

Lithostratigraphy, sequence stratigraphy and depositional setting of the Pliensbachian and Toarcian series in the Lusitanian Basin, Portugal

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Resumo

Palavras-chave: Pliensbaquiano, Toarciano, Bacia Lusitânica, Portugal, Rampa carbonatada, Litostratigrafia, Estratigrafia sequencial

Na Bacia Lusitânica (Portugal Central), as séries do Liásico Médio e Superior são caracterizadas por uma acumulação expressiva de sedimentos margo-calcários, depositados em ambiente de rampa carbonatada homoclinal. Estas séries incluem-se nas Formações de Vale das Fontes, Lemede, S. Gião (e as Formações equivalentes laterais de Prado e de Cabo Carvoeiro) e, parcialmente, de Póvoa da Lomba. Estas unidades, em grande parte controladas por biostratigrafia de amonites, estão organizadas em duas sequências transgressivas-regressivas de 2ª ordem. A primeira (SP) é datada do Pliensbaquiano Inferior à extrema base do Toarciano Inferior; a segunda (ST) é datada do Toarciano Inferior ao Aaleniano Inferior.

Résumé

Mots-clés: Pliensbachien, Toarcien, Bassin Lusitanien, Portugal, Rampe carbonatée, Lithostratigraphie, Stratigraphie séquentielle

Dans le Bassin Lusitanien (Portugal Central), les successions du Lias moyen et supérieur sont caractérisées par une accumulation marno-calcaire expressive, de sédiments qui ont été déposés dans une rampe carbonatée homoclinal. Ces séries sont incluses dans les Formations de Vale das Fontes, Lemede, S. Gião (et dans les Formations équivalentes latérales du Prado et du Cabo Carvoeiro) et, partiellement, de Póvoa da Lomba. Ces unités, en grande partie contrôlées par une biostratigraphie d'ammonites, sont organisées en deux séquences transgressives-régressives de second ordre. La première (SP) date du Pliensbachien Inférieur à la base du Toarcien Inférieur; la seconde (ST) date du Toarcien Inférieur à la base de l'Aalénien.

Abstract

Key-words: Pliensbachian, Toarcian, Lusitanian Basin, Portugal, Carbonate ramp, Lithostratigraphy, Sequence stratigraphy

In the Lusitanian Basin (Central Portugal), the Middle-Upper Liassic series are characterized by an expressive marly limestone accumulation, sediments that were deposited on a homoclinal carbonate ramp. These series belong to the Vale das Fontes, Lemede, S. Gião (and the lateral equivalents Prado and Cabo Carvoeiro Formations) and, partially, to the Póvoa da Lomba Formations. These units, in great part controlled by an accurate ammonite biostratigraphic scale, are organized into two second-order transgressive-regressive sequences. The first one (SP) is dated of early Pliensbachian/lowermost early Toarcian age; the second (ST) is dated of early Toarcian to early Aalenian.

1. Introduction

The Middle and Late Liassic in the western Iberia Margin (Lusitanian Basin) is characterized by carbonate deposits, mainly composed by thick marly limestone successions. The weak lateral facies variation, generally observed at the basin scale, suggests that these sediments were deposited in an epicontinental extensional basin, influenced by eustatic fluctuations and local and regional tectonics. Considering the Late Triassic-late Callovian large cycle (SOARES & *al.*, 1993a; AZERÉDO & *al.*, 2003), those sediments correspond to the maximum transgressive facies observed in the whole basin. Thus, the aim of this work is to present the lithostratigraphy and a sequential scheme of the Pliensbachian and Toarcian series, interpreted in terms of sequence stratigraphy and discuss the hierarchy of the sedimentary cyclicity (2nd -order), following the terminology of T. JACQUIN & P.-C. De GRACIANSKY (1998a) and P.-C. De GRACIANSKY & *al.* (1998).

