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Benthic foraminifers and palaeoenvironment in the Lower and Middle Jurassic of the Western Basque-Cantabrian Basin (Northern Spain)

Foraminíferos bentónicos y paleoambientes del Jurásico Inferior y Medio de la zona occidental de la Cuenca Vasco-Cantábrica (norte de España)

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Abstract

Benthic foraminifers are studied from the Lower and Middle Jurassic of the western Basque-Cantabrian Basin (sections Tudanca, Aguilar de Campoó and Barrios de Villadiegos). Five benthic foraminiferal assemblages are recognized, each one related to a specific trophic palaeoenvironment created by palaeoceanography and relative sea-level change. The *Astacolus-Lingulina*-assemblage occurs in Lower Sinemurian transgressive deposits with high wave-energy. The *Laevidentalina-Eoguttulina*-assemblage is typical for oxygenated transgressive deposits of the Pliensbachian. The *Ammobaculites-Reinholdella*-assemblage is characteristic for anoxic to poorly oxygenated deposits of the Pliensbachian, Toarcian, and Callovian. The *Saracenaria-Pseudolamarckina*-assemblage occurs in low-energy shelf deposits of the Aalenian to Lower Callovian. The *Marginulina-Citharina*-assemblage typifies the high-energy sediments of the Aalenian to Lower Callovian. Benthic foraminifers show also variation with age and variation with changes in the palaeoenvironment related to transgression-regression cycles.

Keywords: Jurassic, Basque-Cantabrian Basin, benthic foraminifers, palaeoecology, Northern Spain

Resumen

Se estudian los foraminíferos bentónicos de edad Jurásico Inferior y Medio de la zona occidental de la Cuenca Vasco-Cantábrica (secciones de Tudanca, Aguilar de Campoó y Barrios de Villadiegos). Se han reconocido cinco asociaciones de foraminíferos bentónicos, cada una de las cuales está relacionada con un paleoambiente trófico específico producido por condicionantes paleoceanográficos y por variaciones relativas del nivel del mar. La asociación *Astacolus-Lingulina* tiene lugar en depósitos transgresivos de alta energía del Sinemuriense inferior. La asociación *Laevidentalina-Eoguttulina* es característica de los depósitos transgresivos y bien oxigenados del Pliensbachiense. La asociación *Ammobaculites-Reinholdella* aparece en los depósitos anóxicos a poco oxigenados de edad Pliensbachiense, Toarciense y Calloviense. La asociación *Saracenaria-Pseudolamarckina* está relacionada con los depósitos de plataforma de baja energía de edad Aaleniense a Calloviense inferior. Y por último, la asociación *Marginulina-Citharina* caracteriza los sedimentos de alta energía del Aaleniense al Calloviense inferior. Los foraminíferos bentónicos muestran también variaciones en relación con la edad y con los cambios en el paleoambiente en función de los ciclos transgresivos-regresivos.

Palabras clave: Jurásico, Cuenca Vasco-Cantábrica, foraminíferos bentónicos, paleoecología, Norte de España

1. Introduction

During Jurassic times, marine sediments deposited in epicontinental sag basins are recorded in various parts of Western and Central Europe. The Jurassic deposits of the Basque-Cantabrian Basin form one of these sag basins. The marine sediments deposited there are interpreted in the context of an interior-sag-basin cycle (Gräfe, 1999). The basin is formed by low extension of continental crust very similar to time-equivalent basins in France (Paris Basin), Germany (S- and N-German Jurassic Basin), and England. Compared to the central Atlantic region, where the ongoing extension culminated in the formation of the first oceanic crust in mid-Jurassic times (Dercourt *et al.*, 1993), the Basque-Cantabrian Basin was plate tectonically stable during the Jurassic. This stable period terminated with the pronounced and widespread so-called late Cimmerian unconformity (Ziegler, 1988) which marked also the termination of widespread deposition of marine sediments in the Basque-Cantabrian Basin.

Benthic foraminifers and the palaeoenvironment of the Lower to Middle Jurassic sedimentary series of the Basque-Cantabrian Basin are dependent on changes in the tectonic, palaeogeographic and palaeoceanographic development in this period in SW-Europe. The period between Triassic-Jurassic boundary and Middle-Late Jurassic boundary can be divided in six depositional phases which are separated by changes in tectonic subsidence and related to that deposition of shallow-marine or outer shelf sediments. Also anoxic sediments are recorded in some periods like the Pliensbachian / Toarcian in the deepest basin parts. The reaction of the benthic foraminiferal fauna on these changes in the marine environment is described in this work.

2. Material, methods, and regional geology

Marine Jurassic sediments are present in the surface and subsurface of the Provinces Santander, Burgos, Palencia and Alava (N-Spain). These sediments were divided in biostratigraphic units by Dahm (1965), Ramirez del Pozo (1971), and Schaaf (1986) (Fig. 1). The connection between facies development and basin-wide tectonic events were described in Schaaf (1986) and Aurell *et al.* (2002).

The investigated area lies in the western part of the Mesozoic Basque-Cantabrian sedimentary realm. It has a structural continuation on the offshore continental shelf of Spain in the Bay of Biscay. A first, early rifting phase happened in the late Triassic and early Jurassic in the North Atlantic realm as well as in the Bay of Biscay. Delta sedimentation and carbonate platforms characterize the early and mid-Jurassic development in the central Atlantic. In the Bay of Biscay, rifting processes ceased in this period and only thin, epicontinental carbonate sediments were deposited in the Basque-Cantabrian Basin. After a Callovian regression follows the progradation of deltaic complexes from the south and west in the mid- and late Jurassic basin. The late Jurassic shows pronounced rifting and subsidence that culminated in the main rifting phase in the early Cretaceous.

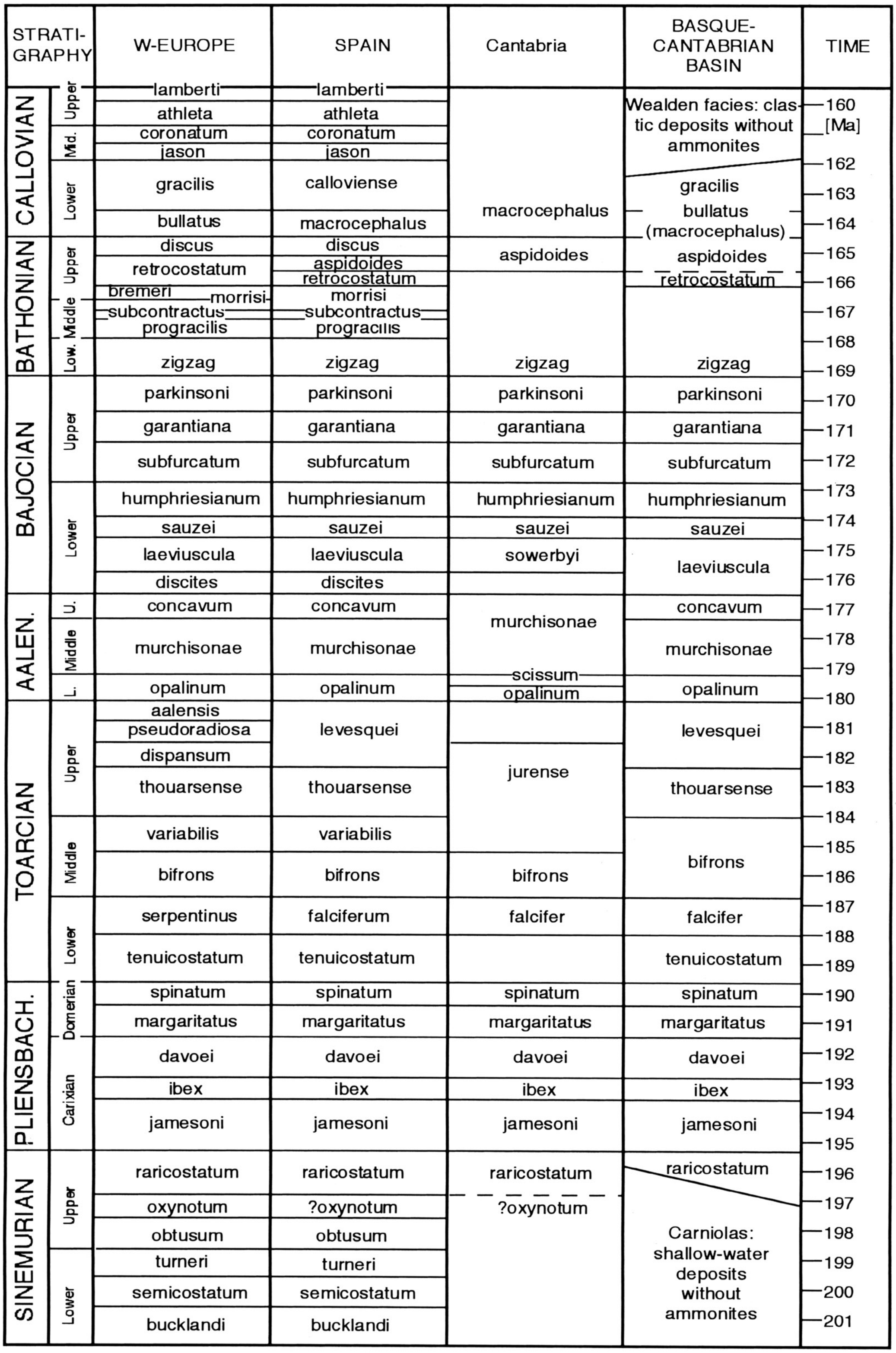
For the study of benthic foraminifers, samples from three north Spanish sections were used. These sections are (from basin center to basin margin) Tudanca, Aguilar de Campoó, and Barrios de Villadiego (Fig. 2). The three sections were described in detail (facies and biostratigraphy) in the work of Schaaf (1986) and are refigured from this contribution (Fig. 3). The benthic foraminifers were studied in 21 samples from Tudanca, 15 samples from Aguilar de Campoó and 10 samples from Barrios de Villadiego. These samples are stored in the collection of Jost Wiedmann at Tübingen University. The benthic foraminifers were preparated from a part of these samples. The foraminifers were all picked from disintegrated marl samples.

The samples were disintegrated with Rewoquat tensides and sieved in fractions 125 to 212, 212 to 300, 300 to 425 and larger than 425 µm. The fractions were then picked. Most samples contain 200 to 300 picked benthic foraminifers. There are few samples, that have only around 100 to 200 benthic foraminifers (Figs. 4-6). One sample from the Upper Sinemurian of Aguilar de Campoó was nearly barren with benthic foraminifers (64). The richest samples, containing more than 300 foraminifers, come from deep ramp deposits of the three sections.

