PALYNOFACIAL APPROACH ACROSS THE CRETACEOUS - PALEOGENE BOUNDARY IN MARAMBIO (SEYMOUR) ISLAND, ANTARCTIC PENINSULA

Rafael RODRÍGUEZ BRIZUELA[1] Sergio MARENSSI[2] Viviana BARREDA[1] and Sergio SANTILLANA[2]

[1] Museo Argentino de Ciencias Naturales "Bernardino Rivadavia", Ángel Gallardo 470, 1405, Buenos Aires, Argentina.
[2] Instituto Antártico Argentino, Cerrito 1248, 1010, Buenos Aires. E-mail: rafarodriguezb@hotmail.com

RESUMEN: *Enfoque palinofacial a través del límite Cretácico - Paleógeno en la Isla Marambio (Seymour), Península Antártica.*
El presente estudio analiza el comportamiento de la materia orgánica palinológica a través del límite Cretácico-Paleógeno de la Isla Marambio (Seymour). El límite estudiado se encuentra en la sección superior de la Formación López de Bertodano y coincide con un horizonte glauconítico. Se analizaron quince muestras las cuales fueron agrupadas en cuatro palinofacies de acuerdo a la composición porcentual de la materia orgánica. La caracterización palinofacial es indicativa de un ambiente de depositación de plataforma marina proximal. La asociación de las palinofacies permitió discriminar la sección estudiada en tres intervalos menores relacionados a tres estadios en el nivel del mar. La integración de estos estadios resulta en una curva de nivel del mar hipotética que refleja un pulso transgresivo-regresivo menor, dentro de una tendencia regresiva general. La máxima profundidad de agua se sugiere cerca de un metro por debajo del límite K-P propuesto. La identificación palinofacial de este pulso es concordante con la idea de un evento transgresivo-regresivo lento y con ciclos internos. La preservación de la materia orgánica a través del límite K-P no sugiere un efecto local del hipotético evento catastrófico global. Considerando la monótona litología de la Formación López de Bertodano que dificulta el reconocimiento de discontinuidades, este trabajo abre la posibilidad de aplicar, en futuras investigaciones, modelos secuenciales basados en el reconocimiento de superficies de máxima inundación.

Palabras clave: *Palinofacies, límite K-P, isla Marambio (Seymour), Antártida.*

ABSTRACT
This study analyzes the palynological organic matter behavior throughout the Cretaceous- Paleogene boundary in Marambio (Seymour) Island, Antarctic Peninsula. The boundary is located in the upper part of the López de Bertodano Formation, coinciding with a widespread glauconitic level. Fifteen samples were analyzed and associated with four palynofacies. Defined palynofacies indicate an inner shelf marine environment of sedimentation. The palynofacial assemblages permitted discriminating the studied section into three minor stratigraphical intervals related to three sea-level stages. The integration of these stages results in a hypothetical sea-level curve, which reflects a minor transgressive - regressive pulse into a general regressive trend. The maximun water depth is about 1 m below the postulated K/P boundary. Palinofacial recognition of this pulse supports the earlier idea of a slow transgressive-regressive event with minor internal transgressive-regressive cycles. Palynofacial data indicates preservation of the organic matter across the K-P boundary, and therefore do not suggest any local effect of the hypothetical global catastrophic K/P event. Considering the monotonous lithology of the López de Bertodano Formation that makes the recognition of unconformities difficult, this work opens the possibility of applying a sequence stratigraphic approach based on the recognition of maximum flooding surfaces for future investigations.

