

Similarities of the K/Pc dinoflagellate cyst associations between South Atlantic and Indian proto-oceans

Similaridades entre associações de cistos de dinoflagelados, K/Pc nos proto-oceanos Atlântico Sul e Índico

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Abstract

In this contribution we present the composition of the Late Cretaceous / Paleocene dinoflagellate cyst assemblages found in the Pelotas Basin, southern Brazil in order to provide a first paleobiogeographical comparison between this location, India and other former Gondwana continents: South America (Argentina and Uruguay), Africa (Nigeria and Western Ghana), Antarctica, Australia, and New Zealand. A total of 13 taxa, some endemic and other cosmopolitan were identified. The paleoenvironment of the Gondwana former members basins, as previously presented and attested by the dinoflagellate cysts are marginal marine nearshore, varying from neritic to shallow neritic and lagoonal or coastal swamps, which permitted the deposition of sediments in anoxic marine conditions. The present analysis of similarity between K/Pc dinoflagellate cyst associations allowed the establishment of paleobiogeographic distribution.

Keywords: Cretaceous; Paleocene; Dinoflagellate cysts; Gondwanan paleobiogeographic distribution.

Resumo

Nesta contribuição analisamos a composição de assembleias de cistos de dinoflagelados encontrados em sedimentos da Bacia de Pelotas, sul do Brasil, durante o intervalo Cretáceo Superior - Paleoceno, com o objetivo de produzir uma primeira comparação com a Índia e outros continentes pertencentes ao Gondwana tais como América do Sul (Argentina e Uruguai), África (Nigéria e Oeste de Gana), Antártica, Austrália e Nova Zelândia. Um total de 13 espécies foi identificado, dentre as quais se observaram táxons endêmicos e cosmopolitas, que permitiram o reconhecimento de paleoambientes que variaram de nerítico raso, lagunar ou pantanoso costeiro, com deposição de sedimentos em condições anóxicas. A presente análise de similaridade entre essas associações de cistos de dinoflagelados permitiu o estabelecimento da distribuição paleobiogeográfica para a Bacia de Pelotas.

Palavras-chave: Cretáceo; Paleoceno; Cistos de dinoflagelados; Distribuição paleobiogeográfica Gondwana.

INTRODUCTION

Marine dinoflagellate cyst assemblages are an excellent proxy for the reconstruction of environmental changes in coastal environments (Brinkhuis, 1994; Sluijs et al., 2005; Pross and Brinkhuis, 2005; Vellekoop et al., 2015). They have also been used to reconstruct relative sea level changes (Sluijs et al., 2005). Recently, various workers have employed environmental requirements of extant taxa, including some species with chronological distribution since the Cretaceous, as well as their onshore-offshore distribution pattern to infer paleoenvironments (Sluijs et al., 2005, 2008; Sluijs and Brinkhuis, 2009; Vellekoop et al., 2015).

In coastal ecosystems, dinoflagellate cysts provide an excellent resource for the reconstruction of changes in basins in terms of nutrient loading, salinity and other environmental stress agents such as wave, current energy, temperature, and water column depth. They can also be indicative of more stable, normal marine and oligotrophic conditions found in offshore settings (Köthe, 1990; Vellekoop et al., 2015).

In this contribution we present Late Cretaceous/Paleocene dinoflagellate cyst assemblages found in the Pelotas Basin, southern Brazil in order to provide a first paleobiogeographical comparison between this location, India and former Gondwana continents: South America (Argentina and Uruguay), Africa (Nigeria and Western Ghana), Antarctica, Australia, and New Zealand (Figure 1). This study also corroborates to the survey of common dinoflagellate cyst taxa found in the Cretaceous of Brazil and India (Mehrotra et al., 2012). Detailed analyses on the composition and distribution of these taxa in the Pelotas Basin are given by Arai et al. (2006), Arai (2007), Premaor (2008), Premaor et al. (2010), Fischer (2012), Fischer et al. (2013) and Menezes (2014).

Paleoenvironments during the Late Cretaceous/Paleocene

Late Cretaceous dinoflagellate cyst associations in the Pelotas Basin reveal lower abundance and high diversity along with fungal and algal spores indicating continental shelf marine nearshore environments. The presence of the spore taxon *Cicatricosisporites* is suggestive of terrigenous contribution of inland waters (Premaor et al., 2010; Menezes, 2014). During the Paleocene, on the other hand, higher diversity and abundance of dinoflagellate cysts in synchrony with reduction of continental contribution suggests distal marine conditions (Menezes, 2014).

In Uruguay, Late Cretaceous sediments from the Punta del Este Basin contain high concentrations of continental elements and dinoflagellate cysts indicative of restricted and eutrophic environments and warmer climates, while Paleocene paleoenvironmental conditions suggest open sea conditions (Daners and Guerstein, 2004). In the Argentine Colorado Basin (Danian), the assemblages are made up of

dinoflagellate cysts and high amounts of continental elements such as spores and pollen grains that were deposited in marginal marine environments (Guerstein et al., 2005; Quattrocchio and Sarjeant, 1996; Quattrocchio and Ruiz, 1999).

According to Di Pasquo and Martin (2013), in the sediments of the Snow Hill Island Formation (early Maastrichtian), in Antarctica, dinoflagellate cysts co-occur with acritarchs indicating permanent marine paleoenvironmental conditions, occasionally marginal, limited by the number of dinoflagellate cysts species and increased continental elements. Micropaleontological data for the Lopez de Bertodano Formation (late Campanian-Maastrichtian) and Sobral Formation (early Paleocene) depict dinoflagellate cyst blooms in low salinity estuarine environments or under a closed bay condition with probable deposition in calm nearshore marine waters (Askin, 1988).

Dinoflagellate cyst zonation for wells within mesozoic sedimentary basins in Australia and in the Papuan Basin was proposed by Helby et al. (1987). In the Otway Basin (Santonian to Danian), a remarkable concentration of organic matter of continental origin in detriment of dinoflagellate cysts allowed Gallagher et al. (2005) to propose a scenario of delta plain progradational depositional settings.

