Ammonites, taphonomic cycles and stratigraphic cycles in carbonate epicontinental platforms

Ammonites, ciclos tafonómicos y ciclos estratigráficos en plataformas epicontinentales carbonáticas

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RESUMEN

Algunas variaciones de los caracteres tafonómicos y la distribución de las asociaciones registradas de ammonites en las plataformas epicontinentales carbonáticas permiten distinguir secuencias tafonómicas elementales, tafosecuencias, taforregistros, tafociclos, megatafosecuencias y supertafociclos que son el resultado de cambios relativos del nivel del mar. La identificación de estos ciclos tafonómicos es de máxima importancia para interpretar los ciclos estratigráficos en las plataformas epicontinentales mesozoicas, en especial cuando no hay evidencias de las variaciones de la línea de costa pero los sedimentos fosilíferos de plataforma externa están ampliamente desarrollados.

Durante el Jurásico Medio se desarrollaron cinco ciclos ambientales de profundización/somerización en las plataformas Castellana, Aragonesa y de Tortosa: cuatro ciclos de profundización media (durante el Aaleniense inferior, el Aaleniense medio-Bajociense inferior, el Bathoniense y el Calloviense) y un ciclo de profundización avanzada (durante el Bajociense superior). Los taforregistros de ammonites de la Biozona Opalinum representan los últimos términos de una megatafosecuencia de so-

merización iniciada durante el Toarciense superior. La máxima profundización y el máximo ascenso relativo del nivel del mar se alcanzaron durante el Biocrón Niortense (Bajociense superior). Los sedimentos de la Subcronozona Polygyralis corresponden a un pico transgresivo de segundo orden. Los episodios de máxima somerización durante el Jurásico Medio, que representan los máximos descensos relativos del nivel del mar, corresponden al Aaleniense medio (Biocrón Murchisonae) y al Calloviense superior (Biocrón Lamberti). Los biocronos Murchisonae y Lamberti forman dos picos regresivos de segundo orden. Las asociaciones registradas de ammonites comprendidas entre estos dos biocronos representan un supertafociclo de segundo orden en la Cuenca Ibérica. Los sedimentos del Jurásico Medio comprendidos entre estas dos discontinuidades estratigráficas, desde el Aaleniense medio hasta el Calloviense superior, también representan un superciclo estratigráfico de segundo orden en la Cuenca Ibérica.

Palabras clave: fosilización, bioestratinomía, fosildiagénesis temprana, tafonomía aplicada, estratigrafía secuencial, estratigrafía genética, plataformas carbonáticas, transgresión, regresión, ciclos ambientales, paleobatimetría, Jurásico Medio, Plataforma Aragonesa, Plataforma Castellana, Plataforma de Tortosa, Cuenca Ibérica.

ABSTRACT

Some variations of the taphonomic features and the distribution of the successive recorded associations of ammonites in the carbonate epicontinental platforms enable to distinguish elementary taphonomic sequences, taphosequences, taphorecords, taphocycles, megataphosequences and supertaphocycles resulting from relative sea-level changes. The identification of such taphonomic cycles is of utmost importance in interpreting the stratigraphic cycles of Mesozoic epicontinental platforms, when no evidence of coastal onlap is preserved but fossiliferous sediments of outer platform are widely developed.

Five environmental cycles of deepening/shallowing were developed in the Castiliane, Aragonese and Tortosa platforms during the Middle Jurassic: four cycles of median deepening (early Aalenian, middle Aalenian early Bajocian, Bathonian and Callovian) and one cycle of advanced deepening (late Bajocian). Ammonite taphorecords of the Opalinum Biozone represent the last terms of a shallowing upwards megataphosequence

which began in the late Toarcian. The maximum deepening and the maximum relative sea-level rise were reached during the Niortense Biochron (late Bajocian). Sediments of the Polygyralis Subchronozone belongs to a second-order peak transgression. Foremost shallowing episodes during the Middle Jurassic, representing peak regression of second order, correspond to middle Aalenian (Murchisonae Biochron) and late Callovian (Lamberti Biochron). Murchisonae and Lamberti biochrons conform two second-order peak regressions. Recorded associations of ammonites comprised between these two biochrons represent a supertaphocycle of second order in the Iberian Basin. Sediments of the Middle Jurassic comprised between these two stratigraphic discontinuities, from the middle Aalenian until the upper Callovian, also represent a stratigraphic supercycle of second order in the Iberian Basin.

Key words: fossilization, biostratinomy, early fossildiagenesis, applied taphonomy, sequence stratigraphy, genetic stratigraphy, carbonate platforms, transgression, regression, environmental cycles, palaeobathymetry, Middle Jurassic, Aragonese Platform, Castiliane Platform, Tortosa Platform, Iberian Basin.

