis* almost always occurs in levels with low diversity and low abundance of marine specimens, such as *Dolocytheridea* Triebel, 1938, *Cythereis* Jones, 1849, *Trachyleberidea* Bowen, 1953, *Cytherella* Jones, 1849. *Perissocytheridea estribeirensis*, generally poorly represented, occurs always in association to *F. merlensis* and in levels poor in marine taxa; the greatest abundance of marine specimens occurs precisely at the levels where there is no *P. estribeirensis* (LAP-14B, LAP-14T and LAP-18M levels), which clearly demonstrates the mixohaline character of this species.

Further south, in the Lisbon region, in Lousa section, stratigraphically equivalent to São João das Lampas, Cabral *et al.* (2008) have also identified the two mixohaline ostracode species discussed: *Fossocytheridea merlensis* and *Perissocytheridea estribeirensis*. Their distribution along the Lousa section is similar to the one verified in São João das Lampas, with *F. merlensis*, much more abundant and frequently occurring (number of samples), sometimes forming monospecific associations of over a thousand individuals, but occurring also in association with marine genera (in this case *F. merlensis* presents a much lower quantity). At Lousa an oligohaline level attributed to a shallow water environment subject to emersion periods must be highlighted, where *F. merlensis* is associated with charophytes, *Heterocypris berthouli* Cabral & Colin, 2008 and *Globotalicypridea vulcanosa* Cabral & Colin, 2008, two ostracode species which range from fresh to brackish water habitats (Cabral *et al.*, 2008). The very

frequent occurrence of *F. merlensis* in this level demonstrates its capacity to tolerate very strong salinity variations, from nearly-freshwater to marine. *P. estribeirensis*, always low in abundance, has a similar behavior in Lousa relative to São João das Lampas, only occurring in levels without or with very few marine genera, which are much better represented in Lousa. Andreu (1978, 1981) described *P. estribeirensis* in the Cenomanian of Varge Mondar section, Lisbon region, occurring in a single level (lagoonal?), together with shallow water marine genera, such as *Dolocytheridea*, *Schuleridea* Swartz & Swain, 1946 and *Cornicythereis*? Gründel, 1966.

The observation that the salinity tolerance of the genus *Fossocytheridea* is related to the individual species is also indicated by data from studies from other regions. Tibert *et al.* (2003) demonstrated that *Fossocytheridea mosbyense* Tibert *et al.*, 2003 is associated with marine ostracodes and planktonic foraminifera marking the most distal brackish water deposits within an estuarine facies in the Cretaceous of Utah, USA. In more landward position, the same authors recovered a monospecific population of *Fossocytheridea kirklandi* Tibert *et al.*, 2003 occurring with charophytes and non-marine gastropods. Also with respect to *Fossocytheridea*, Damotte (1988) in a study with samples from the Cretaceous of the Gulf of Mexico, recorded a species of the genus associated with marine genera *Neocythere* Mertens, 1956 and *Paracypris* Sars, 1866, which was interpreted as indicative of an intertidal to subtidal environment.

Perissocytheridea species have been found in different environmental contexts within the marginal marine environment. Uliana & Musacchio (1978) recorded the species *P. informalis* Uliana & Musacchio, 1978 associated with the non-marine ostracode genera *Ilyocypris* Brady & Norman, 1889 and *Wolburgiopsis* Uliana & Musacchio, 1978, in the Late Cretaceous of Argentina. The paleoecological plasticity of *Perissocytheridea* was also observed in Late Cretaceous species of Morocco, where Andreu (1996) recorded *Perissocytheridea konatei* Vivière, 1985, associated with several marine ostracode species. Likewise, Piovesan *et al.* (2014a) recorded two species of *Perissocytheridea* in the Turonian of the Potiguar Basin associated with marine ostracodes, the latter more diversified and in low abundance, in a marginal marine context.

CONCLUSIONS

Generally, the studied material from the well 9-MO-13-RN, Potiguar Basin, represents a mixohaline environment with salinity variations through the sampled interval. *Perissocytheridea jandairensis* is an euryhaline species occurring in association with both *Fossocytheridea* and typically marine species. Comparing the two *Fossocytheridea* species from the Potiguar Basin, *F. POT 1* seems restricted to less saline environments.

In São João das Lampas, Lusitanian Basin, the depositional environment is also mixohaline, with salinity variations through the studied interval. Based on the two mixohaline species present, it is concluded that

Fossocytheridea merlensis is more tolerant to salinity variations than *Perissocytheridea estribeirensis*, for it occurs individually (which means that the environmental conditions must have been very stressful and may correspond both to a hypohaline environment as to a hyperhaline one), but also associated with marine species in the levels where those are most abundant. *P. estribeirensis* has more restricted characteristics, seeming to be limited to exclusively mixohaline environments.