2. Geological setting and lithostratigraphy

The Jurassic in the Lusitanian Basin is well exposed, including practically the two extremes of the basin: Figueira da Foz-Cantanhede region at the north end and Arrábida sector at the south end (fig. 1). With exception of this last sector, Tomar and, partially, Peniche, the Pliensbachian and Toarcian series in the basin are generally dominated by hemipelagic deposits, represented by marl/limestone alternations, very rich in nektonic (ammonites, belemnites) and benthic (brachiopods, bivalves, crinoids, siliceous sponges) macrofauna. Generally, ammonite biostratigraphic data provides a good stratigraphic resolution in the whole basin (see DOMMERMUES, 1987; ELMÍ & *al.*, 1989; HENRIQUES, 1995; ROCHA & *al.*, 1996; and references therein).

The Jamesoni-Aalensis Zone interval show four main formations (Fm.) (DUARTE & SOARES, 2002): Vale das Fontes Fm., Lemedé Fm., S. Gião Fm. and, partially, Póvoa da Lomba Fm. (fig. 2).

Vale das Fontes Fm.: composed by decimetre to metre-scale marl/centimetre-scale limestone alternations, rich in brachiopods, bivalves, ammonites, belemnites, crinoids and gastropods. This unit comprises several facies such as black shales and bioclastic and lumpy marls and limestones. It ranges in age from Jamesoni to Margaritatus Zone, showing in the basin a thickness variation between 14 to around 100 m. Vale das Fontes Fm. is subdivided into three members: *Marls and limestones with Uptonia and Pentracinus* (MLUP), *Lumpy marlstones and limestones* (LML) and *Marly limestones with bituminous facies* (MLBF).

Lemedé Fm.: composed by centimetre scale marl/decimetre scale limestone bioturbated alternations, very rich in belemnites, ammonites, bivalves and brachiopods. In Tomar, the facies are much more bioclastic (packstone to grainstone) and locally dolomitic, with a very diversified macrofaunal component. This unit ranges in age from the Spinatum Zone to the lowermost part of Polymorphum Zone, reaching north-westwards 35 m of thickness.

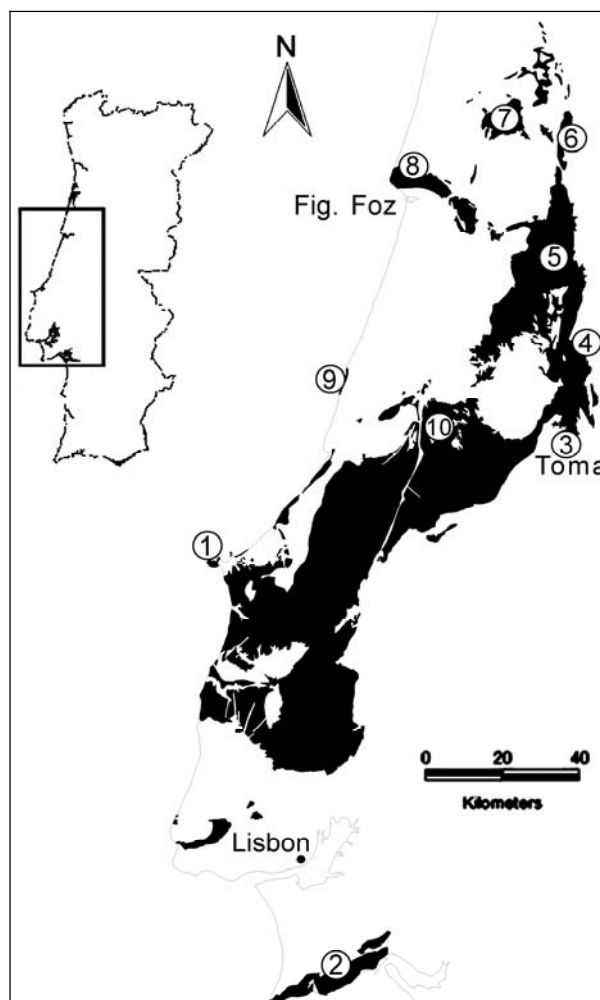


Fig. 1 – Geological map of Jurassic in the Lusitanian Basin. Location of the main Lower Jurassic carbonate outcrops: 1 – Peniche; 2 – Arrábida-Sesimbra; 3 – Tomar; 4 – Alvaiázere; 5 – Rabaçal; 6 – Coimbra; 7 – Cantanhede; 8 – Figueira da Foz; 9 – S. Pedro de Moel; 10 – Porto de Mós.