Keywords: *Palynofacies, K-P boundary, Marambio (Seymour) Island, Antarctica..*

INTRODUCTION

The palynofacies concept was introduced by Combaz (1964) to describe the total assemblage of particulate organic matter recovered from sedimentary rocks by palynological techniques. This practice was successfully applied to paleoenvironmental depositional determinations and sequence stratigraphic interpretations in several sections of the world, and particularly useful to hydrocarbon productive basins (Al-Ameri *et al.* 1999, Jaramillo and Oboh-Ikuenobe 1999, Vallejo *et al.* 2002, Ibrahim 2002, Oboh-Ikuenobe and de Villiers 2003, Ruf *et al.* 2005, del Papa *et al.* 2002, Dybkjaer 2005, Masselter and Hofmann 2005, Cripps *et al.* 2005, Martínez *et al.* 2005, Oboh-Ikuenobe *et al.* 2005, among others). Taking into account the increasing number of papers focused on palynofacies, it is certain that palynofacial analysis provides a useful tool for paleoenvironmental, paleoecological and stratigraphic schemes. In this study we attempt to apply this discipline to analyze the organic matter behavior throughout the Cretaceous-Paleogene (K/P) boundary cropping out in the López de Bertodano Formation of Marambio (Seymour) Island, at the northeastern tip of the Antarctic Peninsula (64° 15´ S and 56° 45´ W, Fig. 1).
Previous studies focused on the geochemistry of the organic matter of the López de Bertodano Formation were conducted by Palamarckzuk *et al.* (1984) and Askin and Jacobson (1989). The aim of this work is twofold: to describe optically the palynofacies of this high latitude K/P section (a first advance was communicated by Rodríguez Brizuela *et al.* 2006), and to vinculate the defined palynofacies with earlier paleoenvi-

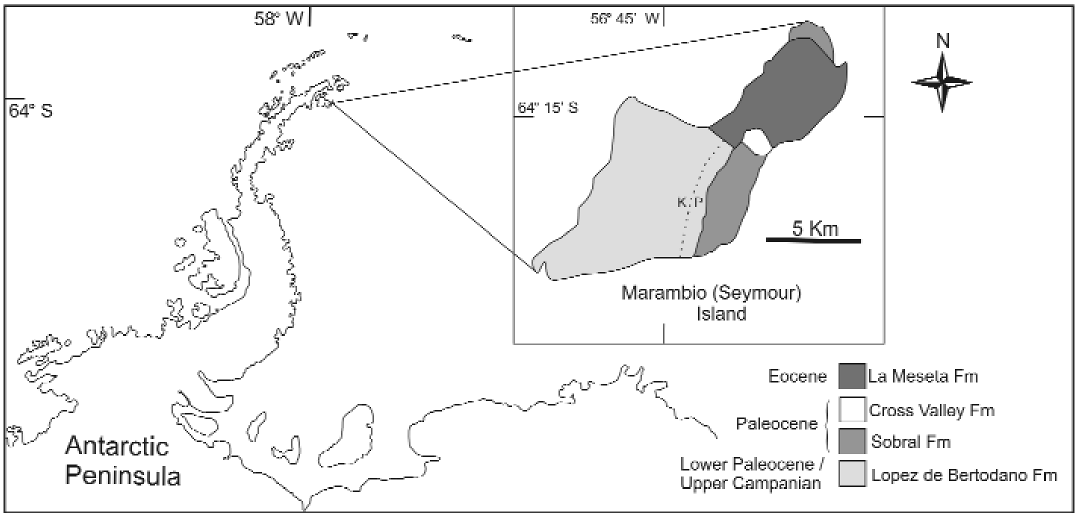

Figure 1: Location and simplified geologic map of Marambio (Seymour) Island.

ronmental and transgressive - regressive (T-R) interpretations (Macellari 1988).

METHODOLOGY

Fifteen samples from the López de Bertodano Formation across the K/P boundary were analyzed in two approximations to the boundary. The first sampling interval spans 9 m of section, with 7 samples 1.5 m apart. Close to the boundary a more detailed sampling (15 cm apart) was realized (Fig. 2). Samples were processed following standard palynological techniques (HCL and HF chemical digestion). No oxidation was applied to sampled material. The residues were not sieved to avoid removing much of the amorphous organic matter.

This study consisted of a semiquantitative analysis under transmitted light microscopy of the three basic types of palynological sedimentary organic matter. Following Batten (1996) these are: amorphous organic matter (AOM), structured organic matter (STOM) and palynomorphs (Pa). At least 300 particles were counted per slide.

AOM includes unstructured organic substances without a clearly defined shape. It occurs in aggregates and finely dispersed, regarded to be bacterially or chemically degraded organic debris. STOM includes phytoclasts (zooclasts are absent in these samples) which are discrete particles with a distinctive shape related to a vegetal-terrestrial origin. These are all kinds of "woody" debris, cuticles, tubes, filaments and other particulate opaque detritus (black debris). Pa refers to all acid resistant microfossils and includes those of terrestrial (pollen and spores, fresh water algae) and marine (dinoflagellates cysts, foraminiferal linings, acritarchs, prasinophyte algae) origin.