In New Zealand, Upper Cretaceous-Paleocene sediments with dinoflagellate cysts occur in the Canterbury, East Coast and Great South basins. In the first basin the Late Cretaceous and Paleocene sediments were deposited in marine nearshore environments during a widespread marine transgressional event whereas some deposits reveal anoxic marine conditions with a strong terrestrial contribution (Willumsen, 2006). In the East Coast Basin, Late Cretaceous dinoflagellate cyst assemblages indicate a low-energy depositional environment deeper than the storm wave base (Crouch et al., 2014) whereas, Paleocene assemblages were interpreted as representative of a shallow-marine to nearshore environment (Hines et al., 2013; Crouch et al., 2014). During the Paleocene of the Great South Basin, abundant terrestrial palynomorphs in association with dinoflagellate cyst communities suggest marine nearshore depositional environments (Willumsen and Vajda, 2010).

In India, Upper Cretaceous - Paleocene sediments are present in several basins. For instance, in the Krishna-Godavari Basin, neritic (Maastrichtian) and deep neritic environments (Paleocene) were established based on dinoflagellate cyst assemblages. The Upper Cretaceous-Paleocene of the Cambay Basin contains sediments deposited under supratidal to intertidal conditions (Grover et al., 2010) whereas in the Cretaceous-Paleocene of the Cauvery Basin, the sediments vary in different locations. Rich dinoflagellate cyst assemblages showed a distinct transitional Maastrichtian/Paleocene, marine nearshore environment (Jain, 1978; Jain et al., 1983; Jain and Garg, 1986). On the other hand, in the Assam-Arakan Basin (late Maastrichtian-Paleocene) the sediments were deposited under marine conditions (Shukla et al., 2008).

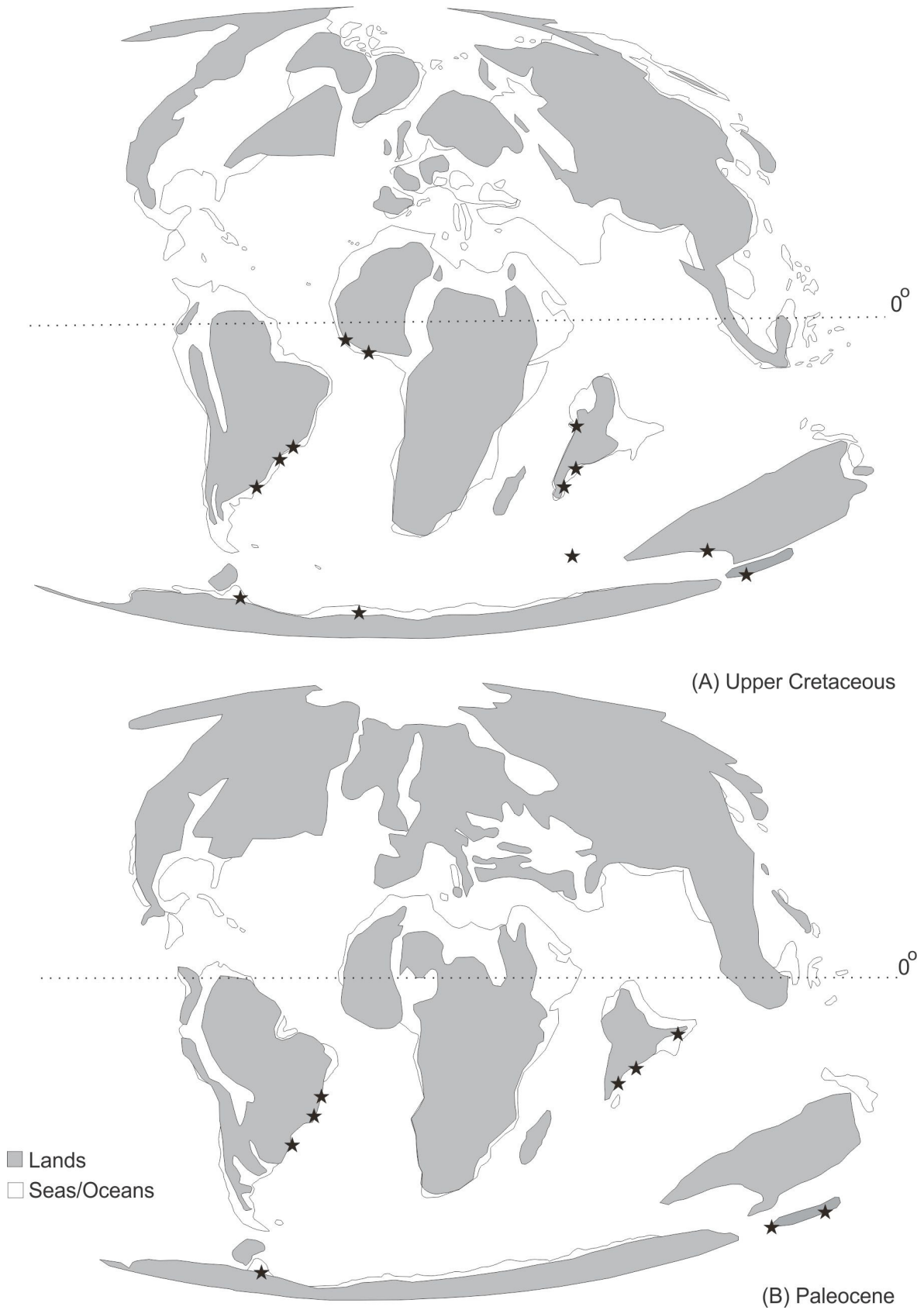


Figure 1. Localities of the dinoflagellate cysts used of the paleogeographic distribution. (A) Upper Cretaceous; (B) Paleocene.

In the southeastern Nigeria, the Anambra Basin dinoflagellate cysts occur with total dominance of terrestrial sporomorphs under shallow seas where, the late Campanian was marked by marine transgression and the Maastrichtian advancement of the shoreline and shallow marine to coastal swamp (Onuigbo et al., 2012). The Tano Basin, western Ghana, consists of the Cretaceous-Tertiary sediments deposited in a marginal marine environment (Atta-Peters and Salami, 2006).