INTRODUCTION

Some preservational characters and the distribution of the ammonites are the result, and enable the interpretation, of different sedimentary environments in the Mesozoic epicontinental platforms (Fernández-López, 1997a). The recorded associations of ammonites formed in distal and deep environments of the platform show distinctive characters with respect to those formed in proximal and shallow environments. Some significant features of the sedimentary basins, such as the variations in the degree of communication of the sedimentary environments, as well as the differences in the degree of turbulence, in the rate of sedimentation and in the rate of sediment accumulation, can be estimated on the basis of the changes in the state of preservation of the ammonites.

The main purpose of this work is to show some preservational features of the ammonites which enable the interpretation of relative changes of sea level, of different order of magnitude and cyclical, occurred in carbonate epicontinental platforms. These taphonomic data are of stratigraphic interest since they provide an independent test of the cycles distinguished in sequence stratigraphy and genetic stratigraphy.

STRATIGRAPHIC CYCLES AND TAPHONOMIC CYCLES

Stratigraphic cycles result from cyclical environmental modifications (*e.g.*, eustatic, climatic and/or tectonic modifications). In the stratigraphical record it is possible to distinguish stratigraphic sequences and cycles of different order, due to relative sea-level changes (Fig. 1). Analogously, as a result from such cyclical environmental modifications, the successive recorded associations of a certain region or sedimentary basin can show cyclical variations in their secondary characters, resulting from taphonomic alteration. A *taphonomic cycle* comprises two or more successive recorded-associations showing cyclical variations in their secondary characters, as a result from an environmental cycle.

Elementary stratigraphic sequences, parasequences, sets of parasequences, taphofacies, depositional systems, systems tracts, depositional sequences of third order, transgressive/regressive cycles of third order and megasequences or supercycles of second order are genetic terms of sequence stratigraphy, comprising rock bodies of the stratigraphical record (Fig. 1). Elementary taphonomic sequences, taphosequences, sets of taphosequences, deepening/shallowing taphorecords, deepening/shallowing taphocycles, megataphosequences and supertaphocycles, as will be exposed in the following paragraphs, are genetic terms of taphonomy comprising preserved elements, taphonic populations or preserved associations of the fossil record.

The identification of taphonomic sequences and cycles enable the test of genetic differences between the fossil record and the stratigraphical record. The stratigraphical record and the fossil record are different in nature, and they can be dissociated and studied separately, as it has been repeatedly shown (Fernández-López, 1984, 1986, 1987b, 1991, 1997b). They also contain different information, and the fossil record may supply relevant data on sedimentary environments and processes which have left no traces in the stratigraphical record (Fernández-López & Gómez, 1990b; Fernández-López, 1991, 1995). In fact, a single stratigraphic level can enclose a set of successive recorded-associations composing different taphorecords. This set of recorded associations forming a condensed association can even correspond to a time interval without stratigraphical record (Fernández-López, 1985b, 1986, 1987b, 1991, 1995).