The preservation of the foraminiferal fauna is unfortunately poor in most samples. Few samples show a good preservation. Frequent abrasion and bioerosion is recorded on the foraminiferal tests. These features are part of intensive taphonomic processes in the marine Jurassic sediments (Herrero and Canales, 2002).

3. Results

Benthic foraminifers were analyzed from 46 samples in three sections; the results are shown in the Figures 4



STRATIGRAPHY		W-EUROPE	SPAIN	Cantabria	BASQUE-CANTABRIAN BASIN	TIME
CALLOVIAN	Upper	lamberti	lamberti		Wealden facies: clastic deposits without ammonites	
		athleta	athleta			160 [Ma]
	Mid.	coronatum	coronatum			
		jason	jason			
	Lower	gracilis	calloviense	macrocephalus	gracilis bullatus (macrocephalus)	162 163
		bullatus	macrocephalus			164
BATHONIAN	Upper	discus	discus	aspidoides	aspidoides	165
		retrocostatum	aspidoides retrocostatum		retrocostatum	166
	Middle	bremeri morrisi	morrisi			
		subcontractus	subcontractus			167
		progracilis	progracilis			168
	Low.	zigzag	zigzag	zigzag	zigzag	169
BAJOCIAN	Upper	parkinsoni	parkinsoni	parkinsoni	parkinsoni	170
		garantiana	garantiana	garantiana	garantiana	171
		subfurcatum	subfurcatum	subfurcatum	subfurcatum	172
	Lower	humphriesianum	humphriesianum	humphriesianum	humphriesianum	173
		sauzei	sauzei	sauzei	sauzei	174
		laeviuscula	laeviuscula	sowerbyi	laeviuscula	175
		discites	discites			176
AALEN.	U.	concavum	concavum	murchisonae	concavum	177
	Middle	murchisonae	murchisonae		murchisonae	178 179
	L.	opalinum	opalinum	scissum opalinum	opalinum	180
TOARCIAN	Upper	aalensis	levesquei		levesquei	
		pseudoradiosa				181
		dispansum		jurense		182
		thouarsense	thouarsense		thouarsense	183
	Middle	variabilis	variabilis		bifrons	184 185
		bifrons	bifrons	bifrons		186
	Lower	serpentinus	falciferum	falcifer	falcifer	187
		tenuicostatum	tenuicostatum		tenuicostatum	188 189
PLIENSBACH.	Domerian	spinatum	spinatum	spinatum	spinatum	190
		margaritatus	margaritatus	margaritatus	margaritatus	191
	Carixian	davoei	davoei	davoei	davoei	192
		ibex	ibex	ibex	ibex	193
		jamesoni	jamesoni	jamesoni	jamesoni	194 195
SINEMURIAN	Upper	raricostatum	raricostatum	raricostatum	raricostatum	196
		oxynotum	?oxynotum	?oxynotum	Carniolas: shallow-water deposits without ammonites	197
		obtusum	obtusum			198
	Lower	turneri	turneri			199
		semicostatum	semicostatum			200
		bucklandi	bucklandi			201

Fig. 1.–Biostratigraphic subdivision of the Jurassic sediments of the Basque-Cantabrian Basin (Northern Spain). Modified after Schaaf (1986: fig. 8). Source of biostratigraphic data: W-Europe after Hardenbol *et al.* (1998), Spain after Mensink and Mertmann (1984a), Cantabria after Dahm (1965), Basque-Cantabrian Basin after Schaaf (1986). Time-scale after Hardenbol *et al.* (1998). Abbreviations: Hett. = Hettangian, Pliensbach. = Pliensbachian, Aalen. = Aalenian, L., Low. = Lower, U., Mid. = Middle, Upp. = Upper.

Fig. 1.–Subdivisión bioestratigráfica de los sedimentos del Jurásico de la Cuenca Vasco-Cantábrica (Norte de España). Modificado de Schaaf (1986: fig. 8). Datos bioestratigráficos: Europa occidental según Hardenbol *et al.* (1998), España de acuerdo con Mensink y Mertmann (1984a), Cantabria según Dahm (1965), Cuenca Vasco-Cantábrica según Schaaf (1986). Escala temporal según Hardenbol *et al.* (1998). Abreviaturas: Hett. = Hettangiense, Pliensbach. = Pliensbachiense, Aalen. = Aaleniense, L., Low. = Inferior, U., Mid. = Medio, Upp. = Superior.

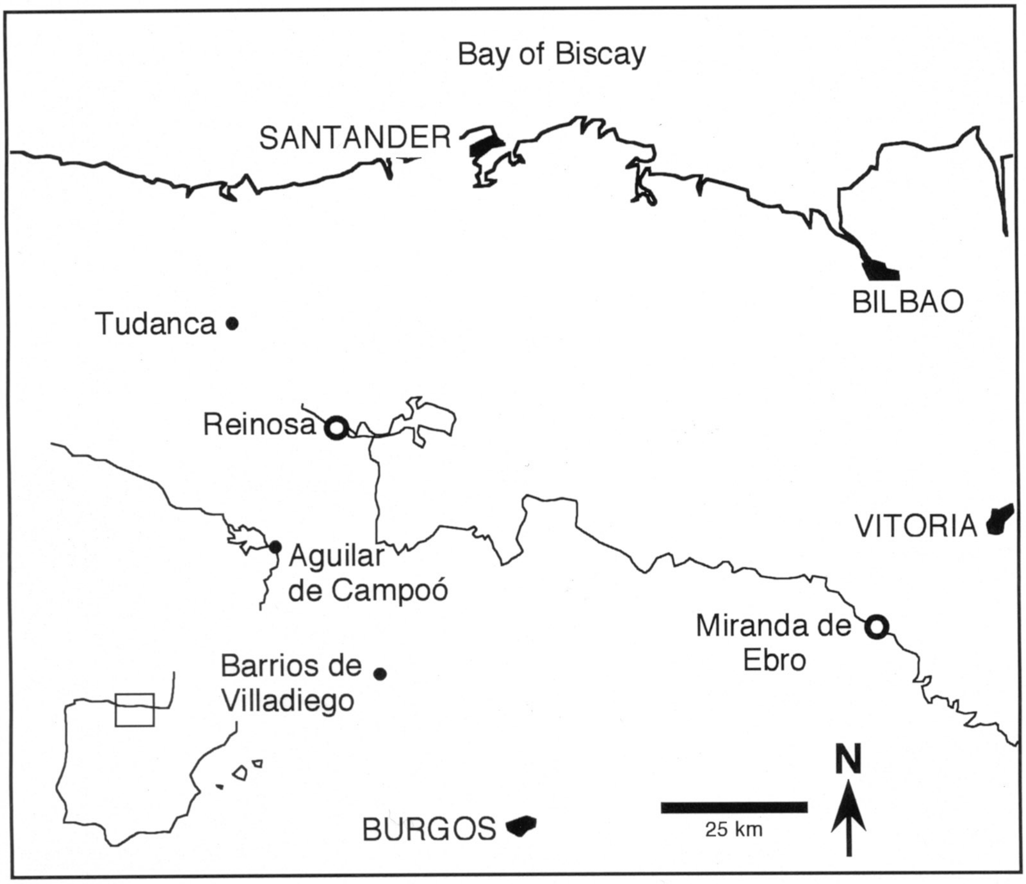


Fig. 2.–Location of the sections Tudanca, Aguilar de Campoó, and Barrios de Villadiego in northern Spain. For details of the location see Dahm (1965: p. 17f).

Fig. 2.–Situación de las secciones de Tudanca, Aguilar de Campoó y Barrios de Villadiego en el norte de España. Para más detalle en relación a dicha localización ver Dahm (1965: p. 17f).

to 6. The benthic foraminiferal fauna is grouped into five assemblages each characteristic for a specific environment. The foraminiferal assemblages are called *Astacolus-Lingulina*-assemblage (Upper Sinemurian), *Laevidentalina-Eoguttulina*-assemblage (Carixian-Domerian, Upper Toarcian), *Ammobaculites-Reinholdella*-assemblage (Pliensbachian-Toarcian), *Saracenaria-Pseudolamarckina*-assemblage (Aalenian-Lower Callovian), and *Epistomina-Trocholina*-assemblage (Bajocian-Lower Callovian). The five assemblages are each representative for a given palaeoenvironment (see below). There are some foraminiferal species which occur opportunistic in several assemblages with varying abundances or are very rare like *Vaginulina sherborni, Astacolus scalptus, Lenticulina impressa, Lenticulina toarcense,* and *Lenticulina virgata* amongst others (Figs. 4-6).

3.1. Astacolus-Lingulina assemblage (Upper Sinemurian)

The *Astacolus-Lingulina*-assemblage characterizes lithofacies represented by bioturbated wackestones, bioclastic packstones and few marlstones. These deposits formed after the abrupt end of the Carniolas sedimentation in the Upper Sinemurian.

Thick-shelled but small *Lingulina regularis* and *Astacolus radiata* are the dominant species. Few other species occur (Figs. 4, 5). *L. regularis* and *A. radiata* are of small size ($< 250\mu m$) compared to younger periods where these species also occur.

Diversity and abundance in the samples is generally very low (Figs. 4-6). Samples from the Upper Sinemurian have the lowest number in benthic foraminifers beside samples from anoxic sediments of Pliensbachian or Toarcian age.

3.2 Laevidentalina-Eoguttulina-assemblage (Carixian-Domerian, Upper Toarcian)

This assemblage characterizes the transgressive deposits of the Carixian-Domerian. These sediments are composed of marl-limestone alternations which become dominantly more calcareous in the uppermost Pliensbachian.