MATERIALS AND METHOD

Dinoflagellate cysts from the Pelotas Basin were extracted following the procedures described by Oliveira et al. (2004), which are summarized as follows: 1- treatment of samples with hydrochloric acid (10% for 24 h.) to remove the carbonates, followed by three washes with distilled water; 2- treatment with hydrofluoric acid (HF 42%), for 48 h to remove the siliceous material, followed by four washes with distilled water; 3- treatment with hydrochloric acid maximum concentration on hot plate (100 °C) for 24 h, followed by three washes with distilled water to remove silicofluorites. After the chemical processing, the residues were sieved in a 5 µm sieve in order to eliminate excess amorphous organic matter. Permanent slides were prepared by mounting the residues in Entellan, which were then analyzed under both fluorescence and white light microscopy.

RESULTS AND DISCUSSION

The K/Pc sediments of the Pelotas Basin contain a total of 13 dinoflagellate cyst species co-occurring in the paleobiogeographic area (Figures 2 and 3). The common species in these basins are: *Cerodinium diebelii* (Alberti, 1959) Lentin and Williams 1987, *Chatangiella spectabilis* (Alberti, 1959) Lentin and Williams (1976), *Disphaerogena carposphaeropsis* (Wetzel, 1933), Sarjeant (1985), *Glaphyrocysta texta* Bujak (1976), *Hafniasphaera* cf. *H. septata* Cookson and Eisenack (1967), *Homotryblium tenuispinosum* Davey and Williams (1966), *Hystrichodinium* cf. *H. pulchrum* Deflandre (1936), *Isabelidinium pellucidum* Deflandre and Cookson (1955), *Manumiella? cretacea* (Cookson, 1956), Bujak and Davies (1983), *Paleocystodinium lidiae* (Górka, 1963), Davey (1969), *Paleocystodinium golzowense* Alberti (1961), *Tanyosphaeridinium* cf. *T. xanthiopyxides* (Wetzel, 1933) Morgenroth (1968), and *Trichodinium castanea* Deflandre (1935).

A total of 10 species found in the Late Cretaceous of the Pelotas Basin co-occur i.e., two in common with Uruguay; three with Argentina and Australia; four with Africa, India and New Zealand and six species with Antarctica. While in the Paleocene eight species are common between Brazil

(Pelotas Basin) and other localities: four in Argentina, two in Uruguay, two in Antarctica, three in India and two in New Zealand. But there are no species in common with Brazil, Africa and Australia (Table 1). In other Brazilian marginal basins, in Late Cretaceous eight species are common, while in Paleocene are four species (Tables 2A, 2B).

This analysis also revealed the presence of various cosmopolitan taxa, some of which are also reported for the northern hemisphere such as *Cerodinium diebelii*, *Hafniasphaera* cf. *H. septata*, *Homotryblium tenuispinosum*, *Manumiella? cretacea*, *Paleocystodinium golzowense* and *Trichodinium castanea*. Cosmopolitan species with worldwide distribution during the Late Cretaceous and Paleocene are *Cerodinium diebelii* and *Paleocystodinium golzowense*. Two of these taxa are restricted to the Late Cretaceous (*Trichodinium castanea*, *Isabelidinium* spp.) and only one to the Paleocene, *Hafniasphaera* cf. *H. septata*.

Chatangiella spectabilis, *Disphaerogena carposphaeropsis*, *Glaphyrocysta* cf. *H. texta*, *Hystrichodinium* cf. *H. pulchrum*, *Paleocystodinium lidiae* and *Tanyosphaeridinium* cf. *T. xanthiopyxides* are reported as endemic species in the Gondwanan territories, while *Disphaerogena carposphaeropsis* is found in South and North hemisphere (Powell, 1992).

According to Premaor (2008), an ample ocean circulation connected the northern to austral proto-oceans, a fact corroborated by the diversity of taxa found in the present study. Distribution of dinoflagellate species in both hemispheres are interpreted as a result of bipolar migration of this species in response to the global warming during the early Danian (Smit and Brinkhuis, 1996; Nøhr Hansen and Dam, 1997; Brinkhuis et al., 1998; Willumsen, 2006; Slimani et al., 2010).

As shown in Figure 2, four taxa are restricted to the Late Cretaceous: *Chatangiella spectabilis*, *Isabelidinium pellucidum*, *Manumiella? cretacea* and *Trichodinium castanea* (Figures 2, 4D, 4H, 4I, 4J and Tables 1 and 2B), which are present in the southern Kerguelen Plateau (Mao and Mohr, 1992) and in the Pelotas Basin, Brazil (Premaor, 2008; Premaor et al., 2010; Menezes, 2014). *Isabelidinium pellucidum*, *Manumiella? cretacea* and *Trichodinium castanea* are recorded in Australia (Helby et al., 1987) and Antarctica (Amenábar et al., 2014), but in other basins only *Manumiella? cretacea* and *Trichodinium castanea* are reported (Askin, 1988; Di Pasquo and Martin, 2013; Castro and Carvalho, 2015). *Isabelidinium pellucidum* is reported from New Zealand (Roncaglia et al., 1999; Schiøler et al., 2002), whereas in Argentina, *Manumiella? cretacea* (Guerstein and Junciel, 2001; Guerstein et al., 2005) marks the K-Pc range. The first taxon (*Chatangiella spectabilis*) is reported from some Brazilian marginal basins, such as Campos Basin, (Arai, 2007) and the Ceará Basin (Lana and Roesner, 2002) while *Isabelidinium pellucidum*, and *Trichodinium castanea* are described in the Barreirinhas, Campos, Espírito Santos, Potiguar, Sergipe and Santos basins (Lana, 1997; Carvalho,