Comparatively, the two studied genera show a different behavior in Brazil and in Portugal: *Perissocytheridea jandairensis* seems to tolerate conditions of higher salinity than *Perissocytheridea estribeirensis*. On the other hand, *Fossocytheridea merlensis* withstands important variations in salinity, which does not seem to occur in the *Fossocytheridea* species of the Potiguar Basin.

The results suggest that, in the Late Cretaceous, both *Fossocytheridea* and *Perissocytheridea* were euryhaline and their tolerance to salinity gradients, in the mixohaline context, is related to the ecology of each individual species.

ACKNOWLEDGEMENTS

E.K. Piovesan is indebted to CAPES for the PDSE scholarship, process number 18919/12-0, for studies at the FCUL, in Portugal and CNPq (proc. 473140/2011-0) for the financial support for field activities in Potiguar Basin. G. Fauth thanks CNPq (The Brazilian Scientific and Technology Developing Council) for the grant (proc. 308544/2012-9). Thanks are also due to M.C. Viviers (Petrobras/Cenpes/BPA) for the support in the study of the Potiguar Basin and to C.T. Bergue (itt Fossil-UNISINOS) for the discussion of the faunistic data of the Santos Basin in this work. The authors gratefully acknowledge A.C. Azerêdo (Department of Geology, FCUL) for the text revision, support in the fieldwork and in the establishment of the stratigraphical basis of the São João das Lampas section; R. Martins (Petrobras/Cenpes/BPA), M.G. Silva (itt Fossil-UNISINOS) and T. Nunes (CBA, FCUL) for the SEM photographs. Finally, we thank A. Lord (Germany) and C.T. Bergue (Brazil) for their helpful and constructive reviews.

REFERENCES

Andreu, B. 1978. *Ostracodes albiens et cénomaniens dans la zone Sud-Pyrénéenne, les Chaines Iberiques Aragonaises, le Portugal*. Travaux du Laboratoire de Géologie de l'Université Paul Sabatier, Thèse 3^{ème} cycle, 290 p.

Andreu, B. 1981. Nouvelles espèces d'ostracodes de l'Albien et du Cénomaniens d'Estremadura (Portugal). *Ciências da Terra*, 6:483-509.

Andreu, B. 1996. Nouvelles espèces d'ostracodes du Turonien supérieur (?)-Coniacien (?)-Santonien de la région de Boulmane, Moyen Atlas, Maroc. Systématique, biostratigraphie, paléoécologie et paléobiogéographie des associations. In: S. Jardiné, I. de Klasz & J.P. Debenay (eds.) *Géologie de l'Afrique et de l'Atlantique Sud*, Actes des Colloques de géologie d'Angers, p. 483-509.

Araípe, P.T. & Feijó, F.J. 1994. Bacia Potiguar. *Boletim de Geociências da Petrobras*, 8:127-141.

Babinot, J.-F. 1988a. Données préliminaires sur les associations d'ostracodes du Cénomaniens de Grèce (Zone sub-pélagonienne, Argolide). Implications paléobiogéographiques et géodynamiques. *Geobios*, 21:435-463. doi:10.1016/S0016-6995(88)80044-5

Babinot, J.-F. 1988b. Première donnée sur les ostracodes du Cénomaniens de Yougoslavie (Istrie du Sud). *Geobios*, 21:5-15. doi:10.1016/S0016-6995(88)80028-7

Babinot, J.-F. & Colin, J.-P. 1976. *Sarlatina* n.g. (Ostracoda): sa position dans l'évolution des Cyprideidini Kollmann, 1960. In: INTERNATIONAL SYMPOSIUM ON EVOLUTION OF POST-PALEOZOIC OSTRACODA, 5, 1976. *Proceedings*, Hamburg NF, p. 161-174.

Bergue, C.T.; Fauth, G.; Vieira, C.E.L.; Santos, A.S. & Viviers, M.C. 2011. New species of *Fossocytheridea* Swain & Brown, 1964 (Ostracoda, Crustacea) in the Upper Cretaceous of Santos Basin, Brazil. *Revista Brasileira de Paleontologia*, 14:149-156. doi:10.4072/rbp.2011.2.03

Bertani, R.T.; Costa, I.G. & Matos, R.M.D. 1990. Evolução tectono-sedimentar, estilo estrutural e "habitat" do petróleo na Bacia Potiguar. In: G.P.R. Gabaglia & E.J. Milani (eds.) *Origem e Evolução de Bacias Sedimentares*, PETROBRAS, p. 291-310.