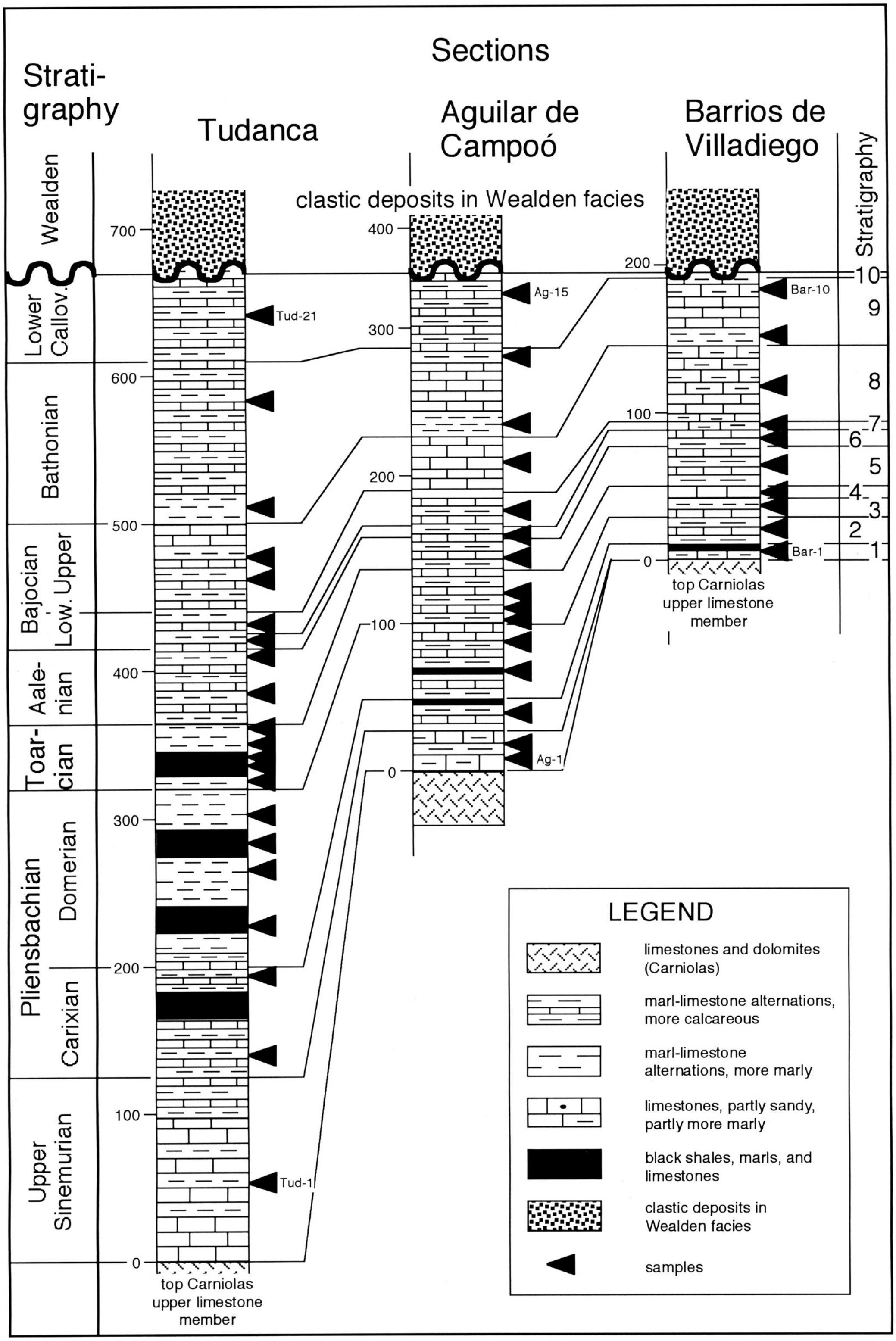


Fig. 3.–Lithofacies and biostratigraphy of the sections Tudanca, Aguilar, Barrios de Villadiego (Basque-Cantabrian Basin, N Spain). Lithofacies simplified after Dahm (1965: pl. 11) and Schaaf (1986: figs. 19, 36). For explanation see text. Abbreviations: 1 = Carixian, 2 = Domerian, 3 = Lower Toarcian, 4 = Upper Toarcian, 5 = Aalenian, 6 = Lower Bajocian, 7 = Middle Bajocian, 8 = Upper Bajocian, 9 = Bathonian, 10 = Lower Callovian.

Fig. 3.–Litofacies y bioestratigrafía de las secciones de Tudanca, Aguilar, Barrios de Villadiego (Cuenca Vasco-Cantábrica, N España). Litofacies simplificadas a partir de Dahm (1965: pl. 11) y Schaaf (1986: figs. 19, 36). Ver el texto para explicación. Abreviaturas: 1 = Carixiense, 2 = Domeriense, 3 = Toarciense inferior, 4 = Toarciense superior, 5 = Aaleniense, 6 = Bajociense inferior, 7 = Bajociense medio, 8 = Bajociense superior, 9 = Bathoniense, 10 = Calloviense inferior.

	639	579	511	478	462	435	419	410	385	360	348	340	333	324	302	285	265	228	193	115	52	(m)
	dr	dr	dr	ir	ir	dr	dr	dr	dr	ir	dr	bs	bs	dr	dr	bs	dr	bs	dr	dr	ir	paleoenvironment
A-R-assemblage								9	5			7	3			7		4				*Lagenammina jurassica*
A-R-assemblage	2	3					2					18	23			28		8				*Haplophragmoides kingakensis*
A-R-assemblage	2										21	15	26	4		18		3				*Ammobaculites fontinensis*
A-R-assemblage			1			3	2				12	26	17	13		17		5				*Ammobaculites lunaris*
A-R-assemblage						1					2	2	2	3	9	6	1	4	2	8		*Ammobaculites multiformis*
A-R-assemblage						1		1	3	2	9	29	18	14	3	6	5	9				*Trochammina elevata*
opportunistic		14	33	23	17	14	2				3		6		2	1		2	8	23	47	*Gaudryina sp.*
opportunistic	17	29	18	17	29	12	6	3				4			6		22		9	12	38	*Textularia sp.*
M-C-assemblage		1		9	5	1		1		7				1								*Trocholina conica*
S-P-assemblage	8	9	2			11	12	33	14					2	7		2		2			*Nubeculinella infraoolithica*
Ld-E- and S-P-assemblage			2			4	2		2		8	1		2	1				1			*Laevidentalina guembeli*
S-P-assemblage	22	6	5		1	3	2	21	3		18			4								*Laevidentalina pseudocommunis*
Ld-E-assemblage	1	3	3			23	7	7	10	1	35	2		19	4		8		19	14		*Laevidentalina terquiemi*
Ld-E- and S-P-assemblage	5		9			8	9	3	4		12			12	11		13		4	2		*Laevidentalina varians*
Ld-E-assemblage	1	4	3			3	2	9	4		8			3	14		9		22	18		*Nodosaria mutabilis*
opportunistic and/or rare					1	1	1		1	4	1					1			1			*Nodosaria pulchra*
Ld-E-assemblage		1				4	2	3	1	2	5			1	1		8		14	10		*Nodosaria regularis*
M-C-assemblage	2	1		14	12	2	1		2	19				1								*Nodosaria simoniana*
Ld-E-assemblage	3	3	4	1		4	2	4	3	2	18			2	7		19		31	12		*Pseudoglandulina irregularis*
M-C-assemblage				33	29					18												*Lingulina pupa*
A-L-assemblage																1	1			2	19	*Lingulina regularis*
opportunistic and/or rare				2			1			1	2						1					*Lingulina tenera*
Ld-E- and S-P-assemblage			3			12	18	5	2		17				19		30		36	47		*Frondicularia dubia*
Ld-E- and S-P-assemblage		3	8			4	7	38	29	2	37		2	12	13		25	1	44	33		*Lenticulina bochardi*
opportunistic		2	3	2	3	1	5	2	3	7	3	2										*Lenticulina communis*
S-P-assemblage	34	38																				*Lenticulina eichenbergi*
opportunistic			3	2	1	5	2	9	5	2	1											*Lenticulina faveolata*
M-C-assemblage				38	29					19												*Lenticulina helios*
opportunistic		1	2	3	4	13	19	9	4	12	29	9	4	19	19	2	36	6	2	39		*Lenticulina impressa*
opportunistic				4	3	2	13	4	2	20	23	22	25	27	16	8	9	2	3			*Lenticulina toarcense*
opportunistic	3	2			1	2	2	9	5		3	1		3		1						*Lenticulina virgata*
S-P-assemblage	29	18	9	2	1	14	19	12	8													*Saracenaria oxfordiana*
S-P-assemblage		3	4			11	12	11	7		3			2			1					*Palmula flabellina*
S-P-assemblage		7	8			5	6	12	9		27			12	17		11		1			*Palmula maior*
S-P-assemblage		4	3			8	2	9	6	8	6			8			2					*Palmula obonensis*
M-C-assemblage	2	1		37	28			1	1	19	2			1								*Palmula zitteli*
M-C-assemblage		1		14	4	1		2	1	8	1			1			1					*Astacolus payardi*
S-P-assemblage	14	9	4	19	6	4	3	9	8													*Astacolus pediacus*
A-L-assemblage										9	8			11	21		12		62	56	44	*Astacolus radiata*
M-C-assemblage																				2	19	*Astacolus rectalonga*
opportunistic		1		5	4	8	3	3	7	2	5	3	1		1		2		1			*Astacolus scalptus*
S-P-assemblage						12	41	39	19	1	11											*Astacolus varians*
S-P-assemblage						5	9	8	2		2			9	6		4		13			*Marginulina alata*
S-P-assemblage				2	1	3	9	9	4		4			9	8		2	7	17			*Marginulina prima*
M-C-assemblage				29	19					19												*Marginulina spinata*
M-C-assemblage				19	11	1	2	2	5	29												*Citharina clathrata*
opportunistic		1	1			3			2			1			1							*Citharina protensa*
opportunistic		2	1			2	5	3	2		3	4	2	6	1	2						*Vaginulina sherborni*
Ld-E- and S-P-assemblage	39	38	37			39	35	21	33		18			39	42	2	12	6				*Eoguttulina liassica*
Ld-E- and S-P-assemblage	20	23	32				6	4		8	12											*Eoguttulina oolithica*
S-P-assemblage	25	26	22			15	17	21	24													*Pseudolamarckina liapinensis*
A-R-assemblage			1				2	1		2	6	51	52	4		48		47				*Reinholdella macfadyeni*
A-R-assemblage											1	13	17	9		39		12				*Rheinholdella dreheri*
S-P-assemblage	45	38	33			39	24															*Epistomina conica*
A-R-assemblage							1			2	6	67	29	8		62		57				*Brizalina liassica*
	274	292	254	275	209	304	315	337	240	225	382	277	227	261	229	249	236	173	292	278	167	Total (benthic foraminifers)
	18	30	26	20	21	39	39	34	35	25	37	18	15	31	23	16	24	15	20	14	5	Number of species

Fig. 4.–Distribution and number of benthic foraminifers in the section Tudanca (Basque-Cantabrian Basin). Location of section and lithofacies see Figures 2 and 3. Last row shows assignment of each species to a foraminiferal assemblage. For palaeoenvironment interpretation (column 2) see text. Abbreviations: ir = inner ramp, high-energy environment, dr = deep ramp, low-energy environment, bs = black shales, A-R-assemblage = *Ammobaculites-Reinholdella*-assemblage, M-C-assemblage = *Marginulina-Citharina*-assemblage, S-P-assemblage = *Saracenaria-Pseudolamarckina*-assemblage, Ld-E-assemblage = *Laevidentalina-Eoguttulina*-assemblage, A-L-assemblage = *Astacolus-Lingulina*-assemblage.