STRATIGRAPHIC AND BIOSTRATIGRAPHIC FRAMEWORK

The sedimentary units involved in Marambio (Seymour) Island correspond to Cretaceous-Eocene strata (Sadler 1988) deposited in a back-arc geotectonic setting (Elliot 1988). The K/P boundary is located in the marine sequence of the López de Bertodano Formation (Rinaldi *et al.* 1978, Rinaldi 1982) (Fig. 1). This unit crops out extensively along the southwestern and central parts of the island, reaching 1.190 m in thickness. The lithology is composed of muddy sandy siltstones, muddy sandstones and occasional glauconitic sandstones deposited in nearshore to offshore environments (Macellari 1988). The López de Bertodano Formation was subdivided into 10 informal lithofacial units (Macellari 1988) and is covered by means of an erosive unconformity by the Danian Sobral Formation (Rinaldi *et al.* 1978), though to represent a prograding delta system (Macellari 1988) or a transgressive incised valley to shoreface depositional system (Marenssi personal observation).

The position of the K/P boundary was postulated in the upper part of the López de Bertodano Formation (between units 9 and 10 of Macellari 1988) coinciding with a widespread glauconite interval. This interpretation was supported by biostratigraphical studies, based mainly on diatoms and silicoflagellates (Harwood 1988), palynology (Askin 1988 a and b) and foraminifera (Huber 1988) as well as by the presence of a positive Iridium anomaly (Elliot *et al.* 1994). The most clear biostratigraphical markers for this interval are dinoflagellates cysts (Askin 1988 a and b). A major change in the palynological components near the presumed K/P boundary is recorded where an assemblage dominated by *Manumiella* sp. is replaced by a *Senegalinium obscurum* dominated one.

Based on our observations, spore-pollen assemblages show minor changes throughout the studied K/P boundary, as previously stated by Baldoni and Barreda (1986) and Askin (1988 b). Maastrichtian- Danian assemblages are dominated by podocarpaceous pollen grains, fern spores and relatively abundant angiosperms, mainly represented by pollen of Nothofagaceae and Proteaceae.

PALYNOFACIES

Visual observation allows assembling the 15 analyzed samples in 4 palynofacies, in order to establish paleoenvironmental and stratigraphic relationships (see Table 1).

Palynofacies A (samples 1 and 10, Fig. 3 A) Characterized by 80 - 90 % of AOM, 10 - 5% of STOM and 10 - 5 % of Pa. STOM is dominated by small and angular black