S. Gião Fm.: corresponds to a very marly dominated unit that ranges in age from the Early Toarcian (lowermost Polymorphum Zone) up to Late Toarcian (Meneghinini Zone). This unit is subdivided into five members (fig. 2), easily recognizable across a large area of the LB: *Marly limestones with Leptaena facies* (MLLF), *Thin Nodular Limestones* (TNL), *Marls and marly limestones with Hildaites and Hildoceras* (MMLHH), *Marls and marly limestones with sponge bioconstructions* (MMLSB) and *Marls and marly limestones with brachiopods* (MMLB). This formation shows in the basin a thickness range from 60 to around 230m.

Base of Póvoa da Lomba Fm.: composed by bioturbated marl/limestone alternations, with an upward increase of calcareous (biomicrite/wackestone, locally packstone) facies. This part of this Formation (MST4B in DUARTE, 1997), ranging in age from the Meneghinini to Opalinum Zones, shows siliceous sponge bioconstructions (DUARTE & *al.*, 2001) and it is particularly rich in *Chondrites*, *Zoophycos*, *Planolites* and *Thalassinoides*.

Chronostratigraphy and Ammonite Biostratigraphy			Lithostratigraphy								
			Arrábida	Tomar	Generality of the Basin		Peniche/S. Pedro de Moel				
Lower Jurassic	AALENIAN	Opalinum	Hiatus	Prado Fm.	Póvoa da Lomba Fm.		Cabo Carvoeiro Fm.	C. Carvoeiro 5			
					Upper	Aalensis Meneghini Speciosum Bonarellii		S. Gião Fm.	Marls and marly limestones with brachiopods	C. Carvoeiro 4	
									Marls and marly limestones with sponge bioconstructions		
					Middle	Gradata Bifrons		Marls and marly limestones with <i>Hildaites</i> and <i>Hildoceras</i> Thin nodular limestones	C. Carvoeiro 3		
	Lower	Levisoni Polymorphum							Marly limestones with <i>Leptaena</i> fauna	C. Carvoeiro 2	
					Lemedo Fm.		C. Carvoeiro 1				
	PLIENSBACHIAN	Upper (Domerian)			Spinatum Margaritatus	Dolomitic marls and limestones with brachiopods of Meia Velha	Vale das Fontes Fm.	Vale das Fontes Fm.	Vale das Fontes Fm.	Marly limestones with bituminous facies	Marly limestones with bituminous facies
		Lower (Carixian)			Davoei Ibex		Coimbra Fm.	Coimbra Fm.		Lumpy marls and limestones	Lumpy marls and limestones
										Marls & limest. with <i>Uptonia</i> and <i>Pentacrinus</i>	Marls & limest. with <i>Uptonia</i> e <i>Pentacrinus</i>
	SINEMURIAN	Raricostatum Obtusum			Sesimbra Dolostones	S. Miguel Beds	Água de Madeiros Fm.	Praia Pedra Lisa Mb. Polvoeira Mb.			

Fig. 2 – Lithostratigraphical chart for the Pliensbachian-Toarcian units of the Lusitanian Basin (DUARTE & SOARES, 2002).

Despite some macroscopic similarities, all these units are defined in terms of different sedimentological and palaeontological (macrofauna and ichnofauna) characteristics (*vide* DUARTE, 1997; DUARTE & SOARES, 2002). The integration of several stratigraphic/sedimentological procedures (e.g. lithofacies analysis, microfacies, sequential evolution, ichnofossils and palaeontological evolution) allows the conclusion that the deposition occurred on a carbonate ramp setting (homoclinal ramp *sensu* READ, 1982) dipping towards the northwest (DUARTE, 1995, 1997).