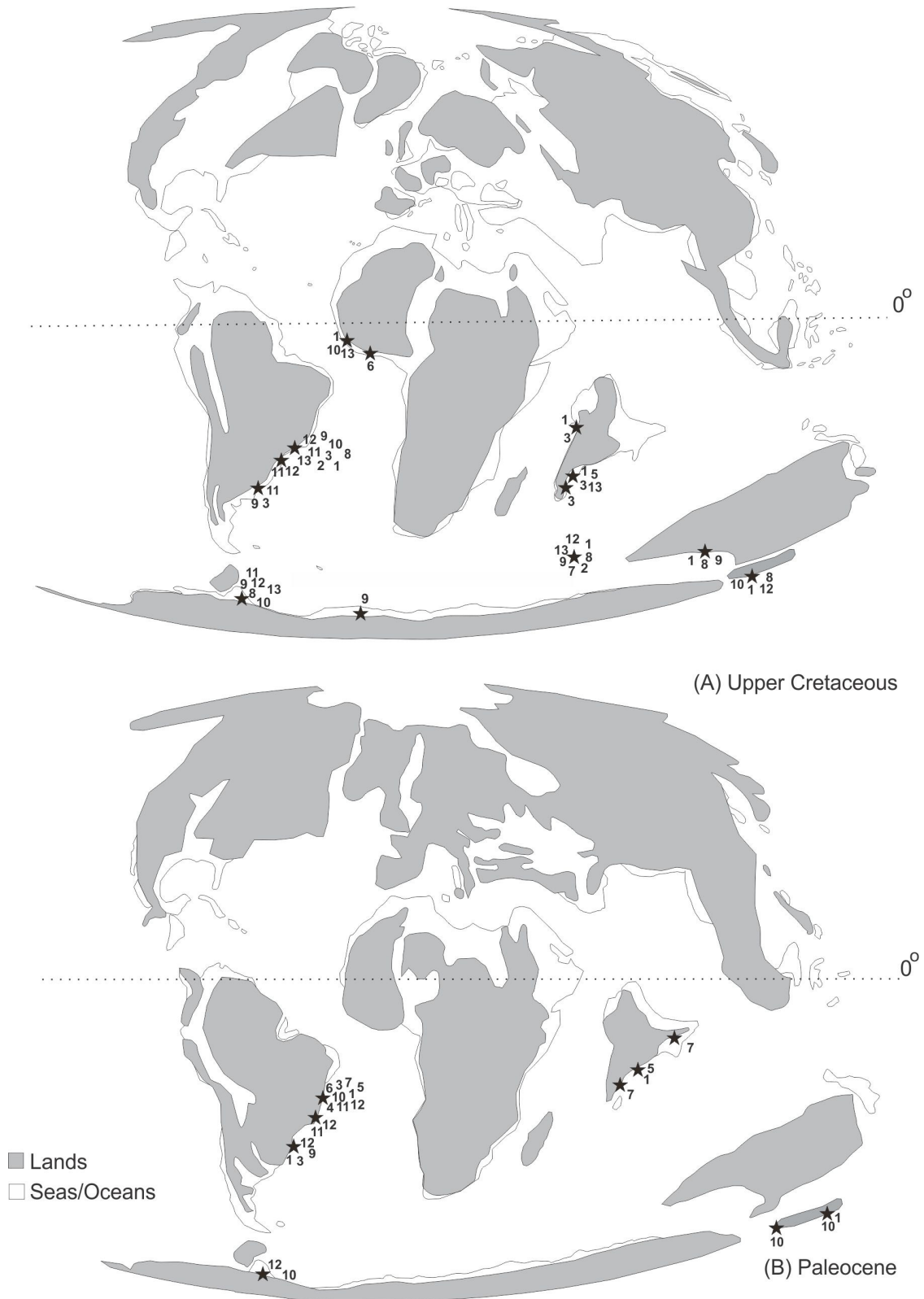


Figure 2. (A) Upper Cretaceous; (B) Paleocene. Paleogeographic distribution of the dinoflagellate cysts, legend: 1- *Cerodinium diebelii*; 2- *Chatangiella spectabilis*; 3- *Disphaerogena carposphaeropsis*; 4- *Glaphyrocysta texta*; 5- *Hafniasphaera* cf. *H. septata*; 6- *Homotryblium tenuispinosum*; 7- *Hystrichodinium* cf. *H. pulchrum*; 8- *Isabelidinium pellucidum*; 9- *Manumiella?* *cretacea*; 10- *Paleocystodinium golzowense*; 11- *P. lidiae*; 12- *Tanyosphaeridium* cf. *T. xanthiopyxides*; 13- *Trichodinium castanea*.