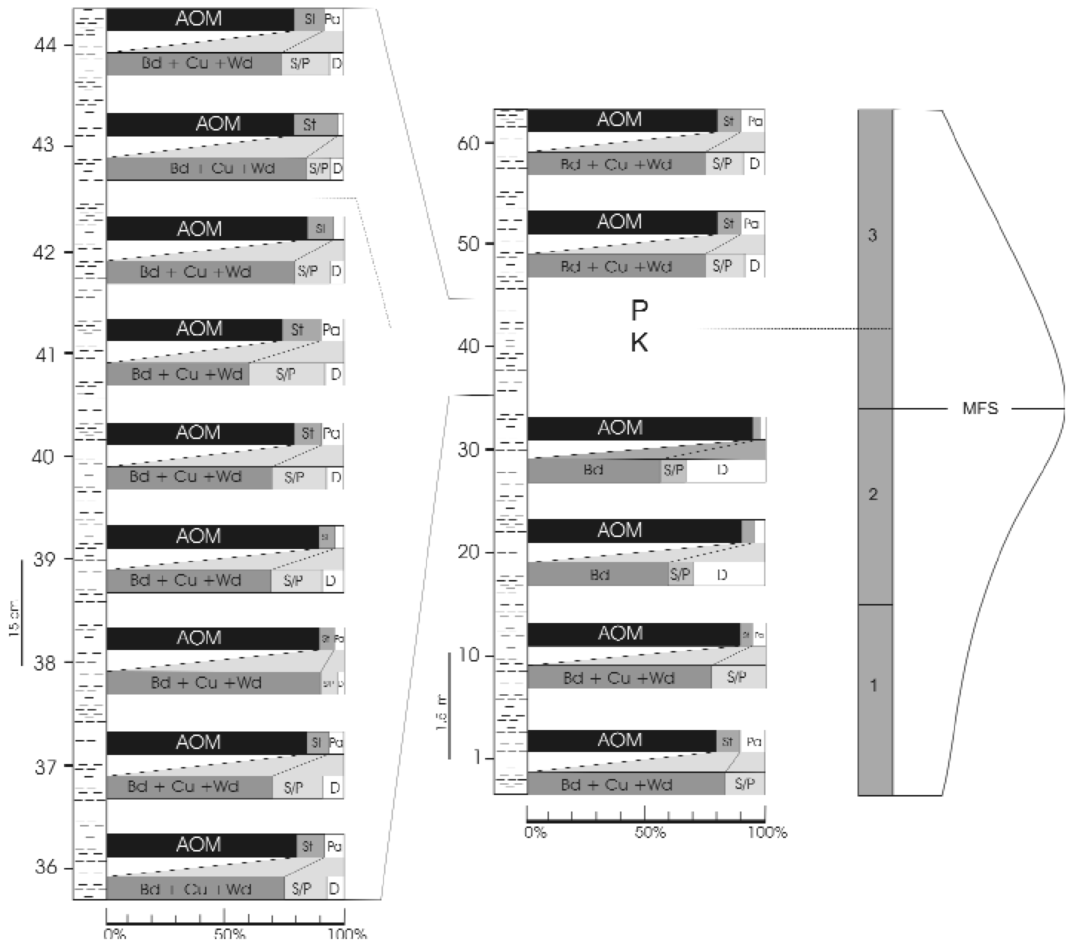

Figure 2: Relative abundance of sedimentary organic matter recovered from the fifteen analyzed samples. AOM, amorphous organic matter. St, structured organic matter. Pa, palynomorphs. Bd, black debris. Cu, cuticles. Wd, woody debris. S/P, spores/pollen grains. D, dinoflagellates cysts. At right, the tree interpreted stratigraphic intervals and sea-level stages with the resulting hypothetical sea-level curve: 1, sea-level "lowstand". 2, transgression. 3, sea-level "highstand". MFS is the maximum flooding surface. K/P is the Cretaceous-Paleogene boundary.

debris, cuticles and "woody" debris. Pa is dominated by degraded terrestrial derived spore and pollen grains. Marine derived palynomorphs are very scarce.

Palynofacies B (samples 20 and 30, Fig. 3 B) Characterized by 90 - 95 % of AOM, 5 - 2,5 % STOM and 5 - 2,5% of Pa. STOM are all small black debris. Pa is dominated by marine derived (85 %) with scarce (15 %) continental derived bisaccate pollen.

Palynofacies C (samples 36 to 44, Fig. 3 C) Characterized by 70 - 85 % of AOM, 20 - 10 % of STOM and 10 - 5% of Pa. STOM are represented by bigger particles of black debris, cuticles and "woody" than palynofacies A and B. It shows an increase in the number of well preserved palynomorphs, with a dominance of terrestrial palynomorphs (75 %) against marine palynomorphs (25%). The presence of pteridophyte spores, fungal spores, angiosperm and gymnosperm pollen grains is indicative of a clear increase in the continental influence in this palynofacies.

Palynofacies D (samples 50 and 60, Fig. 3 D)

TABLE 1: Chart of each analyzed sample and corresponding age, sedimentary environment, palynofacies and sea-level interpretation. MFS is the maximum flooding surface.

Sample	Stratigraphic horizon	Sedimentary environment	Palynofacies (see text for details)	Sea-level interpretation Stratigraphic interval
60	Danian	Inner shelf	D	Highstand Interval 3
50	Danian	Inner shelf		
44	Danian	Inner shelf	C	
43	Danian	Inner shelf		
42	Maastrichtian	Inner shelf		
41	Maastrichtian	Inner shelf		
40	Maastrichtian	Inner shelf		
39	Maastrichtian	Inner shelf		
38	Maastrichtian	Inner shelf		
37	Maastrichtian	Inner shelf		
36	Maastrichtian	Inner shelf		MFS
30	Maastrichtian	Inner shelf	B	Transgression Interval 2
20	Maastrichtian	Inner shelf		
10	Maastrichtian	Inner shelf	A	Lowstand Interval 1
1	Maastrichtian	Inner shelf		