Fig. 4.–Distribución y abundancia de foraminíferos bentónicos en la sección de Tudanca (Cuenca Vasco-Cantábrica). Para la localización y litofacies de la sección ver Figuras 2 y 3. La última fila muestra la asociación de foraminíferos a la que es asignada cada especie. Para la interpretación paleoambiental (columna 2) ver texto. Abreviaturas: ir = rampa interna, ambiente de alta energía, dr = rampa profunda, ambiente de baja energía, bs = arcillas negras, A-R-assemblage = Asociación *Ammobaculites-Reinholdella*, M-C-assemblage = Asociación *Marginulina-Citharina*, S-P-assemblage = Asociación *Saracenaria-Pseudolamarckina*, Ld-E-assemblage = Asociación *Laevidentalina-Eoguttulina*, A-L-assemblage = Asociación *Astacolus-Lingulina*.

	325	280	235	205	175	160	145	120	110	105	87	70	40	20	10	(m)
	dr	dr	dr	ir	ir	dr	dr	dr	dr	bs	dr	bs	dr	ir	ir	paleoenvironment
A-R-assemblage			2		3		1	1		1		9				*Lagenammina jurassica*
A-R-assemblage								1		3		8				*Haplophragmoides kingakensis*
A-R-assemblage								1	1	3		9				*Ammobaculites fontinensis*
A-R-assemblage								1	3	1		12				*Ammobaculites lunaris*
A-R-assemblage								2	1	3	1	8	1			*Ammobaculites multiformis*
A-R-assemblage							2	1	1	2	1	8				*Trochammina elevata*
opportunistic	13	3	5	19	16	12				3	12	7	9	26	27	*Gaudryina sp.*
opportunistic	11	8	10	13	25	7					19	4	3	14	12	*Textularia sp.*
M-C-assemblage	2	1		9	13	1	2									*Trocholina conica*
S-P-assemblage	1		29			3	12	1	2		1					*Nubeculinella infraoolithica*
Ld-E- and S-P-assemblage							2	2	5	3						*Laevidentalina guembeli*
S-P-assemblage	3	9	4	1		5	2		1		1					*Laevidentalina pseudocommunis*
Ld-E-assemblage	2	5	21			22	29	16	13		3	4	9	1		*Laevidentalina terquemi*
Ld-E- and S-P-assemblage		1	13			12	9	2			19	4	2			*Laevidentalina varians*
Ld-E-assemblage			4			3	6				3	6	8			*Nodosaria mutabilis*
opportunistic and/or rare		1					1		2				1			*Nodosaria pulchra*
Ld-E-assemblage		3	3			4	2		2		1	1	4			*Nodosaria regularis*
M-C-assemblage		2	1	8	7	3					1					*Nodosaria simoniana*
Ld-E-assemblage			4			2	3	1	1	1	4	3	2			*Pseudoglandulina irregularis*
M-C-assemblage		2	5	9	13		2	6			2		1			*Lingulina pupa*
A-L-assemblage									2		4	2	3	15	9	*Lingulina regularis*
opportunistic and/or rare			1		1						9	2	4			*Lingulina tenera*
Ld-E- and S-P-assemblage	6	5	9			5	3	9			12	2	24			*Frondicularia dubia*
Ld-E- and S-P-assemblage	1	41	29	5	4	13	19	2	8	3	18	2	12	23		*Lenticulina bochardi*
opportunistic	3	21	6	4	19	12	24	23	1		2					*Lenticulina communis*
S-P-assemblage	41	29	2													*Lenticulina eichenbergi*
opportunistic				19	17	16	14	21								*Lenticulina faveolata*
M-C-assemblage		3	6	14	16	8	9		2		6					*Lenticulina helios*
opportunistic		5	2				1				19	13	12			*Lenticulina impressa*
opportunistic						11	23	34	25	18	3		12			*Lenticulina toarcense*
opportunistic	21		1				2				2					*Lenticulina virgata*
S-P-assemblage	3	9	5	1	1	4	3									*Saracenaria oxfordiana*
S-P-assemblage	3	5	6		1	5	3	2	1		3					*Palmula flabellina*
S-P-assemblage			1			1					1	1	3	1		*Palmula maior*
S-P-assemblage			1			1			1		1		2			*Palmula obonensis*
M-C-assemblage		1		9	7	1	1		1							*Palmula zitteli*
M-C-assemblage		2	4	23	19	7					3					*Astacolus payardi*
S-P-assemblage	1	8	2	2	1	9	5				2		1			*Astacolus pediacus*
A-L-assemblage			5	9		3					8		9	19	12	*Astacolus radiata*
M-C-assemblage					1				1					9	4	*Astacolus rectalonga*
opportunistic		12	4				46	13	31	21						*Astacolus scalptus*
S-P-assemblage	3	6	9	1	2	17	12	16	21	1	3		9			*Astacolus varians*
S-P-assemblage			3			9	6	3	6	1	5	1	9			*Marginulina alata*
S-P-assemblage						2					23	2	19			*Marginulina prima*
M-C-assemblage	2		1	9	11		3		2							*Marginulina spinata*
M-C-assemblage	2	9	4	23	17	1	3	1								*Citharina clathrata*
opportunistic	3	8	1		3		1		1		2			1		*Citharina protensa*
opportunistic	13	12				14	11	28	25	24	39	1	3			*Vaginulina sherborni*
Ld-E- and S-P-assemblage	38	29	19	3	2	29	13	12	19	4	20	2	23	2		*Eoguttulina liassica*
Ld-E- and S-P-assemblage	19	15	12													*Eoguttulina oolithica*
S-P-assemblage	14	33	19	2	4	32	45	23								*Pseudolamarckina liapinensis*
A-R-assemblage		3	7			4	3	33	22	44	9	61	11			*Reinholdella macfadyeni*
A-R-assemblage								8	9	3		12	1			*Rheinholdella dreheri*
S-P-assemblage	33	15	21	3	7	12	8	4	3		1					*Epistomina conica*
A-R-assemblage							4	2	3	18	2	29	4			*Brizalina liassica*
	238	306	281	186	210	290	335	269	216	157	265	213	201	111	64	Total (benthic foraminifers)
	23	31	38	21	24	34	37	29	31	19	37	26	28	10	5	Number of species

Fig. 5.–Distribution and number of benthic foraminifers in the section Aguilar de Campoó (Basque-Cantabrian Basin). Location of section and lithofacies see Figures 2 and 3. Last row shows assignment of each species to a foraminiferal assemblage. For palaeoenvironment interpretation (column 2) see text. Abbreviations see Fig. 4.

Fig. 5.– Distribución y abundancia de foraminíferos bentónicos en la sección de Aguilar de Campoó (Cuenca Vasco-Cantábrica). Para la localización y litofacies de la sección ver Figuras 2 y 3. La última fila muestra la asociación de foraminíferos a la que es asignada cada especie. Para la interpretación paleoambiental (columna 2) ver texto. Para las abreviaturas ver la Fig. 4.

	182	145	117	90	80	62	45	35	20	5	(m)
	dr	dr	ir	ir	dr	dr	ir	dr	dr	dr	paleoenvironment
A-R-assemblage								1		1	*Lagenammina jurassica*
A-R-assemblage										2	*Haplophragmoides kingakensis*
A-R-assemblage	1							1			*Ammobaculites fontinensis*
A-R-assemblage								2		2	*Ammobaculites lunaris*
A-R-assemblage	1	1						2	1	3	*Ammobaculites multiformis*
A-R-assemblage							6			2	*Trochammina elevata*
opportunistic	9	12	19	7	14	8	3	33	19	8	*Gaudryina sp.*
opportunistic	12	4	8	29	1	2	8	8	12	18	*Textularia sp.*
M-C-assemblage	4		11	13		2	12	2			*Trocholina conica*
S-P-assemblage	1	2			1						*Nubeculinella infraoolithica*
Ld-E- and S-P-assemblage						3	2				*Laevidentalina guembeli*
S-P-assemblage	3	8			3	2		4			*Laevidentalina pseudocommunis*
Ld-E-assemblage	1	4			4	3	2	8	5	2	*Laevidentalina terquemi*
Ld-E- and S-P-assemblage	1	3			1	4		3	1	1	*Laevidentalina varians*
Ld-E-assemblage	1					3			1		*Nodosaria mutabilis*
opportunistic and/or rare		1						1	1		*Nodosaria pulchra*
Ld-E-assemblage			2		1				1		*Nodosaria regularis*
M-C-assemblage			8	9			3				*Nodosaria simoniana*
Ld-E-assemblage	9	4			3	2	2	7	6		*Pseudoglandulina irregularis*
M-C-assemblage		1	4	3	1		3				*Lingulina pupa*
A-L-assemblage									2	3	*Lingulina regularis*
opportunistic and/or rare	1	1	3		1			1		1	*Lingulina tenera*
Ld-E- and S-P-assemblage	6	19			14	42	2	33	56	4	*Frondicularia dubia*
Ld-E- and S-P-assemblage	48	44	11	8	51	42	33	37	44	9	*Lenticulina bochardi*
opportunistic		13			12		2		2		*Lenticulina communis*
S-P-assemblage	41										*Lenticulina eichenbergi*
opportunistic	33	19	3	2		4	4	3	2		*Lenticulina faveolata*
M-C-assemblage	2		7	8			9	2			*Lenticulina helios*
opportunistic						3		2	12		*Lenticulina impressa*
opportunistic			3	8	61	67	62	53	14		*Lenticulina toarcense*
opportunistic				2		6		4	2		*Lenticulina virgata*
S-P-assemblage	59	44	1	2	41	23					*Saracenaria oxfordiana*
S-P-assemblage		14			34	22					*Palmula flabellina*
S-P-assemblage	1				1					3	*Palmula maior*
S-P-assemblage					1			1	1		*Palmula obonensis*
M-C-assemblage			8	6	1		5		1		*Palmula zitteli*
M-C-assemblage			13	11		1	8	3	2	1	*Astacolus payardi*
S-P-assemblage	9			2	2			8			*Astacolus pediacus*
A-L-assemblage	6	3		2	2		29		4	2	*Astacolus radiata*
M-C-assemblage							18			4	*Astacolus rectalonga*
opportunistic							8	7			*Astacolus scalptus*
S-P-assemblage					9	8	6	3	5		*Astacolus varians*
S-P-assemblage						3		2		2	*Marginulina alata*
S-P-assemblage					2				3		*Marginulina prima*
M-C-assemblage	1		6	9	1	1	7				*Marginulina spinata*
M-C-assemblage	8	5	9	15	6	2	24			1	*Citharina clathrata*
opportunistic				3	3		4	2			*Citharina protensa*
opportunistic	5	7			52	48	15	33	12		*Vaginulina sherborni*
Ld-E- and S-P-assemblage	15	2	2	2	2	13	29	27	19	8	*Eoguttulina liassica*
Ld-E- and S-P-assemblage	22										*Eoguttulina oolithica*
S-P-assemblage	38	4			24						*Pseudolamarckina liapinensis*
A-R-assemblage					4	2	6	3	2	17	*Reinholdella macfadyeni*
A-R-assemblage				2			2			5	*Rheinholdella dreheri*
S-P-assemblage	14	15		2		13					*Epistomina conica*
A-R-assemblage						4	1	3	2	29	*Brizalina liassica*
	352	230	118	145	353	333	315	299	232	128	Total (benthic foraminifers)
	28	23	17	21	30	27	29	31	27	23	Number of species