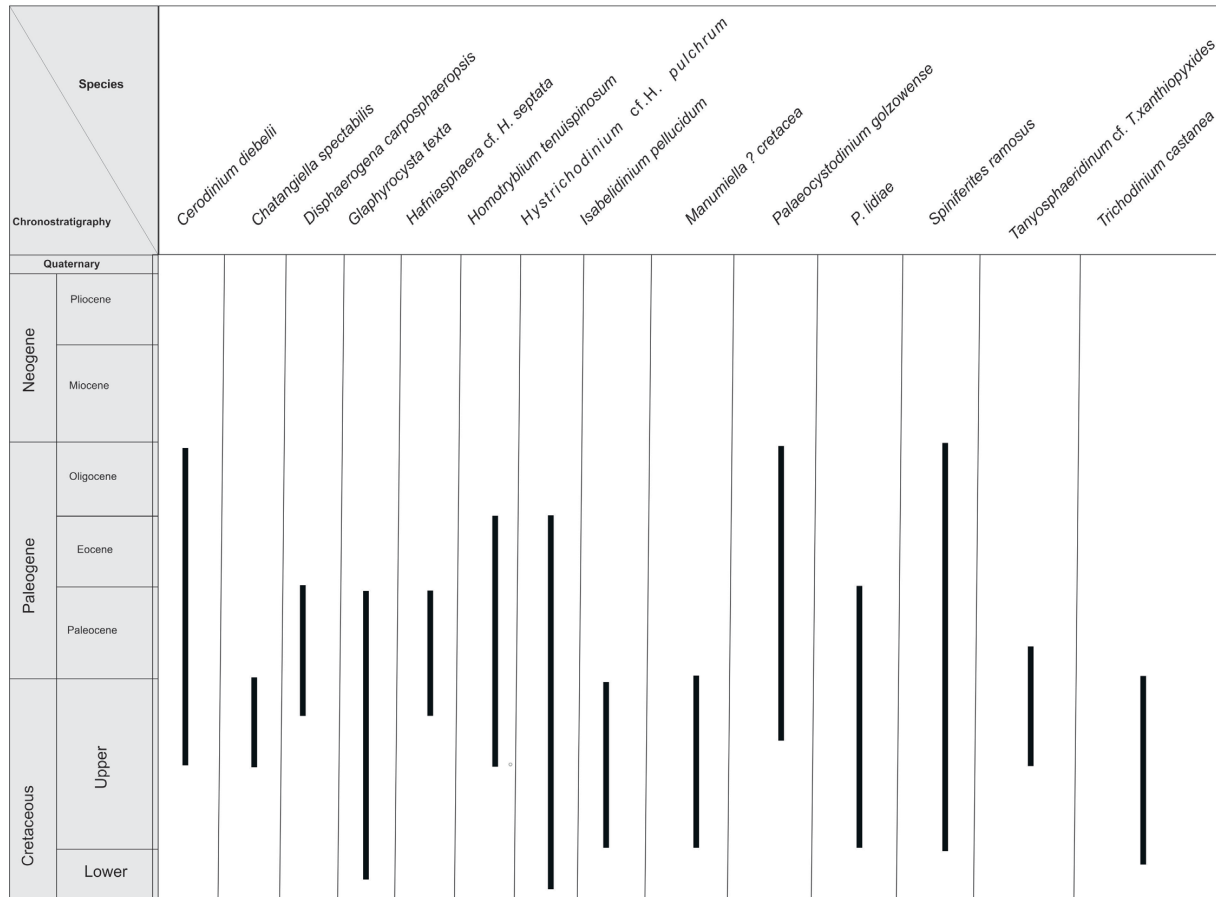


Figure 3. Proposed biostratigraphic distribution of the 13 species of dinoflagellate cysts found in the Pelotas Basin, according to paleogeographical patterns observed in former Gondwana basins.

2001; Arai, 2007; Fauth et al., 2012). Among these four species, *Trichodinium castanea* is the only species occurring in the Atlantic coast of Africa (Atta-Peters and Salami, 2006) and in India (Mehrotra et al., 2005, 2012). This taxon also suggests a cosmopolitan distribution due to its occurrence in both hemispheres. It is also noteworthy that Williams and Bujak (1985) and Williams et al. (1993) recorded it in the Northern Hemisphere (Valangian to late Campanian).

Cerodinium is a cosmopolitan genus of tropical and subtropical provinces (Lentin and Williams, 1980) while *Chatangiella* and *Isabelidium* indicated that their depositional areas were outside the tropical zone (Premaor et al., 2010). We suggest that the regions occupied by these genera were located in subtropical areas.

In the Late Cretaceous *C. diebelii* (Figures 2, 4K, Tables 1, 2A) is known to occur in both hemispheres, but is rare in high latitudes (Mao and Mohr, 1992). As can be seen in Figure 2A; it is present in Atlantic coast of Africa (Atta-Peters and Salami, 2006); on the southern Kerguelen Plateau (Mao and Mohr, 1992) and in Australia (Helby et al., 1987). But in New Zealand it occurs from Late Cretaceous

(Roncaglia et al., 1999) to Paleocene (Crouch et al., 2014). In India, it is reported from Late Cretaceous to the Paleocene (Prasad and Pundeer, 2002; Mehrotra et al., 2005). In South America, it is known to occur in the Paleocene of Argentina (Quattrocchio and Sarjeant, 1996). In the Pelotas Basin (Fischer, 2012; Fischer et al., 2013; Menezes, 2014) it is recorded at the K/Pc boundary. In other Brazilian marginal basins (Pernambuco-Paraíba, Almada and Sergipe) it is recorded from the Late Cretaceous to the Paleocene (Arai, 2007; Arai et al., 2000; Ferreira, 2004). Genus *Cerodinium* suggests low continental influence with little terrigenous input (Köthe, 1990).

In the Cretaceous of some petroliferous basins of India, *Disphaerogena carposphaeropsis* (Figures 2, 4A, Tables 1, 2A) is recorded (Mehrotra et al., 2012). In South America, Guerstein et al. (2005) reported it from the K/Pc boundary of Argentina and in the Pelotas Basin of south Brazil it ranges from the K/Pc boundary to the Paleocene (Fischer, 2012; Fischer et al., 2013; Menezes, 2014). In other Brazilian marginal basins such as Campos, Ceará, Pernambuco-Paraíba