In spite of this generic geological context, the lateral facies variations across the southern half of the Lusitanian Basin, show three major tectono-palaeogeographic settings: Arrábida-Sesimbra, Tomar and Peniche, with special sedimentological features and, consequently, a different lithostratigraphic chart (fig. 2).

Arrábida-Sesimbra: in this sector the outcrops are very scarce and the ammonite biostratigraphic control is very poor. The series is composed by dolomitic and bioclastic limestone facies, corresponding to the most shallow marine sediments observed in the whole basin. The sedimentary succession is included in the informal Dolomitic marls and limestones with brachiopods of Meia Velha Fm. (MANUPPELLA & AZERÊDO, 1996), lacking in this sector all Middle and Upper Toarcian. This sedimentary gap is also observed in the Algarve Basin, south of Portugal (ROCHA, 1976; MANUPPELLA & *al.*, 1988), where the Toarcian is restricted to two small outcrops.

Tomar: located in the southeastern part of the Lusitanian Basin, the Middle-Upper Liassic series is very condensed (DUARTE, 1997), when compared to the whole basin. The facies are bioclastic-rich (essentially benthonic) in calcareous dominated successions belonging to three formal formations: Vale das Fontes Fm. and Lemedo Fm. of Pliensbachian age and Prado Fm., lateral equivalent of S. Gião Fm. (fig. 2) (DUARTE & SOARES, 2002). In Tomar the series typifies the proximal part of the homoclinal ramp (DUARTE, 1997), well developed towards north and west. The occurrence of ammonites is rare, but allows in some places an accurate biostratigraphic control (MOUTERDE & *al.*, 1971; MOUTERDE & ROCHA, 1983).

Peniche: the unique feature of this sector, located in the southwestern part of the Basin and well exposed along the cliffs of the Peniche peninsula, is the strong siliciclastic and oolitic resedimented accumulation observed in the Toarcian succession (Cabo Carvoeiro Fm., DUARTE & SOARES, 2002). The influx of these sediments seems to have been related with turbiditic mechanisms (WRIGHT & WILSON, 1984). Despite this sedimentary setting for the Toarcian, and such as observed in other parts of the Basin, the Pliensbachian is here dominated by a thick succession of marl/limestone alternations (fig. 3). In this sector is located the type-section of Vale das Fontes and Lemedo Fms..

3. Sequence stratigraphy

Considering the northern sector of the Lusitanian Basin, A. F. SOARES & *al.* (1993a,b) subdivided the whole Late Triassic-extremely late Mid Jurassic cycle in to eight megasequences (A to H), bounded by regional discontinuities. The duration of these sequences, approximately equivalent to stages, places each megasequence with second-order sequence (*sensus* VAIL & *al.*, 1991) or, considering the hierarchy of sedimentary cyclicity, with transgressive-regressive facies cycles (*sensus* JACQUIN & GRACIANSKY, 1998a,b).

In our case study, the Pliensbachian-Toarcian series of the Lusitanian Basin is subdivided into two second-order sequences (SP and ST), with equivalent duration in time to Pliensbachian and Toarcian stages (DUARTE, 2003; DUARTE & *al.*, 2004b; figs. 3 to 5). The thickness of these sequences is highly variable, dependent on the palaeogeographic position of each sector in the basin, controlled by the ramp profile and accommodation space. In both second-order sequences the thickness increases from southeast (Tomar region) towards the northwest (Figueira da Foz-Cantanhede sectors), following the direction of the dipping ramp.