Berthou, P.-Y. 1984. Résumé synthétique de la stratigraphie et de la paléogéographie du Crétacé moyen et supérieur du bassin occidental portugais. *Geonovas*, 7:99-120.

Boomer, I. & Eisenhauer, G. 2002. Ostracod faunas as palaeoenvironmental indicators in marginal marine environments. In: A.H. Holmes & A.R. Chivas (eds.) *The Ostracoda: applications to Quaternary research*, AGU, p. 135-149. doi:10.1029/131gm07

Brito, I.M. 1976. História geológica das bacias sedimentares do Nordeste do Brasil. *Anais da Academia Brasileira de Ciências*, 48:463-474.

Cabral, M.C.; Azerêdo, A.C. & Boavida, E.A. 2014. Improving palaeoecological understanding of the Cenomanian units in Lisboa-Sintra region: the S. João das Lampas section. In: R. Rocha; J. Pais; J.C. Kullberg & S. Finney (eds.) *STRATI 2013*. First International Congress on Stratigraphy: at the cutting edge of Stratigraphy, Springer, p. 1055-1060. doi:10.1007/978-3-319-04364-7_201

Cabral, M.C.; Colin, J.-P. & Azerêdo, A.C. 2008. Taxonomy and palaeoecology of new brackish ostracod species from the Middle Cenomanian of Lousa, Lisbon region, Portugal. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 264:250-262. doi:10.1016/j.palaeo.2007.04.019

Choffat, P. 1885. *Recueil de monographies stratigraphiques sur le Système Crétacique du Portugal*. 1^{ère} étude: contrées de Cintra, de Bellas et de Lisbonne. Section des Travaux Géologiques du Portugal, Lisboa, 68 p.

Coimbra, J.C.; Costa, K.B. & Fauth, G. 2006. Palaeoenvironmental significance of allochthonous vs. autochthonous Late Quaternary ostracodes from Imaruí Lagoon and d'Una River, southern Brazil. *Revista Brasileira de Paleontologia*, 9:295-302.

Colin, J.-P.; Carbonel, P. & Olteanu, R. 1990. A review on the paleobiogeography and paleoecology of the closest groups of *Cytherissa* from the Mesozoic *Fabanella* and *Vernoniella* to the Cenozoic *Cyprideis*. *Bulletin de l'Institut de Géologie du Bassin d'Aquitaine*, 47/48:119-133.

Colin, J.-P.; Tambareau, Y. & Krasheninnikov, V.A. 1996. Ostracodes limniques et lagunaires dans le Crétacé supérieur du Mali (Afrique de l'Ouest): systématique, paléoécologie et affinités paléobiogéographiques. *Revue de Micropaléontologie*, 39:211-222. doi:10.1016/s0035-1598(96)90063-x