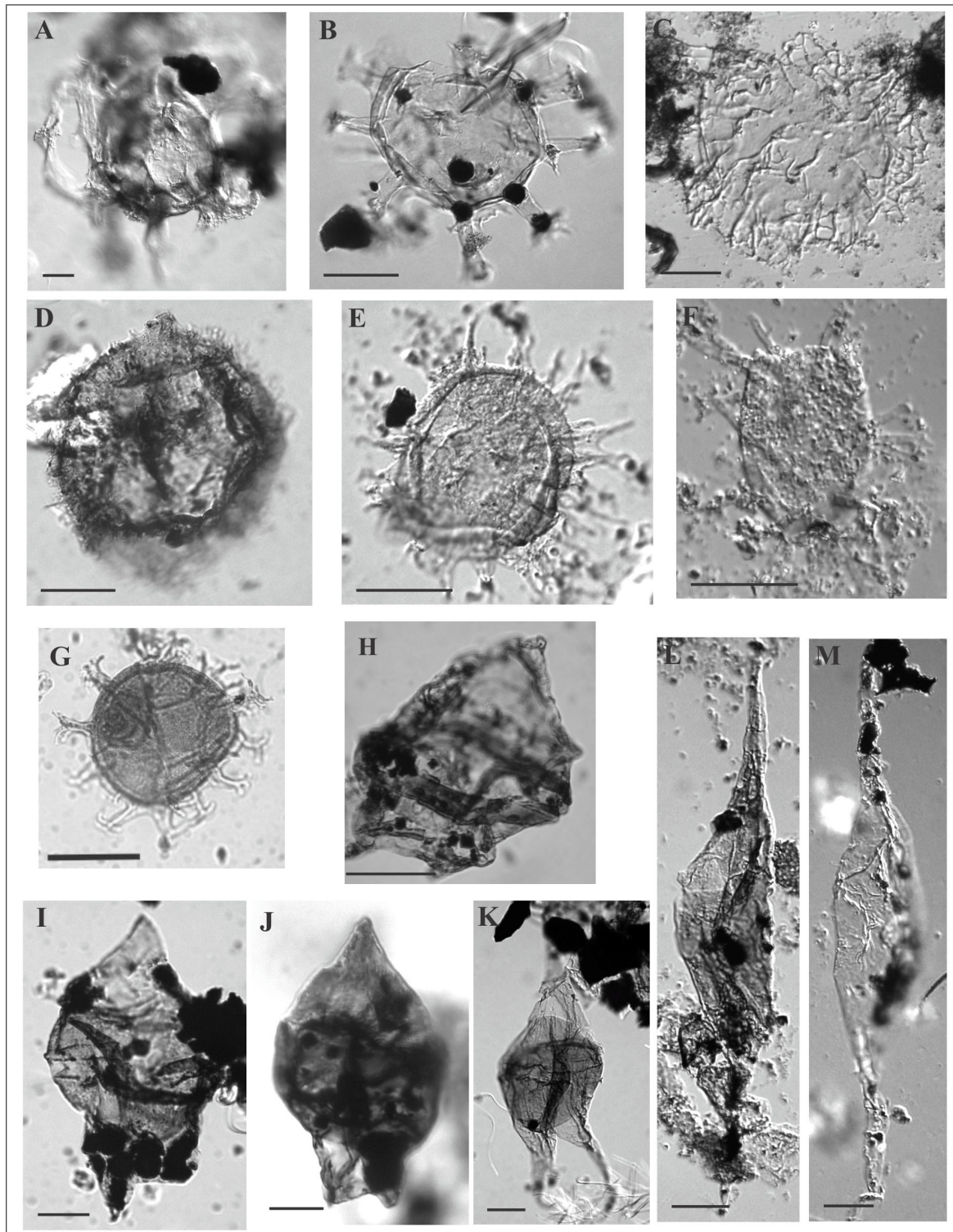


Figure 4. (A) *Disphaerogena carposphaeropsis*, sample (sam.). 4689 England Finder (EF). C25-2; (B) *Homotryblium tenuispinosum*, sam. 4699, EF. R17-3/R18-1; (C) *Glaphyrocysta texta*, sam. 4689, EF. D47-4; (D) *Trichodinium castanea*, sam. 4722, EF. G37-4; (E) *Hystrichodinium* cf. *H pulchrum*, sam. 4689, EF. G47-2; (F) *Tanyosphaeridium* cf. *T. xanthiopyxides*, sam. 4710, EF. P40; (G) *Hafniasphaera* cf. *H septata*, sam. 4690, EF. N47-1; (H) *Manumiella?* *cretacea*, sam. 4704, EF. H43-4; (I) *Chatangiella spectabilis*, sam. 4721, EF. P43-1; (J) *Isabelidium pellucidum*, sam. 4703, EF. B40-1; (K) *Cerodinium diebelii*, sam. 4689, EF. K32-2; (L) *Paleocystodinium golzowense*, sam. 4686, EF. D33; (M) *Paleocystodinium lidiae*, sam. 4689-1, EF. E47-4. Scale bar = 25 μ m.

Table 1. Common species between Brazil, Argentina, Uruguay, Antarctica, India, New Zealand, Australia, Africa, and the southwest Indian Ocean.

Species	Country									
	Brazil	Argentina	Uruguay	Antarctica	India	New Zealand	Australia	Africa	Southern Kerguelen Plateau	
<i>Cerodinium diebelii</i>	K/Pc Pc K	Pc			K Pc	K Pc		K	K	
<i>Chatangiella spectabilis</i>	K								K	
<i>Disphaerogena carposphaeropsis</i>	K/Pc Pc K	K/Pc			K					
<i>Glaphyrocysta texta</i>	Pc				K/Pc					
<i>Hafniasphaera cf. H. septata</i>	Pc Pc/ys				K/Pc					
<i>Homotryblium tenuispinosum</i>	Pc Pc/ys	K						K		
<i>Hystrichodinium cf. H. pulchrum</i>	K/ys	K			Pc/ys				K	
<i>Isabelidinium pellucidum</i>	K			K		K	K		K	
<i>Manumiella? cretacea</i>	K	K		K			K		K	
<i>Paleocystodinium golzowense</i>	K/Pc Pc K				Pc	K Pc K/Pc		K		
<i>Paleocystodinium lidiae</i>	K/Pc K	K	K/Pc	K						
<i>Tanyosphaeridium cf. T. xanthiopyxides</i>	K/Pc K	Pc	K/Pc	K/Pc		K			K	
<i>Trichodinium castanea</i>	K			K	K		K	K	K	

K: present only in the Cretaceous; K/Pc: present in the Cretaceous-Paleocene boundary; Pc: present only in the Paleocene; Pc/ys: present since Paleocene to younger strata and K/ys: present since the Cretaceous to younger strata.

and Potiguar it is recorded in the Late Cretaceous (Lana and Roesner, 2002; Sarkis et al., 2002; Arai, 2007).