Fig. 6.–Distribution and number of benthic foraminifers in the section Barrios de Villadiegos (Basque-Cantabrian Basin). Location of section and lithofacies see Figures 2 and 3. Last row shows assignment of each species to a foraminiferal assemblage. For palaeoenvironment interpretation (column 2) see text. Abbreviations see Fig. 4.

Fig. 6.– Distribución y abundancia de foraminíferos bentónicos en la sección de Barrios de Villadiegos (Cuenca Vasco-Cantábrica). Para la localización y litofacies de la sección ver Figuras 2 y 3. La última fila muestra la asociación de foraminíferos a la que es asignada cada especie. Para la interpretación paleoambiental (columna 2) ver texto. Para las abreviaturas ver la Fig. 4.

Laevidentalina terquiemi, Ld. varians, and *Eoguttulina liassica* are the characteristic taxa. Very common are also *Lenticulina bochardi, Nodosaria mutabilis, N. regularis*, *Frondicularia dubia*, *Pseudoglandulina irregularis*, *Nubeculinella infraoolithica*, and *A. radiata*. Especially individuals of *L. bochardi* become very large in size during the Domerian (500 to 1000 µm in diameter).

The diversity increases during the Carixian and stays high in the whole Domerian. Only in the marginal section of Barrios de Villadiego, diversity is a little lower (Fig. 6).

3.3 Ammobaculites-Reinholdella-assemblage (Pliensbachian, Lower Toarcian)

During the Pliensbachian and Toarcian, black shales and dark limestones were deposited especially in the central parts of the basin (Walrabe-Adams *et al.*, this volume). The organic-rich shales occur in the Tudanca section in the Pliensbachian and in the Lower Toarcian. In the more marginal sections Aguilar de Campoó and Barrios de Villadiego, only in the Pliensbachian black shales were recorded. In the Toarcian dominate light-gray mudstones (see below).

In samples from dark shales, *Ammobaculites fontinensis*, *A. lunaris, A. multiformis*, and *Reinholdella macfadyeni* are the characteristic taxa. Also occur *Trochammina elevata, Brizalina liassica,* and *Haplophragmoides kingakensis*. The size of all species is small, rarely individuals larger than 212 µm occur. Only in one sample from the Lower Toarcian, benthic foraminifers are commonly larger in size (212-300 µm). This may attributed to less anoxic conditions (Riegraf, 1985).

The diversity is somewhat lower than in the Domerian and in the Bajocian, but the number of individuals in a taxa is higher. None of the samples was totally barren of benthic foraminifers. In the Toarcian of SW-Germany, Riegraf (1985) reported a cyclicity between barren samples from laminated black shales and samples containing small benthic foraminifers from poorly or non-laminated sediments in between. Usually, barren samples had the highest C_{org}-values in his study. Therefore, laminated black shales from the Pliensbachian and Toarcian of the Basque-Cantabrian Basin may not be covered by the present samples.

3.4 Saracenaria-Pseudolamarckina-assemblage (Aalenian-Lower Callovian)

Marl-limestone alternations characterize sediments of the Bajocian to Lower Callovian. Especially in the Bajocian, small sponge bioherms occur together with bioclastic packstones. All samples are from marlstones, so the information of benthic foraminifers is biased to the palaeoenvironment of the marlstones (see Chapter 4).

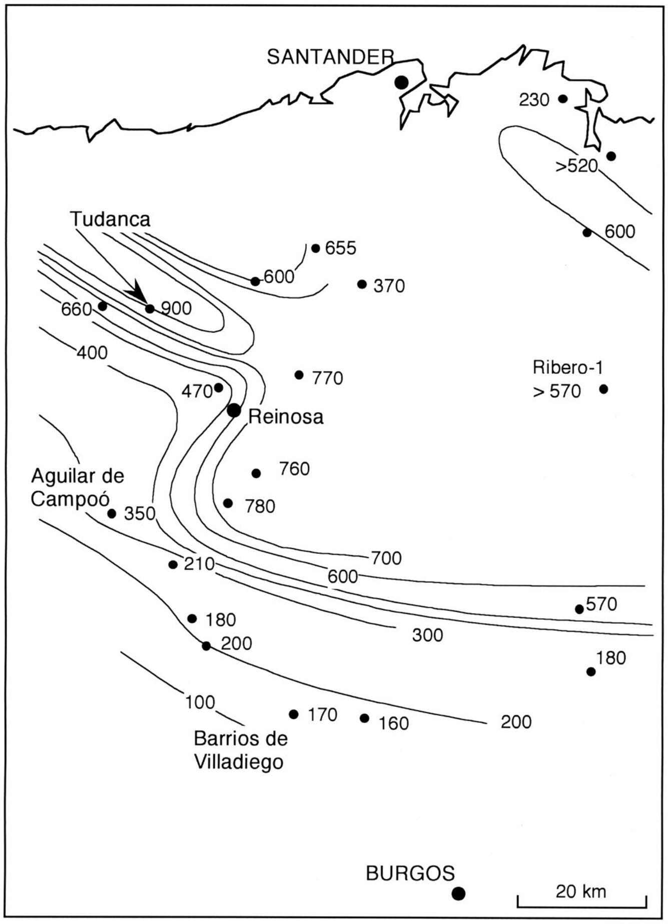


Fig. 7.–Isopach map of marine Jurassic sediments in the Basque-Cantabrian Basin (Sinemurian-Callovian, after Schaaf, 1986: fig. 38, modified) and borehole information from Ribero-2 (Gräfe, 1996).

Fig. 7.–Mapa de isopacas de los sedimentos marinos del Jurásico en la Cuenca Vasco-Cantábrica (Sinemuriense-Calloviense, según Schaaf, 1986: fig. 38, modificado) e información del sondeo Ribero-2 (Gräfe, 1996).

Characteristic taxa are *Saracenaria oxfordiana* and *Pseudolamarckina liapinensis*. Very common occur also *Astacolus pediacus, Eoguttulina liassica,* various smooth, thin-shelled species of *Palmula, Laevidentalina, Nodosaria, Marginulina, Lenticulina bochardi, L. eichenbergi, Frondicularia dubia*, *Pseudoglandulina irregularis* , *Nubeculinella infraoolithica*, and *Epistomina conica* (Figs. 4-6). Especially individuals of *S. oxfordiana* are frequently larger than 425 µm in size. Generally, the average size of all benthic foraminiferal species is around 212-425 µm compared to a size lower than 212 µm in the *Ammobaculites-Reinholdella*-assemblage. The Diversity is as high as in the Pliensbachian (Fig. 4).

3.5 Marginulina-Citharina-assemblage (Bajocian to Lower Callovian)

Sediments of the Bathonian to Callovian are composed of packstones, argillaceous wackestones, and alternations of marlstones with mud- to wackestones. All foraminiferal samples of this assemblage are from marlstones which occur above or below sponge bioherms and bioclastic packstones and where is evidence for elevated wave energy.

The characteristic taxa of this assemblage are thick-shelled and ornamented *Marginulina spinata* and *Citharina clathrata*. Also occur *Trocholina conica*, *Lenticulina helios, Lingulina pupa*, *Astacolus payardi, Nodosaria simoniana, N. pulchra, Palmula zitteli,* and *Eoguttulina liassica.* The size of most individuals is around 300 μm.

The diversity is somewhat lower than in the *Saracenaria-Pseudolamarckina-* and *Laevidentalina-Eoguttulina*-assemblages, but higher than in the *Astacolus-Lingulina-* and *Ammobaculites-Reinholdella*-assemblages (Figs. 4-6).

3.6. Foraminiferal diversity in the Jurassic of the Basque-Cantabrian Basin

The diversity (number of species) of the benthic foraminiferal assemblages increases from the Upper Sinemurian to the Toarcian in all three sections (Figs. 4-6). It drops in the "black shale" phases of the Pliensbachian and Lower Toarcian. Diversity increases again in the more marly parts of the Aalenian to Bathonian. Limited information from high-energy deposits of the Bajocian suggests a somewhat lower benthic foraminiferal diversity there.

4. Discussion

4.1. Model for the palaeoenvironment

From an analysis of an isopach map of Jurassic sediments (Fig. 7) the geometry of the marine Jurassic sedimentary realm is reconstructed. The depositional geometry in the marine Jurassic is characterized by a NE to ENE dipping mixed carbonate to clastic ramp with a dip angle lower than 1°. This ramp was divided in the Jurassic by a NE to SW tending fault (Fig. 8). Therefore, the sediments to the east were deposited in a slightly deeper-marine environment, than to the west. There is no deep-marine Jurassic recorded at the present day margin of Cantabria or in the present-day Bay of Biscay (Aurell *et al.*, 2002). Therefore, the Jurassic ramp has its deepest parts south of Santander and formed an epicontinental trough in a slowly subsiding continental crust.