Relationships between the different cyclical processes that have conditioned the continuity/discontinuity of the stratigraphical record or of the fossil record in carbonate epicontinental platforms can be tested on the basis of the relative duration of such processes (Fig. 1). The calibration between stratigraphic cycles and taphonomic cycles has been accomplished on
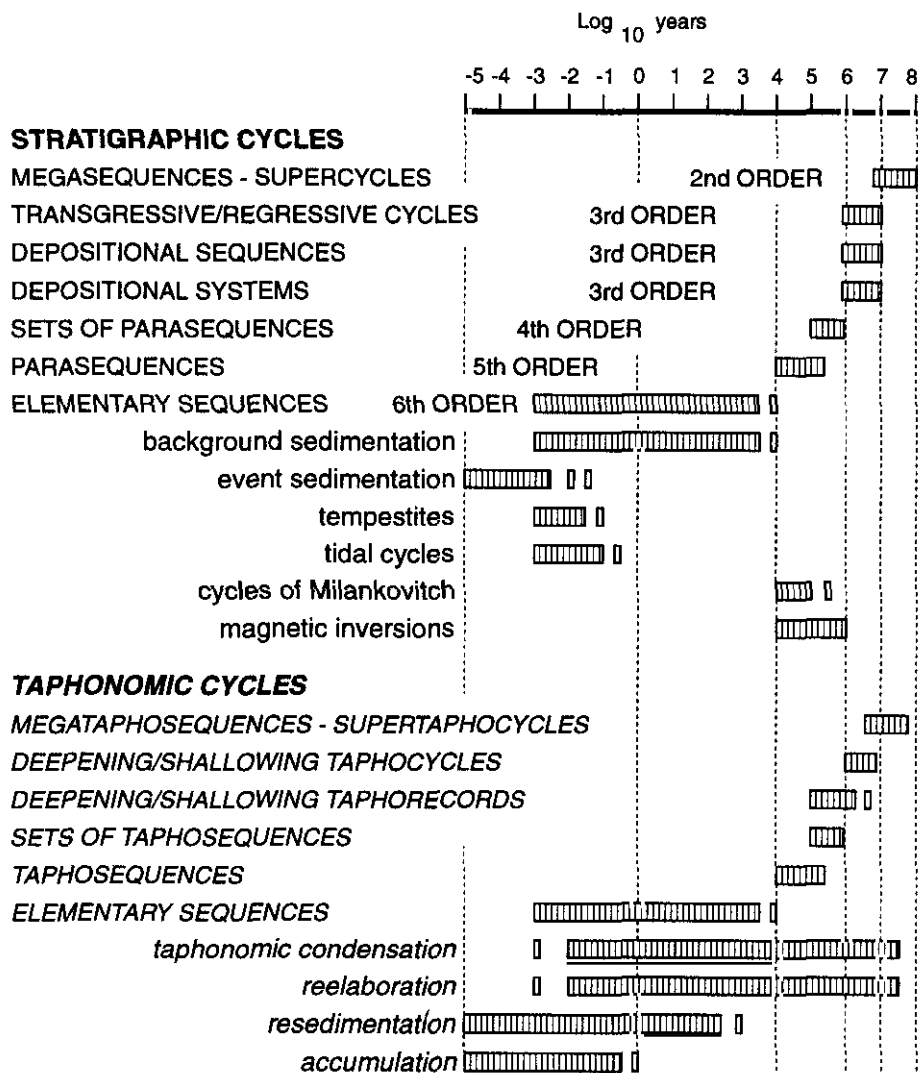
Log $_{10}$ years

STRATIGRAPHIC CYCLES

MEGASEQUENCES - SUPERCYCLES — 2nd ORDER

TRANSGRESSIVE/REGRESSIVE CYCLES — 3rd ORDER

DEPOSITIONAL SEQUENCES — 3rd ORDER

DEPOSITIONAL SYSTEMS — 3rd ORDER

SETS OF PARASEQUENCES — 4th ORDER

PARASEQUENCES — 5th ORDER

ELEMENTARY SEQUENCES — 6th ORDER

background sedimentation

event sedimentation

tempestites

tidal cycles

cycles of Milankovitch

magnetic inversions

TAPHONOMIC CYCLES

MEGATAPHOSEQUENCES - SUPERTAPHOCYCLES

DEEPENING/SHALLOWING TAPHOCYCLES

DEEPENING/SHALLOWING TAPHORECORDS

SETS OF TAPHOSEQUENCES

TAPHOSEQUENCES

ELEMENTARY SEQUENCES

taphonomic condensation

reelaboration

resedimentation

accumulation

Fig. 1.–Temporal resolution of stratigraphic and taphonomic cycles of different order, as well as of some processes mentioned in text.
Fig. 1.–Solución temporal de los ciclos estratigráficos y de los ciclos tafonómicos de diferente orden, así como de algunos procesos mencionados en el texto.

the basis of the geochronological and geochronometric data published by Gradstein *et al.*, (1994), Callomon (1995), Odin, Galbrun & Renard (1995) and Gradstein and Ogg (1996).

ELEMENTARY SEQUENCES

Elementary sequences are stratigraphic cycles of sixth-order and rhythms, of centimetric or millimetric thickness, representing a cyclicity lower than 20.000 years. Elementary sequences developed in carbonate epicontinental platforms result from gradual variations in the turbulence and in the rate of sedimentation (Fig. 2).