- Cronin, T.M. 1988. Ostracods and sea-level changes; case studies from the Quaternary of North and South Carolina, U.S. Atlantic Coast Plain. In: P. De Deckker, J.-P. Colin & J.-P. Peyrouquet (eds.) *Ostracoda in the Earth Sciences*, Elsevier, p. 77-88.
- Damotte, R. 1988. Ostracodes crétacés du forage 95, Campagne JOIDES 10, Golfe du Mexique. *Cretaceous Research*, **9**:159-170. doi:10.1016/0195-6671(88)90015-8
- Dias-Brito, D.; Moura, J.A. & Würdig, N.L. 1988. Relationships between ecological models based on ostracods and foraminifers from Sepetiba Bay (Rio de Janeiro-Brazil). In: T. Hanai; N. Ikeya & K. Ishizaki (eds.) *Evolutionary Biology of Ostracoda*, Elsevier, p. 467-484. doi:10.1016/S0920-5446(08)70202-4
- Fauth, G.; Santos, A.S.; Vieira, C.E.L.; Bergue, C.T.; Musachio, E.A.; Ferreira, E.P.; Escamilla, J.H.; Carvalho, M.A.; Viviers, M.C. & Fauth, S.B. 2012. Bioestratigrafia integrada do Cretáceo Superior da Bacia de Santos: ostracodes, carófitas e palinóforos. *Boletim de Geociências da Petrobras*, **20**:229-258.
- Frenzel, P. & Boomer, I. 2005. The use of ostracods from marginal marine, brackish waters as bioindicators of modern and Quaternary environmental change. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **225**:68-92. doi:10.1016/j.palaeo.2004.02.051
- Garbett, E. & Maddocks, R.F. 1979. Zoogeography of Holocene Cytheracean ostracodes in the bays of Texas. *Journal of Paleontology*, **53**:841-919.
- Gross, M.; Ramos, M.I.; Caporaletti, M. & Piller, W. 2013. Ostracoda (Crustacea) and their palaeoenvironmental implications for the Solimões Formation (Late Miocene, Western Amazonia, Brazil). *Journal of South American Earth Science*, **42**:216-241. doi:10.1016/j.jsames.2012.10.002
- Keyser, D. 1977. Ecology and zoogeography of Recent brackish-water Ostracoda (Crustacea) from south-west Florida. In: H. Löffler & D. Danielopol (eds.) *Aspects of Ecology and Zoogeography of Recent and Fossil Ostracoda*, Dr. W. Junk b.v. Publishers, p. 207-221.
- Kullberg, J.C.R. 2000. *Evolução tectônica mesozóica da Bacia Lusitaniana*. Universidade Nova de Lisboa, Ph.D. Thesis, 361 p.
- Kullberg, J.C. et al. 2013. A Bacia Lusitaniana: estratigrafia, paleogeografia e tectônica. In: R. Dias; A. Araújo; P. Terrinha, & J.C. Kullberg (eds.) *Geologia de Portugal, Geologia Mesozoica de Portugal*, Escolar Editora, p. 195-347.
- Mebrouk, F.; Colin, J.-P. & Hennache, F. 2011. Un gisement d'ostracodes non-marins dans l'Éocène inférieur du Djebel Amour, Atlas saharien central, Algérie : taxonomie, paléoécologie et paléobiogéographie. *Carnets de Géologie / Notebooks on Geology*, **4**:83-97. doi:10.4267/2042/42328
- Medley, P.; Tibert, N.E.; Patterson, W.P.; Curran, H.A.; Greer, L. & Colin, J.-P. 2007. Paleosalinity history of middle Holocene lagoonal and lacustrine deposits in the Enriquillo Valley, Dominican Republic based on pore morphometrics and isotope geochemistry of Ostracoda. *Micropaleontology*, **53**:409-419. doi:10.2113/gsmicropal.53.5.409
- Mohriak, W.U. 2003. Bacias sedimentares da margem continental brasileira. In: L.A. Bizzi; C. Schobbenhaus; R.M. Vidotti & J.H. Gonçalves (eds.) *Geologia, Tectônica e Recursos Minerais do Brasil*, CPRM, p. 87-94.
- Monteiro, M.C. & Faria, T.R. 1988. Planície de maré no poço 9-MO-13-RN, Formação Jandaíra - um exemplo do passado. In: CONGRESSO BRASILEIRO DE GEOLOGIA, **35**, 1998. *Anais*, Belém, p. 809-823.
- Morsi, A.M.M. & Wendler, J.E. 2010. Biostratigraphy, palaeoecology and palaeogeography of the Middle Cenomanian-Early Turonian Levant Platform in Central Jordan based on ostracods. In: C. Homberg & M. Bachmann (eds.) *Evolution of the Levant Margin and Western Arabia Platform since the Mesozoic*. London, Geological Society, p. 187-210 (Special Publications 34).
- Neale, J.W. 1988. Ostracodes and palaeosalinity reconstructions. In: P. De Deckker, J.-P. Colin & J.-P. Peyrouquet (eds.) *Ostracoda in the Earth Sciences*, Elsevier, p. 125-155.
- Nicolaidis, D.D. & Coimbra, J.C. 2008. *Perissocytheridea carrenoae* sp. nov. (Crustacea, Ostracoda) and associated calcareous microfauna from Yecua Formation (Miocene), Bolivia. *Revista Brasileira de Paleontologia*, **11**:179-186. doi:10.4072/rbp.2008.3.04