By distensive tectonic movements during a Triassic and Jurassic first rifting phase, a tilted block mosaic forms the basement of the later epicontinental Jurassic basin. These tilted blocks control the distribution of the sedimentary realms within the carbonate ramp (Fig. 8). Triassic rifting movements are accompanied by volcanic tholeiitic rocks derived from the mantle. These volcanics broke out along the fault zones between the tilted blocks (Meschede, 1987). During the Jurassic, the rifting movements ceased in the Bay of Biscay and only slowly subsiding continental crust created accommodation space for the Jurassic sediments with a thickness of 200 to 1000 m (Aurell *et al.*, 2002).

The homoclinal carbonate ramp in the Jurassic is characterized by a series of E to W tending facies realms. Southward, in the shallowest part, grainstones and wackestones of the shallow subtidal were deposited in a storm-dominated environment (Schaaf, 1986). To the north, there follow monotonic and pelitic wackestones to mudstones partly intercalated with turbidites. The deepest sedimentary realm is characterized by black shales intercalated with light-gray mudstones deposited in a hemipelagic environment. North of the Las Caldas anticline the environment shallows again and lead over to the northern margin of the Jurassic epicontinental basin. Later in the Middle and Late Jurassic uplift of the eastern part of the Spanish Meseta terminated the marine sedimentation in this part of the Basque-Cantabrian Basin.

4.2. Development of the ramp system in the Jurassic

4.2.1. Early Sinemurian

A flat shallow subtidal depositional area characterizes this period. Sabkha-like sediments (mostly dolomites) of the Carniolas Formation (or Rio Polla and Villanueva de Puerta Fm., Aurell *et al.*, 2002) dominate the sediments. Sea-level changes shift the facies realms at least two times from S to N and backwards (Visser, 1984; Schaaf, 1986). Microfacies types of the Carniolas show a broad variation of various types typical for supratidal, intertidal and shallow subtidal types (Visser, 1984; Aurell *et al.*, 2002). There are slightly thicker sediments recorded towards the N. The base of the Carniolas is a sharp erosion surface the top an angular unconformity (basin margins) or a paraconformity (basin center, Aurell *et al.*, 2002).

4.2.2. Late Sinemurian - Late Pliensbachian

In the Late Sinemurian (Raricostatum Zone) the sedimentation of Carniolas ceased abruptly. In a short-term event, open-marine sedimentary conditions established (Schaaf, 1986). Only locally, sandstones were deposited above the Carniolas. These clastic sediments have been

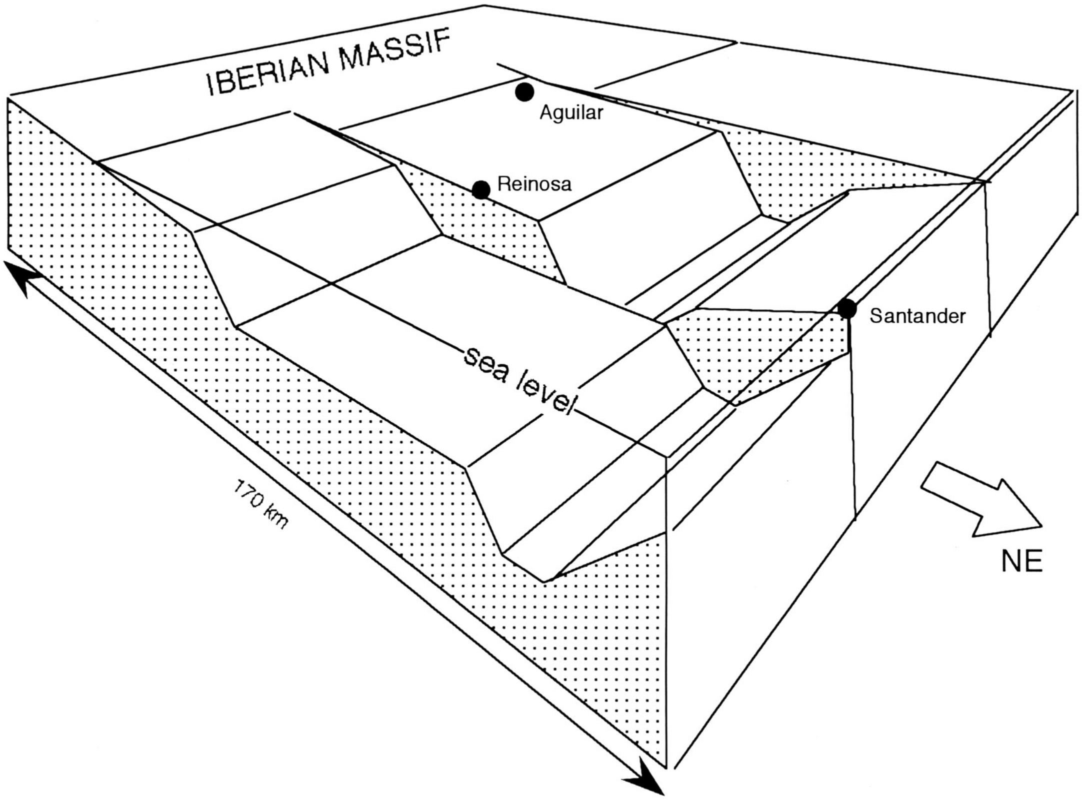


Fig. 8.–Palaeogeometry of the depositional realm in the marine Jurassic of the western Basque-Cantabrian Basin. Modified after Schaaf (1986, fig. 39). The figure is schematic and not to scale (vertical and horizontal).

Fig. 8.–Paleogeometría del ambiente de depósito en el Jurásico marino de la zona occidental de la Cuenca Vasco-Cantábrica. Modificado de Schaaf (1986, fig. 39).La figura es esquemática y no está representada a escala ni vertical ni horizontal.

interpreted as Incised Valley Fill (Aurell *et al.*, 2002). Above these clastic deposits and the Carniolas, a sharp iron-impregnated transgressive surface occurs. There were bioclastic wackestones and mudstones deposited above this surface, containing a diverse fauna, characteristic for open-marine sedimentary environments (Aurell *et al.*, 2002).

At the base of the Pliensbachian, an iron-encrusted, bioturbated transgressive surface is recorded (Aurell *et al.*, 2002). In the Lower to Upper Pliensbachian the facies belt with shallow-marine sediments was shifted towards the south and more and more deep-marine sediments dominate the sedimentary realm (Fig. 9A). Between the Ibex Zone and the Margaritatus Zone black shales spread from the deeper basin parts nearly all over the whole epicontinental basin (Schaaf, 1986). This event may be a consequence of influx of nutrient-rich water from the evolving North Atlantic (Schaaf, 1986). Marl-limestones alternations which become more calcareous upward were deposited between the black shale events.

4.2.3. Latest Pliensbachian (Spinatum Zone)

This period is characterized by a strong regression. Facies belts shift to the north and black shales were only deposited in the deepest parts of the basin (Fig. 9B). Bioclastic packstones were deposited in marginal areas of the basin (Aurell *et al.*, 2002). These deposits terminate the Pliensbachian transgression-regression cycle.

4.2.4. Early to Middle Toarcian (Bifrons Zone)

A pronounced rise in sea-level shifts the facies belts on the carbonate ramp towards the south. This rise in sea-level is expressed as sharp iron-encrusted transgressive surface above the bioclastic packstones of the Spinatum Zone (Aurell *et al.*, 2002). Monotonous hemipelagic marlstones and black shales were deposited containing a low-diversity benthos fauna. Only rarely, distal tempestites were recorded (Fig. 9C). Black shales are restricted to the deepest parts of the ramp. Typical shallow-marine facies types were not observed.