The species of *Glaphyrocysta* were considered as indicators of a nearshore shallow marine environment (Brinkhuis and Zachariasse, 1988; Eshet et al., 1992; Slimani et al., 2010). *Glaphyrocysta texta* (Figures 2, 4C, Tables 1, 2A) is present only in India in the Early Cretaceous (Mehrotra and Sarjeant, 1987). This taxon is recorded in South America in the Paleocene of Uruguay (Daners and Guerstein, 2004) and in Brazil, in the Pelotas Basin (Menezes, 2014). Daners and Guerstein (2004) suggest that *Glaphyrocysta* marks its last appearance in the Danian and is not present in records above this age. Our study shows that India has the earliest record of this species while the latest is found in South America. Therefore, it is likely that their migration occurred from India to South America as it was benefited by the climatic change during the K/Pc boundary.

The species *Hafniasphaera cf. H. septata* (Figures 2, 4G, Tables 1, 2A) is a cosmopolitan species. It occurs from Late Cretaceous to Paleocene of India (Prasad and Pundeer, 2002) and appears in Brazil (Pelotas Basin) only since the Paleocene (Menezes, 2014) and in the Sergipe Basin from

Paleocene to Eocene (Ferreira, 2004). In the Northern Hemisphere, Williams and Bujak (1985) marked this species from Paleocene to early Eocene. This suggests the fact that species dispersed out of India during the Paleocene.

Our analysis indicates that *Homotryblium tenuispinosum* (Figures 2, 3B, and Tables 1, 2A) is restricted to the Atlantic Ocean between Brazil and Africa. In Africa, it occurs in the Late Cretaceous (Onuigbo et al., 2012) while in Brazil, we observe it only in the Paleocene-Eocene of the Pelotas Basin and in other Brazilian marginal basins such as Sergipe and Pernambuco-Paraíba (Sarkis et al., 2002; Ferreira, 2004).

For the Northern Hemisphere, Williams et al. (1993) showed that the range of this taxon extends from the Paleocene to the Oligocene. According to Fischer (2012), genus *Homotryblium* is associated with the input of terrigenous elements and temperature increase while Ferreira (2004) uses it as an indicator of the Paleocene/Eocene Thermal Maximum. The terrigenous input clearly suggests that the sea level was low under a neritic shallow environment, possibly lagoonal with increased salinity. High tolerance of *Homotryblium* to high salinity is presented by Pross

Table 2A. Common species between the Pelotas Basin and other marginal Brazilian basins.

SPECIES	AUTORS	AGE/RANGE	BASINS
<i>Cerodinium diebelii</i>	Arai et al. (2000)	Turonian- Senomanian	South Atlantic
	Arai (2007)	FAD/ LAD - late Maastrichtian	Pernambuco-Paraíba
		FAD/ LAD - late Maastrichtian	Almada
	Ferreira (2004)	middle Paleocene	Sergipe (Baixo Mosqueiro)
<i>Disphaerogena carposphaeropsis</i>	Fischer (2012); Fischer et al. (2013); Menezes (2014)	Cretaceous-Paleocene	Pelotas
		FAD/ LAD late Maastrichtian	Pernambuco-Paraíba
	Arai (2007)	FAD/ LAD late Maastrichtian	Campos
	Lana and Roesner (2002)	early - late Maastrichtian	Ceará (Mundaú)
<i>Hafniasphaera cf. H. septata</i>	Sarkis et al. (2002)	Maastrichtian	Pernambuco-Paraíba
	Ferreira (2004)	Paleocene-Eocene	Sergipe (Baixo Mosqueiro)
<i>Homotryblidium tenuispinosum</i>	Menezes (2014)	Paleocene	Pelotas
	Ferreira (2004)	middle Paleocene -Eocene	Sergipe (Baixo Mosqueiro)
	Menezes (2014)	Paleocene	Pelotas
<i>Hystrichodinium cf. H. pulchrum</i>	Arai (2007)	early Paleocene	Pernambuco-Paraíba
		FAD middle Campanian - LAD early Maastrichtian	Ceará
		FAD early Albian - LAD early Campanian	Sergipe
	Menezes (2014)	FAD early Albian - LAD late Santonian	Espirito Santo
		FAD Vraconian - LAD lower Maastrichtian	Campos
		Paleocene	Pelotas
Lana and Roesner (2002)	early Campanian-late Maastrichtian	Ceará (Mundaú)	

and Schmiedl (2002) whereas its prevalence in lagoonal environments is indicated by Radi and Vernal (2008).

Hystrichodinium cf. H. pulchrum (Figures 2, 4E and Tables 1, 2A) in India ranges from the Paleocene to the Eocene (Mehrotra et al., 2005), whereas in the southern Kerguelen Plateau it is recorded from Late Cretaceous (Mao and Mohr, 1992). In South America it is present only in Brazil (Pelotas Basin) from Paleocene (Menezes, 2014) and from Cretaceous in Brazilian marginal basins (Ceará, Sergipe, Espirito Santo and Campos) (Lana and Roesner, 2002; Arai, 2007).

Paleocystodinium golzowense (Figures 2, 4L and Tables 1, 2B) presented a large geographical range extending from the Late Cretaceous to the Paleocene in New Zealand (Roncaglia et al., 1999; Willumsen and Vajda, 2010; Willumsen, 2011; Crouch et al., 2014), India (Mehrotra et al., 2012). In Antarctica, Bowman et al. (2015) reported this species at the K/Pg boundary. In South America, its record is found in Brazil (Pelotas Basin) from the K/Pc. boundary to the Paleocene (Fischer, 2012; Fischer et al., 2013; Menezes, 2014) and in Brazilian marginal basins such as Pernambuco-Paraíba and Sergipe basins (Sarkis et al., 2002; Arai, 2007) it occurs in the Late Cretaceous. Synchronous

to its occurrence in South America, *Paleocystodinium golzowense* has also been reported in Africa (Atta-Peters and Salami, 2006). For the Northern Hemisphere, Williams and Bujak (1985) and Williams et al. (1993) reported its range between late Eocene and late Miocene. Bijl et al. (2011) indicates its presence in the Southern Ocean in the Paleogene transantarctic flora and included it in cosmopolitan and low-latitude to mid-latitude groups.