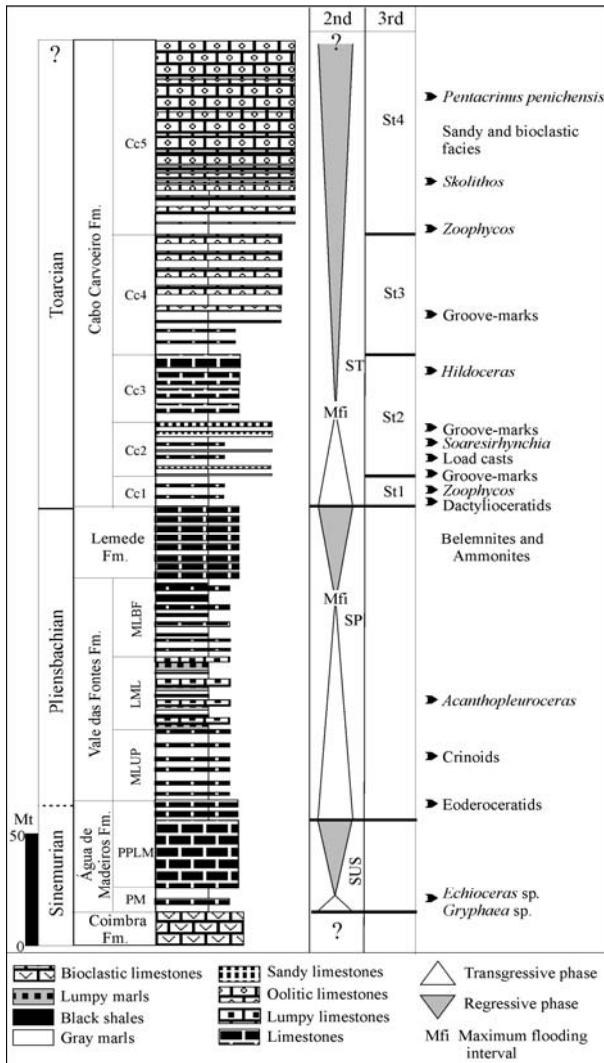


Fig. 3 – Summary stratigraphic log of the Upper Sinemurian – Upper Aalenian (?) at Peniche: lithostratigraphy, sequence stratigraphy (second and third-order sequences) and some sedimentary characteristics. According to L. DUARTE & *al.* (2004).

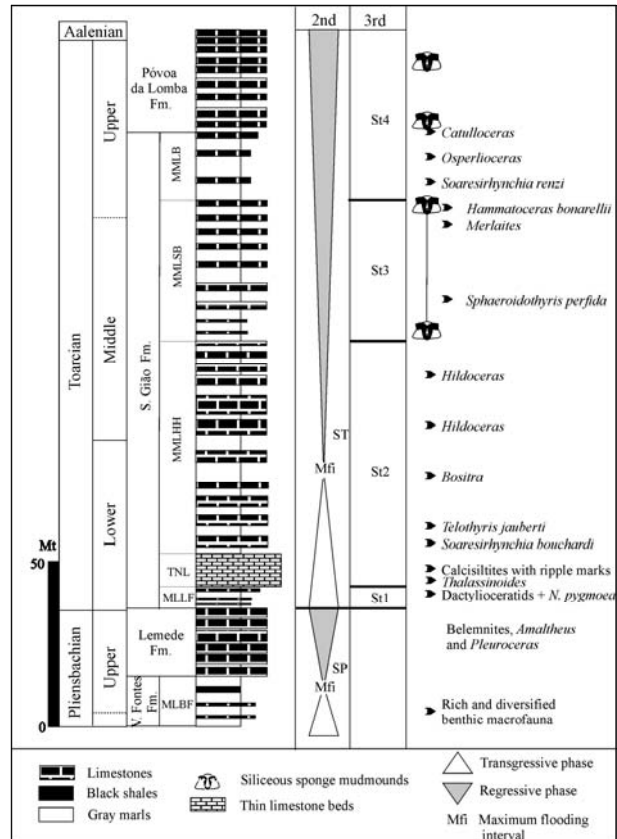


Fig. 4 – Summary stratigraphic log of the Upper Pliensbachian – Lower Aalenian succession at Rabaçal: lithostratigraphy, sequence stratigraphy (second- and third-order sequences) and some sedimentary characteristics. This section is considered as one of the main field references for the Pliensbachian-Aalenian of Portugal, due to the available high biostratigraphic control (MOUTERDE & *al.*, 1964-65; ROCHA & *al.*, 1987; Henriques 1992), corresponding to the type-section of the S. Gão Formation (lowermost Polymorphum Zone to Meneghini Zone; DUARTE & SOARES, 2002).