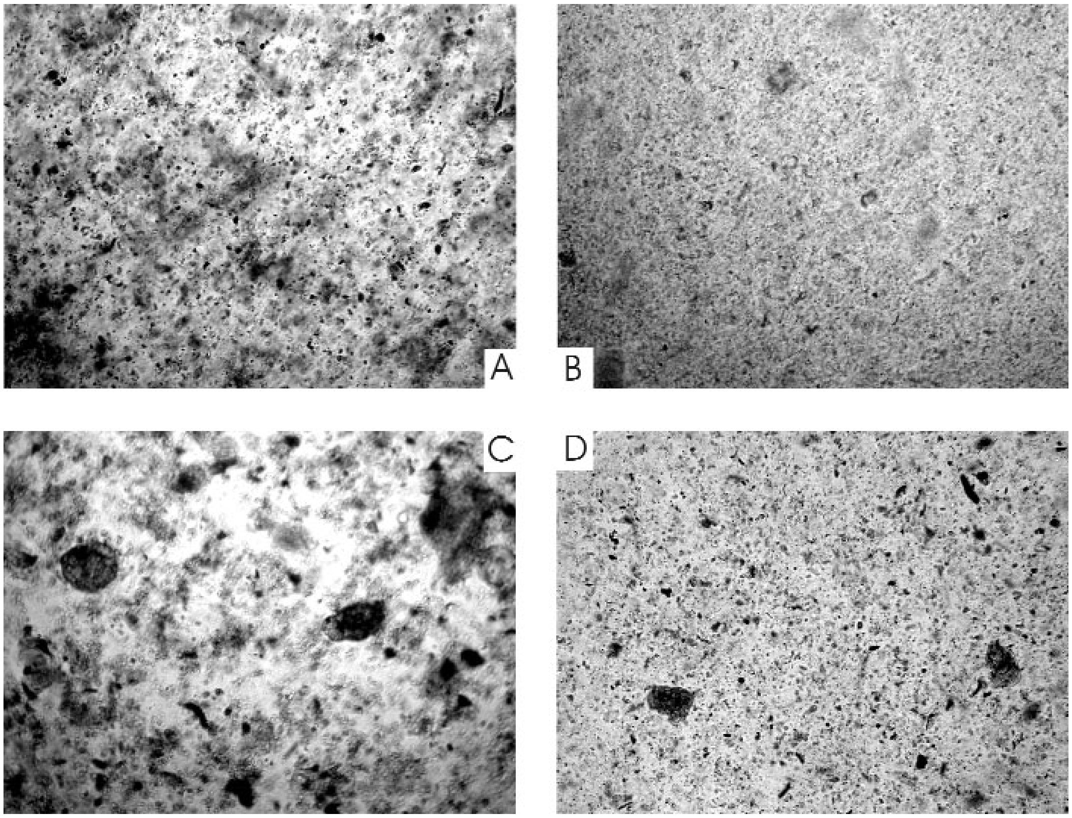

Figure 3: Microphotographs (X250) and general view of the four palynofacies (A,B,C and D). See text for details.

Characterized by 80 % of AOM, 10 % of STOM and 10 % Pa. It is similar to palynofacies C, but differs in showing a decrease in the STOM size. There is still a predominance of terrestrial palynomorphs, but they are less common than in palynofacies C.

PALEOENVIRONMENTAL SIGNIFICANCE

The basic concept that provides a relationship between palynofacies analysis and sedimentological paleoenvironmental interpretations is that particulate organic matter is transported and deposited similarly to clastic detritical grains of the same size and specific gravity (Traverse 1994). Experimental laboratory studies and field evidence (Holmes 1994, Brush and Brush 1994, Streel and Richelot 1994, Gastaldo 1994) demonstrated that flow conditions of a determined transport agent generate differences in the sorting process due to hydrodynamic particularities of sporomorph types and phytoclasts. Thus, each sedimentary facies is characterized by its palynological organic matter occurrence and composition.

The association of sedimentary organic matter in a marine shelf progressively changes from an inner to an outer position (Oboh-Ikuenobe and de Villiers 2003). The palynofacies here defined, dominated by AOM with moderate terrestrial and marine material, support an inner shelf marine environment of sedimentation for the K/P section of the López de Bertodano Formation, in concordance with the organic matter distribution observed by Oboh-Ikuenobe and de Villiers (2003).

In order to relate this palinofacial analysis to any hypothetical environmental stress, the studied K/P boundary indicates preservation of the organic matter and does not suggest a decrease in the biological production. This was also reported on the base of total organic carbon content (Askin and Jacobson 1989), where no significant variations in analytic data were found.