Paleocystodinium lidiae (Figures 2, 4M, and Tables 1, 2B) is restricted to Antarctica (Amenábar et al., 2014) and South America: Argentina) during the Late Cretaceous (Guerstein and Junciel, 2001), Late Cretaceous-Paleocene of Uruguay (Daners and Guerstein, 2004), Brazil (Pelotas Basin) in the K/Pc boundary and Paleocene (Fischer et al., 2013; Menezes, 2014). In other Brazilian marginal basins such as Almada and Sergipe (Arai, 2007; Ferreira, 2004) its presence is noted during the Cretaceous and Paleocene.

Tanyosphaeridium cf. T. xanthiopyxides (Figures 2, 3, 4F and Tables 1, 2B) is reported from Late Cretaceous of New Zealand, (Roncaglia et al., 1999) and in Southern Kerguelen Plateau (Mao and Mohr, 1992). In Antarctica, this species occurs at the K/Pg boundary (Askin, 1988; Bowman et al., 2015). In Argentina, Guerstein and Junciel (2001) recorded

Table 2B. Common species between Pelotas Basin and others marginal Brazilian basins.

SPECIES	AUTORS	AGE/RANGE	BASINS
<i>Isabelidinium pellucidum</i>	Arai (2007)	FAD middle Campanian middle -LAD early Maastrichtian	Ceará
		FAD late Campanian - LAD early Maastrichtian	Campos
	Lana and Roesner (2002)	early Campanian - early Maastrichtian	Ceará (Mundaú)
	Premaor (2008); Premaor et al. (2010); Menezes (2014)	Late Campanian	Pelotas
<i>Manumiella? cretaceum</i>	Arai (2007)	FAD Santonian – LAD early Maastrichtian	Campos
	Premaor (2008); Premaor et al. (2010); Menezes (2014)	late Campanian	Pelotas
<i>Paleocystodinium golzowense</i>	Arai (2007)	FAD/LAD late Maastrichtian	Pernambuco-Paraíba
		FAD/LAD late Maastrichtian	Sergipe
	Fischer (2012); Fischer et al. (2013); Menezes (2014)	Cretaceous-Paleocene	Pelotas
	Sarkis et al. (2002)	Maastrichtian	Pernambuco-Paraíba
<i>Paleocystodinium lidiae</i>	Arai (2007)	FAD/ LAD late Maastrichtian	Almada
	Ferreira (2004)	Maastrichtian- middle Paleocene	Sergipe (Baixo Mosqueiro)
	Fischer (2012); Fischer et al. (2013)	Cretaceous-Paleocene	Pelotas
	Premaor (2008), Premaor et al. (2010); Menezes (2014)	late Campanian	Pelotas
<i>Tanyosphaeridium cf. T. xanthiopyxides</i>	Arai (2007)	FAD late Santonian - LAD middle Campanian	Campos
	Menezes (2014)	late Campanian and Paleocene	Pelotas
<i>Trichodinium castanea</i>	Arai (2007)	FAD/ LAD middle Albian	Barreirinhas
		FAD middle Cenomanian - LAD middle Turonian	Potiguar
		FAD late Aptian - LAD middle Campanian	Sergipe
		FAD early Albian - LAD middle Campanian	Espirito Santo
		FAD early Albian - LAD middle Campanian	Campos
		FAD early Albian - LAD middle Campanian	Campos
		FAD/LAD early Aptian	Pelotas
	Carvalho (2001)	late Aptian to middle Albian	Sergipe
	Premaor (2008); Premaor et al. (2010); Menezes (2014)	late Campanian	Pelotas
	Lana (1997)	Late Cretaceous	Potiguar
	Fauth et al. (2012)	Campanian	Santos

it in the Paleocene. It is also present in Uruguay from the Late Cretaceous to the Paleocene (Daners and Guerstein, 2004). In Brazil, in the Pelotas Basin, it is reported from K/Pc boundary and Paleocene (Fischer et al., 2013; Menezes, 2014) and during the Cretaceous of the Campos Basin (Arai, 2007).

The remarkable concentration of terrigenous materials in sediments of Campanian age in the Pelotas Basin is suggestive of relative low sea levels that were possibly followed by various positive and negative oscillations until the end of the

late Maastrichtian. The K/Pc boundary is also regarded as a time of marine oscillations observed worldwide. On the other hand, the high diversity of cysts observed in the Paleocene of the Pelotas Basin, indicate higher sea levels in the Paleocene as observed by the continuously warming trend. A support for this hypothesis is given by Quattrocchio and Sarjeant (1996), who recorded a synchronous marine transgression in Argentina during the Maastrichtian-Danian.

The paleoenvironments of the basins of former members of Gondwana, as previously presented and attested by the dinoflagellate cysts, are marginal marine nearshore, varying from neritic to shallow neritic and lagoonal or coastal swamps, which permitted the deposition of sediments in anoxic marine conditions. The present analysis of the similarities of the K/Pc dinoflagellate cysts associations between the South Atlantic and Indian proto-oceans permitted the proposal of a biostratigraphic distribution chart of the 13 taxa found in the Pelotas Basin, according to paleogeographical patterns as shown in Figure 3.

FINAL CONSIDERATIONS

In this study we observed that most of the dinoflagellate cyst taxa are endemic species and a few are cosmopolitan with restricted temporal distribution which allow an effective biostratigraphical correlation between southern Brazil, other regions of South America, India, Africa, Antarctica, Indian Ocean wells, Australia and New Zealand. The paleoenvironment in the studied basins, as reflected by dinoflagellate cyst assemblages were marginal marine nearshore, varying from neritic to shallow neritic and lagoonal or coastal swamp, conducive to the deposition of sediments in anoxic conditions. After millions of years of drift of Gondwana, some continents were still partially connected.

With the aid of micropaleontological proxies such as dinoflagellate cysts and the dominance of endemic species in Cretaceous, it is possible to visualize the gradual opening between continental passageways and the establishment of new marine currents. As they distanced between themselves marine currents underwent changes in directions. We believe that the understanding on the distribution of marine planktonic taxa, endemic and cosmopolitan, during the Cretaceous-Paleogene, is fundamental to the knowledge of marine currents and their role on the structuring of paleogeographical provinces.

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