- Pessoa Neto, O.C.; Soares, U.M.; Silva, J.G.F.; Roesner, E.H.; Florencio, C.P. & Souza, C.A.V. 2007. Bacia Potiguar. *Boletim de Geociências da Petrobras*, **15**:357-387.
- Piovesan, E.K.; Bergue, C.T. & Fauth, G. 2010. New ostracode species from the Upper Cretaceous of the Santos Basin, Brazil. *Revista Brasileira de Paleontologia*, **13**:175-180. doi:10.4072/rbp.2010.3.02
- Piovesan, E.K.; Cabral, M.C.; Colin, J.-P.; Fauth, G. & Bergue, C.T. 2014a. Ostracodes from the Upper Cretaceous deposits of the Potiguar Basin, Northeastern Brazil: taxonomy, paleoecology and paleobiogeography, part 1: Turonian. *Carnets de Géologie / Notebooks on Geology*, **14**:211-252. doi:10.4267/2042/54003
- Piovesan, E.K.; Cabral, M.C.; Colin, J.-P.; Fauth, G. & Bergue, C.T. 2014b. Ostracodes from the Upper Cretaceous deposits of the Potiguar Basin, Northeastern Brazil: taxonomy, paleoecology and paleobiogeography, part 2: Santonian-Campanian. *Carnets de Géologie / Notebooks on Geology*, **14**:315-351. doi:10.4267/2042/54151
- Rey, J.; Dinis, J.L.; Callapez, P. & Cunha, P.P. 2006. *Da rotura continental à margem passiva. Composição e evolução do Cretácico de Portugal*. Cadernos de Geologia de Portugal, INETI, 75 p.
- Ribeiro, A.; Antunes, M.T.; Ferreira, M.P.; Rocha, R.B.; Soares, A.F.; Zbyszewski, G.; Almeida, F.M.; Carvalho, D. & Monteiro, J.H. 1979. *Introduction à la Géologie Générale du Portugal*. Lisboa, Serviços Geológicos de Portugal, 114 p.
- Ribeiro, A.; Silva, J.B.; Cabral, J.; Dias, R.; Fonseca, P.; Kullberg, M.C.; Terrinha, P. & Kullberg, J.C. 1996. *Tectonics of the Lusitanian Basin*. Final Report Project MILUPOBAS, Contract nº JOU-CT94-0348, ICTE/GG/GeoFCUL, Lisboa, 126 p.
- Rosenfeld, A. & Vesper, B. 1977. The variability of the sieve pores in Recent and fossil species of *Cyprideis torosa* (Jones, 1850) as an indicator for salinity and palaeosalinity. In: H. Löffler & D. Danielopol (eds.) *Aspects of Ecology and Zoogeography of Recent and Fossil Ostracoda*, Dr. W. Junk b.v. Publishers, p. 55-67.
- Sandberg, P.A. 1964. The ostracod genus *Cyprideis* in the Americas. *Stockholm University Contributions in Geology*, **12**:1-234.
- Szczuchura, J.; Abd-Elshafy, E. & Babinot, J.-F. 1991. Late Albian to Early-Mid-Cenomanian ostracodes from Northern Galala Plateau, Egypt. *Acta Paleontologica Polonica*, **36**:3-38.
- Swain, F.M. & Brown, P.M. 1964. Cretaceous Ostracoda from wells in the southeastern United States. *Bulletin of North Carolina Department of Conservation and Development*, **78**:1-55.
- Tibert, N.; Colin, J.-P. & Leckie, M. 2009. Taxonomy, biostratigraphy and paleoecology of Cenomanian and Turonian ostracodes from the Western Interior Basin, Southwest Utah, USA. *Revue de Micropaléontologie*, **52**:85-106. doi:10.1016/j.revmic.2007.02.006
- Tibert, N.E.; Colin, J.P.; Leckie, R.M. & Babinot, J.P. 2003. Revision of the ostracode genus *Fossocytheridea* Swain & Brown, 1964: Mesozoic ancestral root for the modern eurytopic *Cyprideis* Jones. *Micropaleontology*, **49**:205-230. doi:10.1661/0026-2803(2003)049[0205:rotogf]2.0.co;2

- Tibert, N.; Leckie, R.M.; Eaton, J.G.; Kirkland, J.I.; Colin, J.-P.; Eithold, E. & McCormick, M.E. 2002. Recognition of relative sea-level change in Upper Cretaceous coal-bearing strata: a paleocological approach using agglutinated foraminifera and ostracodes to detect key stratigraphic surfaces. *In*: H. Olson & R.M. Leckie (eds.) *Micropaleontologic Proxies for Sea Level Change and Stratigraphic Discontinuities*. Tulsa, Society for Sedimentary Geology, p. 263-299 (Special Publication 75).
- Uliana, M.A. & Musacchio, E.A. 1978. Microfósiles calcáreos no marinos del Cretácico superior en Zampal, provincia de Mendoza, Argentina. *Ameghiniana*, **15**:111-135.
- Viviers, M.C.; Koutsoukos, E.A.M.; Silva-Telles, A.C. & Bengtson, P. 2000. Stratigraphy and biogeographic affinities of the late Aptian-Campanian ostracods of the Potiguar and Sergipe basins in northeastern Brazil. *Cretaceous Research*, **21**:407-455. doi:10.1006/cres.2000.0205

Received in August, 2014; accepted in December, 2014.