Sequence SP

The Pliensbachian succession shows a typical second-order transgressive/regressive sequence (megasequence D, *in* SOARES & *al.*, 1993a,b), with a dominant marly deposition at the base (Carixian and early Domerian time: Vale das Fontes Fm.) and a calcareous dominant facies at the top (late Pliensbachian to extreme base of early Toarcian: Lemedo Fm.).

The basal discontinuity of the sequence SP is particularly well observed in the western part of the basin (S. Pedro de Moel), dated roughly from the Sinemurian/Pliensbachian boundary (DUARTE & *al.*, 2004b). The series shows a large transgressive phase, ending in the middle-upper part of Margaritatus Zone (around Subnodosus/Gibbosus Subzone boundary; figs. 3 and 4). The whole basin is marked by an organic-rich deposition period (DUARTE & RODRIGUES, 2005; DUARTE & *al.*, 2005).

During the Spinatum Zone the sedimentation returned to a calcareous regime, very rich in benthic macrofauna. In southeastern sectors of the basin this

regressive phase is represented by bioclastic/grainstone facies, representing minimum accommodation space. The upper discontinuity of the sequence SP, observed in the whole basin (DT1 in DUARTE, 1997), is dated from the lowermost Polymorphum Zone (intra-Mirabile Subzone).

Considering the nature of the sediments, dominated by hemipelagic marly limestones, without inner ramp facies development, the weak lateral facies variation of the Pliensbachian series does not allow the recognition of third-order sequences.