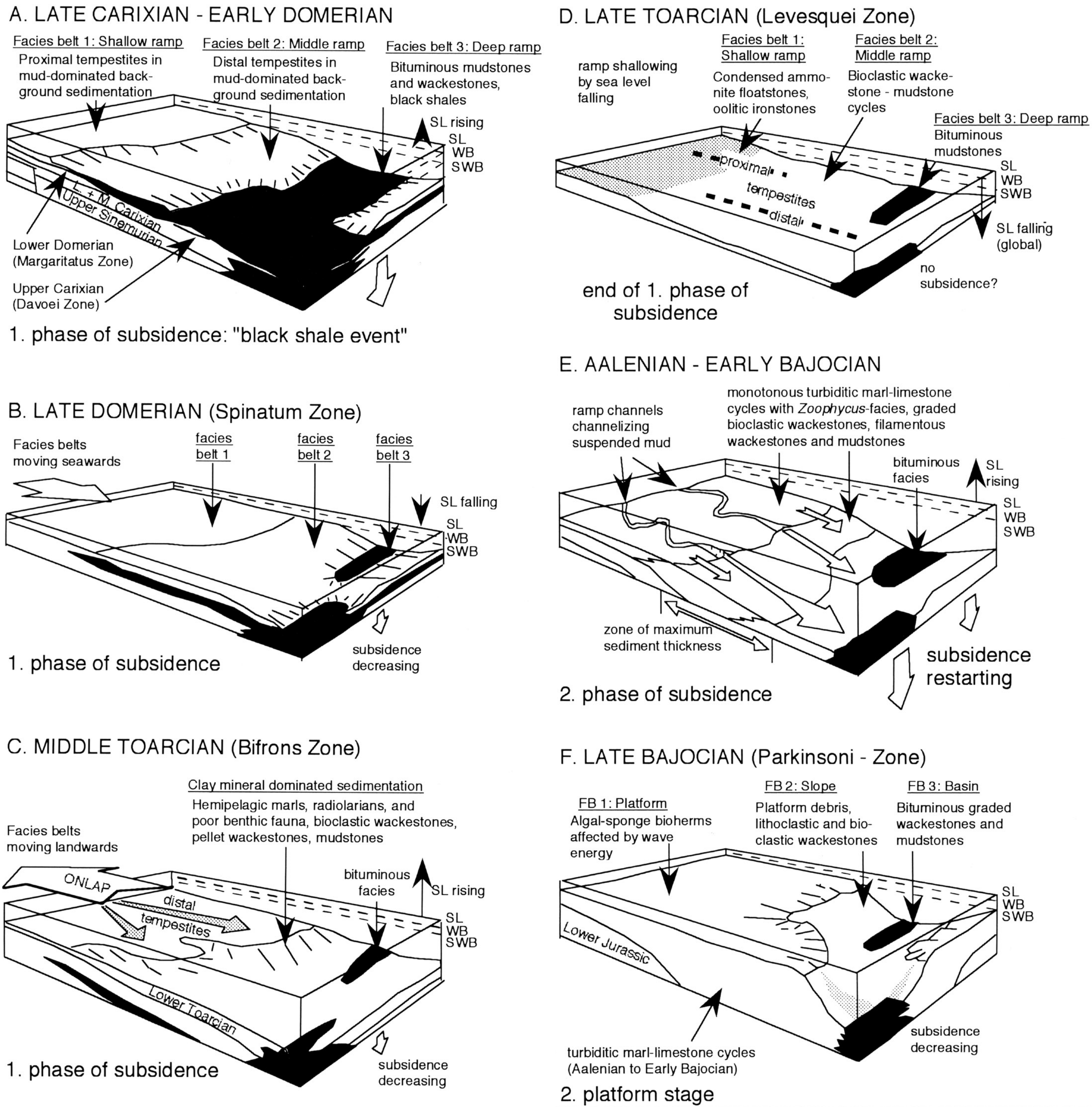


Fig. 9.–Fases del desarrollo de la rampa marina carbonatada durante el Jurásico inferior y medio en la Cuenca Vasco-Cantábrica. Todas las figuras son esquemáticas y no están representadas a escala ni vertical ni horizontal Modificado de Schaaf (1986, fig. 44). Zonas en negro = depósito de arcillas negras y sedimentos ricos en materia orgánica con variaciones en el nivel de oxigenación. Fases en la subsidencia y estadios de plataforma según Wiedmann *et al.* (1983). Abreviaturas: SL = nivel del mar, WB = nivel de base de oleaje normal, SWB = nivel de base de oleaje de tormenta, FB = cinturón de facies. 9A. Carixiense superior a Domeriense inferior. 9B. Domeriense superior (Zona de Spinatum). 9C. Toarciense medio (Zona de Bifrons). 9D. Toarciense superior (Zona de Levesquei). 9E. Aaleniense a Bajociense medio. 9F. Bajociense superior (Zona de Parkinsoni).

Fig. 9.–Phases in the development of the marine carbonate ramp in the Early and Middle Jurassic of the Basque-Cantabrian Basin. All figures are schematic and not to scale (vertical and horizontal). Modified after Schaaf (1986, fig. 44). Black parts = deposition of black shales and organic-rich sediments with varying degree of oxygenation. Subsidence phases and platform stage after Wiedmann *et al.* (1983). Abbreviations: SL = sea level, WB = normal wave base, SWB = strom wave base, FB = facies belt. 9A. Late Carixian to Early Domerian. 9B. Late Domerian (Spinatum Zone). 9C. Middle Toarcian (Bifrons Zone). 9D. Late Toarcian (Levesquei Zone). 9E. Aalenian to Middle Bajocian. 9F. Late Bajocian (Parkinsoni Zone).

4.2.5. Late Toarcian (Levesquei Zone)

Condensation and storm sedimentation characterizes this period (Fig. 9D). Stratigraphically condensated iron-oolitic ammonite-floatstones were deposited together with tempestites and fossil-poor mudstones. This type of sedimentation is terminated by an unconformity at the base of the Aalenian (Opalinum Zone, Aurell *et al.*, 2002).

4.2.6 Aalenian to Bajocian

In the Aalenian, condensation and iron-impregnated surfaces are common. From the Late Aalenian to the Bajocian, uniform facies with monotonous pelitic limestone rhythmites were deposited overall and are evidence for strong sea-level rise. Most of the pelitic carbonates are turbiditic in origin (Schaaf, 1986). Towards the south, laterally extended fans with bioclasts are widespread (Fig. 9E). Black shales are only recorded in the deepest part of the basin. Typical are wackestones with bioclasts, filaments, and *Zoophycus* (Aurell *et al.*, 2002). Upward in the marl-limestone alternations, more and more sponge bioherms and bioclastic packstones are intercalated (Sauzei and Humphresianum Zones, Aurell *et al.*, 2002)

4.2.7. Bajocian to Early Bathonian

Increasing sediment accumulation together with decreased subsidence led to a steepened ramp in the N and a flat platform in the S. The platform area is characterized by thin and stratigraphically condensed ammonite marlstones. Above the ammonite marlstones, thickening-upward turbiditic wackestones containing reworked algal-sponge material were deposited. In the Parkinsoni Zone, the platform was occupied by a highly diverse shallow-water fauna composed of siliceous sponges, incrusting algae and others (Parkinsoni Zone, Benke, 1981, Schaaf, 1986). Northward, reef-debris from these “sponge-reefs” dominates the facies belt and forms a transition towards the black shales of the deepest basin (Fig. 9F).

4.2.8. Late Bathonian to Early Callovian

A deepening event in the Garantiana Zone separates bioclastic wackestones with proximal tempestites in the southern ramp from the older sponge bioherms. The bioclastic wackestones continue to the north without sharp boundary with filamentous wackestones and marls as deep-water facies that overly also bioclastic shallow-water deposits of the Parkinsoni Zone. In the deepest parts of the basin, these filamentous wackestones are rich in organic matter and alternate with black shales and organic-rich radiolarites. Especially in the Bullatus Zone, black shales occur in the basin center (Tudanca) partly until the unconformity to the Wealden deposits.

4.2.9. Late Callovian and Post-Callovian

An uplift event in the Late Callovian terminates the marine sedimentary history in most parts of the ramp. This tectonic event is enhanced by a global sea-level fall (Benke, 1981). Towards the east, the marine Jurassic continues in the late Jurassic (Floquet and Rat, 1975; Mensink and Mertmann, 1984a, b; Bádenas, 1996). The uplifted sediments were partly eroded in the southern parts of the ramp. Only in the deepest parts of the eastern ramp, a continuous transition to the clastic Purbeck and Wealden facies is observed (Aurell *et al.*, 2002).

During the Jurassic-Cretaceous transition, clastic deposits in Wealden facies dominate the sedimentary realm (Pujalte, 1982). After this regressive phase the marine Cretaceous cycle of the Basque-Cantabrian Basin continues the sedimentary history in this part of northern Spain (Gräfe, 1999; Martín-Chivelet *et al.*, 2002).

4.3 Palaeogeography

From the Late Sinemurian to the Early Callovian, the Cantabrian sedimentary realm is part of an epicontinental sea that extended from the proto-North Atlantic to the Tethys and northward to Germany and England and in the later North Sea (Bassoullet *et al.*, 1993). In the Late Sinemurian there was a large transgression from the NW in the area of the present-day W-Portugal, the N Spanish realm, and the Pyrenees. The emerged Iberian Meseta Block was reduced and a marine connection between North Atlantic and Tethys area was created north of the Iberian Meseta (Bassoullet *et al.*, 1993).

This seaway allowed the influx of marine macro-fauna composed mainly of bivalves and ammonites. This macrofauna is not distinguishable from the NW-European faunal realm in France, England and Germany. But in the Middle Jurassic, a faunal provincialism was recognized in the N Spanish Jurassic. This provincialism was founded in the deepening of the seaways to NW-Europe and in the creation of small basins with small sub-ecosystems in the Cantabrian Jurassic.

In the Callovian, clastic non-marine sediments prograded from W to E in the basin and terminated the marine sedimentation.

4.4. Trophic regime within the benthic foraminiferal fauna

Nutrient availability and the degree of oxygenation of the near-surface sediment and of water near the sediment-water interface are the most important factors that control the benthic foraminiferal distribution (Van der Zwaan *et al.*, 1999). The distribution of the foraminiferal assem-

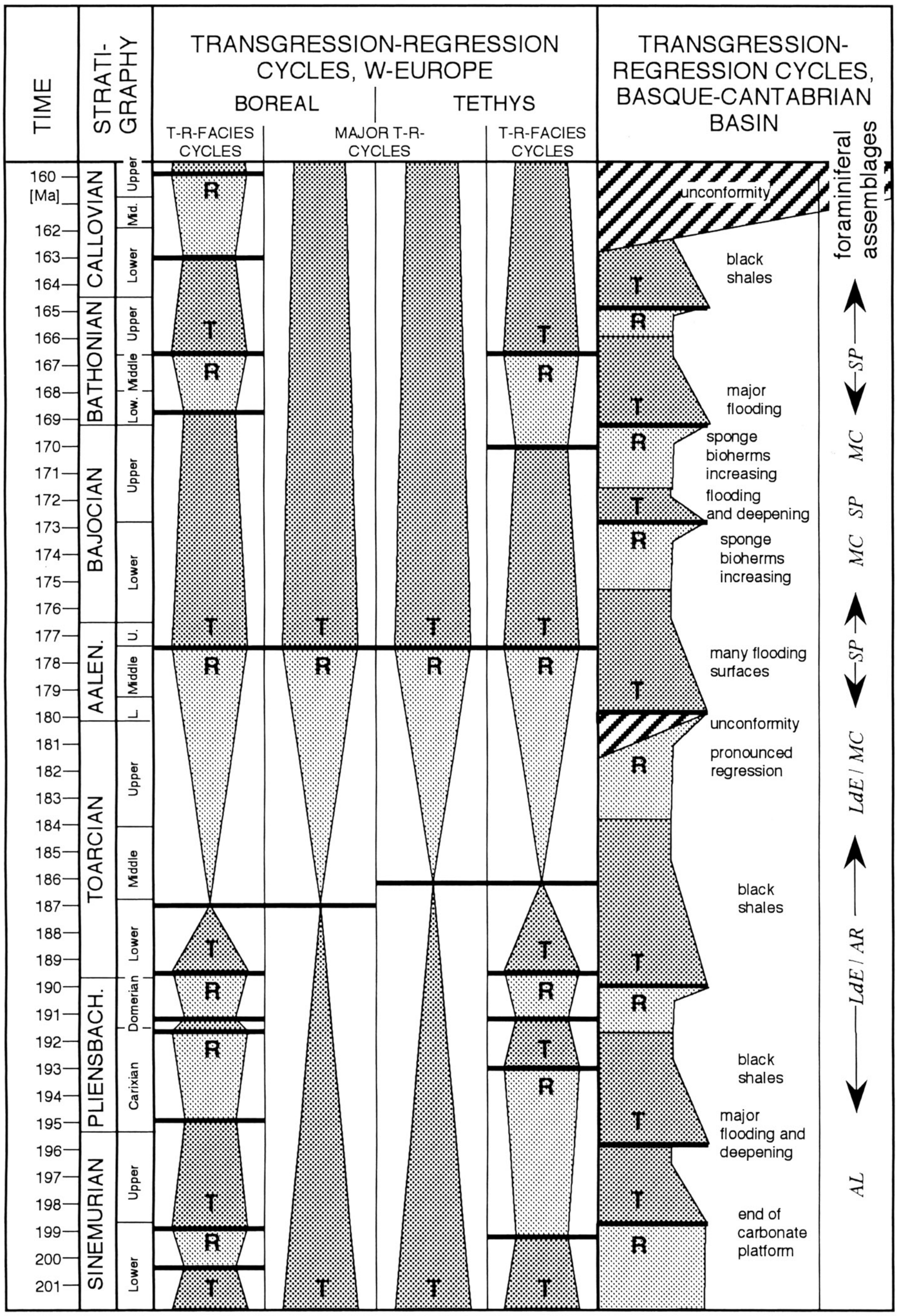


Fig. 10.–Ciclos transgresivos- regresivos en la Cuenca Vasco-Cantábrica con las asociaciones de foraminíferos bentónicos relacionadas (columna derecha, este trabajo) y comparación de estos ciclos con ciclos similares en Jacquin *et al.* (1998) y Hardenbol *et al.* (1998, cuadro 6). Abreviaturas: *AL* = Asociación *Astacolus-Lingulina*, *LdE* / *AR* = Asociación *Laevidentalina-Eoguttulina* alternando con la asociación *Ammobaculites-Reinholdella*, *LdE* / *MC* = Asociación *Laevidentalina-Eoguttulina* alternando con la asociación *Marginulina-Citharina*, SP = Asociación *Saracenaria-Pseudolamarckina*, MC = Asociación *Marginulina-Citharina*.