PALYNOFACIES AND SEA LEVEL VARIATIONS

Palynofacial studies allow distinguishing landward from basinward depositional shifts (Tyson and Follows 2000) in response to sea level variations. The palynofacial assemblages of this work, similar to the organic matter distribution observed by Vallejo *et al.* (2002), permitted discriminating the studied section into three minor stratigraphical intervals related to three sea-level stages (Fig. 2).

The first interval is represented by palynofacies A and is interpreted as a sea-level "lowstand" stage. It is dominated by terrestrial derived organic matter which is formed by small and angular phytoclasts and degraded spore and pollen grains. The second interval is represented by palynofacies B, interpreted as a transgressive stage. In this interval the number of marine palynomorphs increase and terrestrial organic matter is less common. All terrestrial palynomorphs are bisaccate pollen grains, which are a long distance dispersed from the source area. The third interval is represented by palynofacies C and D and interpreted as a sea-level "highstand" stage. This interval shows a remarkable increase in the number and diversity of terrestrial palynomorphs in detriment to marine palynomorphs and an increase in the size and abundance of phytoclasts.

The distribution of particulate organic matter along the section indicates an increase in the terrestrial input from the base (palynofacies A and B) to the top (palynofacies C). This input starts to decrease in the upper part of the section where the size of phytoclasts and abundance of terrestrial palynomorphs decrease (palynofacies D). The integration of palynofacial data into an hypothetical sea-level curve (Fig. 2) reflects a progressively sea-level rise and then a fall. The maximum water depth is suggested between sample 30 and 36, about 1 m below the postulated K/P boundary (Fig. 2, Table 1).

CONCLUDING REMARKS AND DISCUSSION

A major T-R cycle was interpreted for the López de Bertodano Formation (Macellari 1988), where the K/P section represents the deepest facies of the Maastrichtian transgressive peak in the Marambio (Seymour) Island. The section analyzed in this contribution supports this assumption, with a maximun depth about 1 m below the postulated K/P boundary (Fig. 2). This peak corresponds to a transgressive pulse in a general regressive trend, and therefore sustains the idea of a slow T-R event with minor T-R internal cycles (Macellari 1988). As confirmed by the palynofacial analysis, at the peak of the transgression, first and second intervals (Fig. 2, Table 1), the basin is starved of terrigenous material (Van Wagoner *et al.* 1990) allowing glauconite to form at the water-sediment interfase. The increase in the terrestrial input in the third interval (Fig. 2, Table 1) reflects a landward migration of the shoreline.

In spite of the positive Ir anomaly in the K/P boundary of Marambio (Seymour) Island, which was vinculated to the Chicxulub impact (Claeys *et al.* 2002), this work does not suggest any local effect of the hypothetical global catastrophic K/P event. Palynofacial data obtained in this work indicates preservation of the organic matter across the K-P boundary, and therefore support the earlier idea (Askin and Jacobson 1989) that there were no palpable declines in floral and planktonic productivity across the K-P interval in Marambio (Seymour) Island. This particular feature was also reported to the K-P boundary in west India (Cripps *et al.* 2005).

Considering the monotonous lithology of the López de Bertodano Formation that makes the recognition of unconformities difficult, this work opens the possibility of applying a sequence stratigraphic approach based on maximum flooding surfaces (MFS) for future investigations. In an exhaustive paper, Catuneanu (2002) reviews the concepts, merits and limitations of each sequence stratigraphic model, recommending flexibility when choosing the model for a specific case of study. Following these suggestions, a model relative to the transgressive- regressive curve (T-R curve) could be adopted, due to the prolonged stage of base level rise within the López de Bertodano Formation (Macellari 1988) that do not correspond with the depositional sequence model of the Exxon group, relative to the base level curve (Catuneanu 2002). The model relative to the T-R curve includes the genetic sequence model (Galloway 1989) and the T-R sequence model (Embry 1993), based on the shift from landward to seaward migration of the shoreline. The MFS corresponds to a genetic sequence boundary, in the sense of Galloway (1989), who differed with the Exxon model in drawing the sequence boundaries in MFS instead in lowstand unconformities. In this model, the MFS is placed at the top of a transgressive lag and indicates the establishment of the highstand system tract. Applying the proposal of Embry (1993), a MFS could be used to subdivide a T-R sequence into a transgressive system tract and a regressive system tract.

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