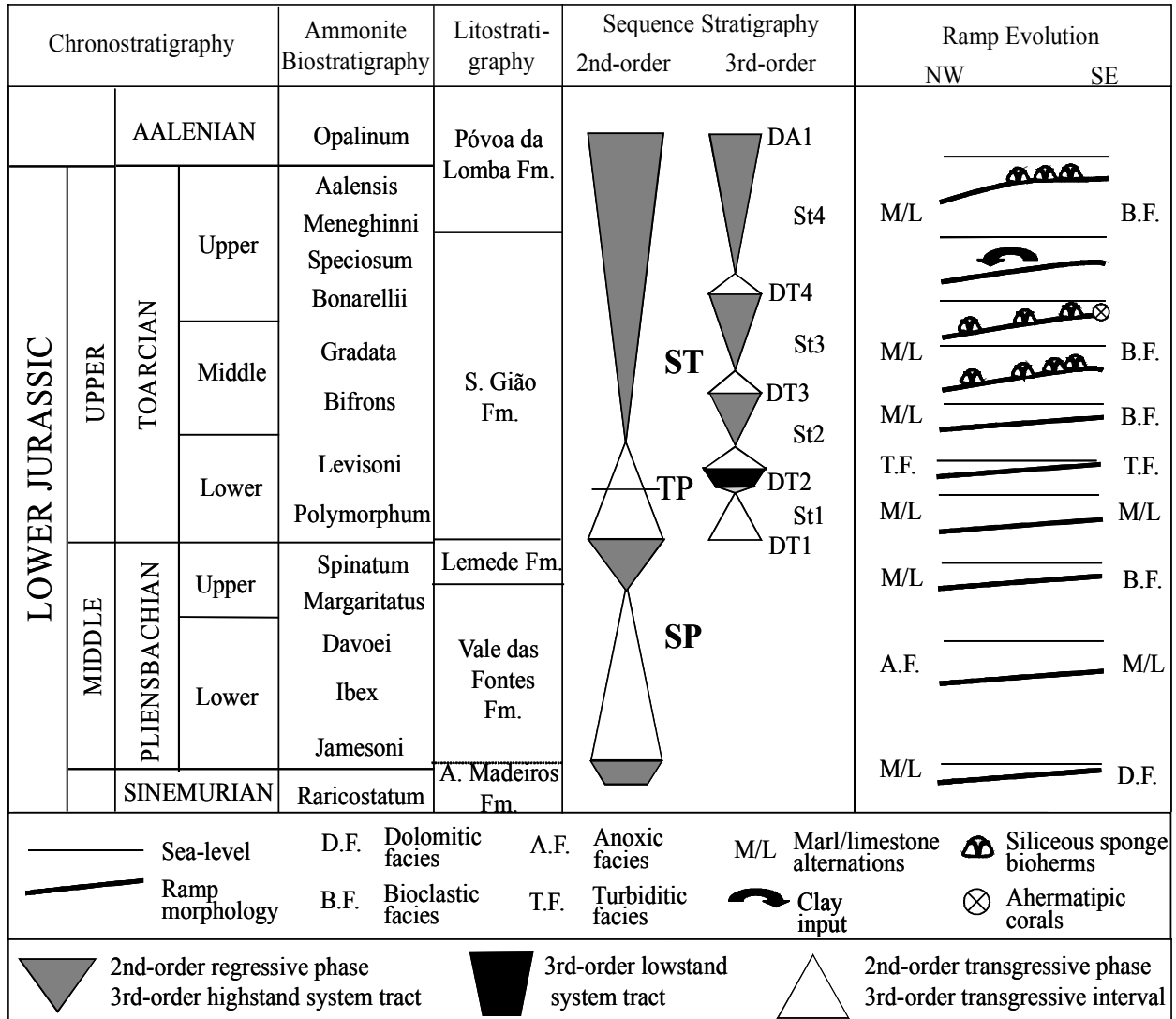


Fig. 5 – Sequence stratigraphy and carbonate ramp evolution for the Pliensbachian-Toarcian units of the Lusitanian Basin. TP – Tectonic phase; DT1-DA1 – 3rd-order sequence boundaries.

Sequence ST

This second-order depositional sequence is dated from the early Toarcian to early Aalenian and includes the S. Gião Fm. and the lowermost part of Póvoa da Lomba Fm.. In the stratigraphic chart of A. F. SOARES & al. (1993a,b), this sequential unit corresponds to the megasequence E and it is subdivided into four third-order depositional sequences (St1 to St4; MST1 to MST4 in DUARTE, 1995, 1997; figs. 3 to 5), each one bounded by regional discontinuities, recognised over most parts of the Lusitanian Basin (DUARTE & al., 2001; 2004a,b).

The base of sequence ST (Polymorphum Zone) corresponds to an abrupt flooding event, through a generalised marly accumulation in the whole basin.

However, around the Polymorphum/Levisoni interval, an important tectonic activity occurred in the whole basin, responsible by a great sedimentary change (DUARTE & SOARES, 1993; DUARTE, 1995, 1997; DUARTE & al. 2004a,b), with special facies features in Peniche (WRIGHT & WILSON, 1984) and Arrábida (KULLBERG & al., 2001). The marly dominance observed at the top of the Levisoni Zone, coincident with the MMLHH Mb., marks the maximum peak transgression of the Toarcian second-order sequence (DUARTE, 2003; DUARTE & al., 2004a,b). This event ends with some evidences of pelagic deposition, shown by thin-shelled bivalve-rich (*Bositra* sp.) horizons (fig. 4).

The Upper Toarcian-Lower Aalenian succession shows a regressive trend, ending this second-order

sequence with an upward increase of calcareous and bioclastic content, including ahermatipic corals in the eastern sectors (fig. 5). The discontinuity is dated from the Opalinum Zone and shows different sedimentary

records in the basin (DUARTE, 1997; DUARTE & HENRIQUES, 2001; DA1 in DUARTE & al., 2001; fig. 5).

This sequence varies between 75-80 m in Tomar and around 280 m thick in the Coimbra sector.

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