Fig. 10.–Transgression-regression cycles in the Basque-Cantabrian Basin with associated benthic foraminiferal assemblages (right column, this work) and the comparison of these cycles with similar cycles from Jacquin *et al.* (1998) and Hardenbol *et al.* (1998, chart 6). Abbreviations: *AL* = *Astacolus-Lingulina* assemblage, *LdE* / *AR* = *Laevidentalina-Eoguttulina* assemblage alternating with *Ammobaculites-Reinholdella* assemblage, *LdE* / *MC* = *Laevidentalina-Eoguttulina* assemblage alternating with *Marginulina-Citharina* assemblage, SP = *Saracenaria-Pseudolamarckina* assemblage, MC = *Marginulina-Citharina* assemblage.

blages within the studied successions (Figs. 3-6) shows distinct variations between high-energy conditions, low-energy conditions, low-oxygen or anoxic environment and normal oxygenated open shelf conditions.

Such changes are evidenced also by foraminiferal test morphology. Usually, thick-shelled, ornamented forms are typically found in high-energy environments. Such forms are present and dominant in the *Astacolus-Lingulina*-assemblage as well as in the *Marginulina-Citharina*-assemblage (Figs. 4-6, Chapter 3). The high-energy conditions in the depositional environment are evidenced by numerous sedimentologic features and by benthic macrofaunal associations (Schaaf, 1986; Aurell *et al.*, 2002).

Benthic foraminiferal faunas from anoxic to low-oxic sediments show the highest abundance of primitive agglutinated morphotypes together with some smooth-shelled, small calcareous forms. The *Ammobaculites-Reinholdella*-assemblage is such an association. If one looks in detail in the series of black shales and organic-rich marl- and limestones of the Pliensbachian and Toarcian, important variation in the organic content, degree of bioturbation and occurrence of benthic macrofauna is evident (Riegraf, 1985; Röhl *et al.*, 2000; Gahr, this volume), Such variations mimic the varying degree of free oxygen in the uppermost sediment column as well as in the lowest parts of the water column just above sea-floor. Usually, laminated black shales with high organic content are free of bioturbation and barren of autochthonous microfossils (Riegraf, 1985). Such black shales are present in the marine Jurassic of Spain (Schaaf, 1986), but are not present in the investigated samples here.

Instead of, nearly all samples show evidence of slight bioturbation, weak or no lamination, presence of some benthic macrofauna (Schaaf, 1986), and a low-diversity benthic foraminiferal microfauna composed of typically small benthic foraminiferal taxa (smaller than 212 µm) but rich in individuals (Figs. 4-6, Chapter 3). The presence of *Reinholdella macfadyeni* and other species of this genus may be more related to the CO_2-content of the environment than to the O_2-content (Riegraf, 1985).

Most of the species of the *Ammobaculites-Reinholdella*-assemblage are very tolerant forms which occur in environments that reflect elevated levels of organic carbon influx (Riegraf, 1985; Kaminski *et al.*, 1999). But they can also occur (in low numbers) in high-diversity foraminiferal assemblages together with complex foraminifers as well as in oligospecific assemblages together with the previously cited small forms. This ubiquity points to a wide range of adaptive strategies typical of r-strategists.

Normal oxygenated, low-energy faunas may composed of larger, smooth-shelled calcareous morphotypes and/or elongated epifaunal elements. The *Laevidentalina-Eoguttulina*-assemblage and the *Saracenaria-Pseudolamarckina*-assemblage are typical representatives for such associations. They occur mostly in marl-limestone alternations composed of light-gray marlstones and mudstones to wackestones composed of fine-grained bioclasts. Bioturbation is very common and the associated macrofauna is very rich and diversified (Schaaf, 1986). There is no evidence for current or wave-action. Therefore, the benthic foraminiferal fauna is also high-diversified, has a high number of fragile, thin-shelled and elongated morphotypes and may contain also sessile morphotypes like species from *Nubeculinella*.

Studies on different benthic faunal groups have shown that stable ecosystems favour the development of complex and highly diverse faunas, whereas in ecosystems that exhibit severe environmental fluctuations, e.g., shallow water or low oxygen environments, diversities are generally low (Hottinger, 1983, 1997; Schmiedl *et al.*, 2000). These observations can be supported in this study. In the bioturbated dark marls, mudstones and wackestones of the Pliensbachian and Toarcian, the foraminifers are rare, lower in diversity and probably restricted to levels which show no or weak laminations. Intercalations of barren black shale horizons with foraminiferal-bearing horizons that contain the fauna of the *Ammobaculites-Reinholdella*-assemblage together with the absence of larger-sized benthic foraminifers and complex-ornamented forms point to a stressed environment with high supply rates of organic matter.

More stable environments of the Carixian-Domerian and of the Bajocian and Bathonian show high-diversity benthic foraminiferal faunas of varying size with a complex pattern of test morphology, ornamentation and shell resistance.

4.5. Transgression-regression cycles and benthic foraminifers

After the deposition of the shallow-marine carbonates in the Sinemurian (Carniolas), sediments in the marine Jurassic of the Basque-Cantabrian Basin can be subdivided into seven transgression-regression cycles (Schaaf, 1986; Aurell *et al.*, 2002). The basal unconformities of these cycles occur at the base of the Upper Sinemurian (basal Obtusum Zone), in the uppermost Sinemurian (Raricostatum Zone), near the Pliensbachian-Toarcian boundary (Spinatum Zone), in the basal Aalenian (base Opalinum Zone), at the top of the Lower Bajocian (Humphresianum Zone), near the top of the Parkinsoni Zone, and near the Bathonian-Callovian boundary (Fig. 10). These unconformities are well established by distinct surfaces with bioturbated iron crusts, angular unconformities, and shallowing-deepening recorded by changes in lithofacies and macrofaunal content (Aurell *et al.*, 2002). Also the benthic foraminiferal assemblages are either recorded in the transgressive (*Laevidentalina-Eoguttulina*- and *Saracenaria-Pseudolamarckina*-assemblages) or in the regressive parts (*Astacolus-Lingulina*- and *Marginulina-Citharina*-assemblages) of the cycles. The *Ammobaculites-Reinholdella*-assemblage mirrors a specific palaeoceanographic condition – the deposition of black shales occurring in the deepest parts of the cycles.

Obviously, these transgression-regression cycles do not correlate very well to similar cycles discussed in Jacquin *et al.* (1998) (Fig. 10). Especially the prominent cycle boundary of Jacquin *et al.* (1998) at the base of the Concavum Zone (near the Aalenian-Bajocian boundary) that separates their Ligure cycle from their North Sea cycle is not matched in the Basque-Cantabrian Basin. The reason for these deviations can only be supposed in a different tectonic subsidence regime in the Basque-Cantabrian Basin compared to NW- and Central Europe.

There are numerous depositional sequences recognized in the Lower and Middle Jurassic of European basins (Rioult *et al.*, 1991; Hardenbol *et al.*, 1998). These sequences are not recognized in this study, because of low resolution of sampling and limited information from outcrops for this purpose. However, third-order depositional sequences are recognizable, for example, in the marine Jurassic of the Iberian Ranges (Gahr, this volume) if an adequate sample resolution is present. In a more detailed study of the marine Jurassic of the Basque-Cantabrian Basin, the five benthic foraminiferal assemblages given here may be split further in smaller associations that may be correlatable to depositional sequences in a similar way as shown in Cubaynes *et al.* (1990) and Rey *et al.* (1993, 1994).

5. Conclusions

The herein studied marine Jurassic sediments form one megasequence in the sense of Wiedmann *et al.* (1983). The base of this megasequence is characterized by break-up of the Triassic and pre-Triassic basement in tilted blocks due to Jurassic distensive movements. This tectonic event starts in the late Triassic and is mostly terminated in the early Jurassic. After the break-up, only slow distensive movements are exhibited by the slow subsiding basin in the Early and Middle Jurassic. The Jurassic subsidence phase is terminated in the Callovian with the uplift of the western basin part. In the eastern basin part between Burgos and Vitoria, marine sedimentation is terminated in the late Jurassic.

Benthic foraminifers are studied from the marine Lower and Middle Jurassic of the western Basque-Cantabrian Basin (sections Tudanca, Aguilar de Campoó and Barrios de Villadiegos). This study revealed five benthic foraminiferal assemblages, each one related to a specific trophic palaeoenvironment created by palaeoceanography and relative sea-level change. Therefore, the *Laevidentalina-Eoguttulina*- and the *Saracenaria-Pseudolamarckina*- assemblage occurs in transgressive parts of relative sea-level cycles and in low-energy conditions. The *Astacolus-Lingulina*- and *Marginulina-Citharina*-assemblages occur in the regressive, high-energy parts of transgression-regression cycles. The *Ammobaculites-Reinholdella* assemblage is adapted to the specific conditions of a low-oxygen environment linked to the deposition of organic-rich sediments in various periods of the Pliensbachian, Toarcian and Early Callovian.

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