ELEMENTARY SEQUENCES
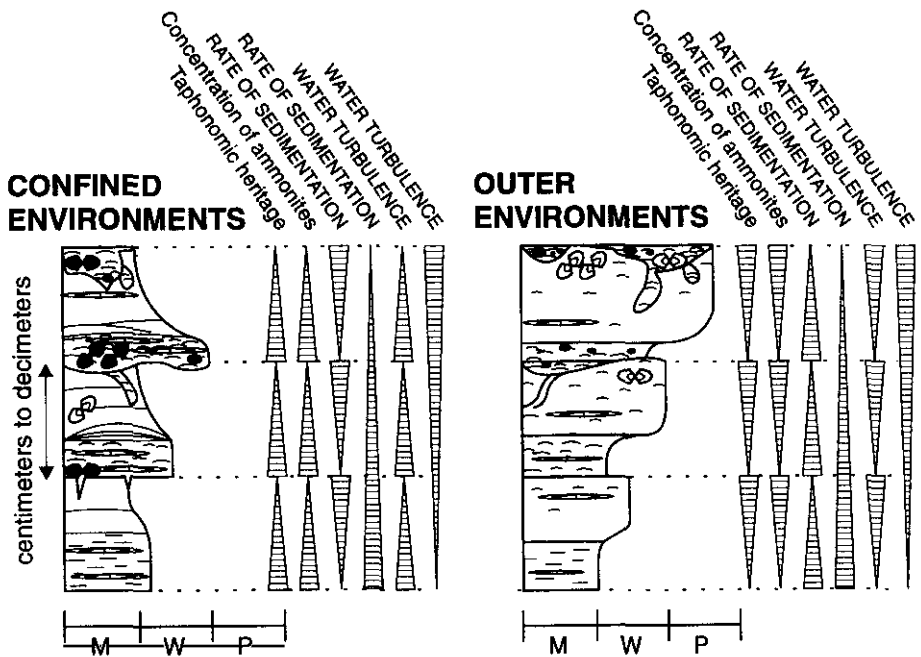
	M	Mudstone
	W	Wackestone
	P	Packstone
		Marly limestone
		Bioclasts
		Intraclasts
		Remobilization surface
		Sharp surface

		Mud cracks
		Microbial laminae
		Reelaborated ammonites
		Resedimented ammonites
		Biogenic borings
		Bioturbation
		Thalassinoides
		Zoophycos

In outer environments, when decreases in the rate of sedimentation are associated with increases in the degree of turbulence of the waters, the preserved associations of ammonites show gradual increase in the concentration and in the degree of taphonomic heritage, as some taphonomic processes such as biodegradation-decomposition, encrustation, sedimentary infill, concretion, abrasion, bioerosion, fragmentation, reorientation, disarticulation, regrouping and removal of ammonite remains are intensified. The *winnowed beds* described by Monaco (1995) were formed in these conditions. In confined environments, in contrast, when increases in the rate of sedimentation are associated with decreases in the degree of turbulence, the same taphonomic processes lead to the formation of ammonite associations with decreasing values of concentration and taphonomic heritage. The factors influencing these elementary sequences can be very diverse. Some authors consider that tidal cycles, monthly or semiannual (equinoctial), can be a cause of this periodicity (Ferry and Mangold, 1995) while others have related them to climatic cyclicity (Ferry, 1991; Vera Torres, 1994; Reboulet, 1995; Miall, 1995, 1997).

Interpreting the marl-limestone rhythmites formed in carbonate platforms requires to distinguish between background and event sedimentation (cf. Aigner, 1985; Brett and Baird, 1986; Fernández-López and Gómez, 1990c; García Ramos, Valenzuela y Suárez de Centi, 1992; Fürsich and Oschmann, 1993; López Martínez and Fernández-López, 1993; Brett, 1995). The carbonate background sedimentation in the outer platform is characte-

Fig. 2.–Examples of elementary sequences of the Middle Jurassic of the Iberian Range, showing the changes in turbulence and rate of sedimentation. During the development of parasequences, in carbonate outer platform environments, the degree of turbulence increases as the rate of sedimentation decreases. During the development of elementary sequences, however, the water turbulence increases in outer platform environments, but decreases in confined environments. Simultaneously, the rate of sedimentation decreases in outer platform environments, but increases in confined environments. Similarly, the degree of taphonomic heritage (estimated by the proportion of reelaborated elements) and the concentration of ammonite remains increase in outer platform environments, but the values of these two parameters decrease in confined environments.

Fig. 2.–Ejemplos de secuencias elementales del Jurásico Medio de la Cordillera Ibérica, con indicación de las variaciones en el grado de turbulencia y en la tasa de sedimentación. Durante el desarrollo de las parasecuencias, en los ambientes de plataforma externa carbonática, aumenta el grado de turbulencia y disminuye la tasa de sedimentación. Durante el desarrollo de las secuencias elementales, sin embargo, el grado de turbulencia aumenta en los ambientes abiertos, pero disminuye en los ambientes confinados. Simultáneamente, la tasa de sedimentación disminuye en los ambientes abiertos, pero aumenta en los ambientes confinados. Durante el desarrollo de estas secuencias elementales, el grado de herencia tafonómica (estimado por la proporción de elementos reelaborados) y la concentración de restos de ammonites aumentan en los ambientes abiertos de plataforma, pero los valores de estos dos parámetros disminuyen en los ambientes confinados de plataforma.
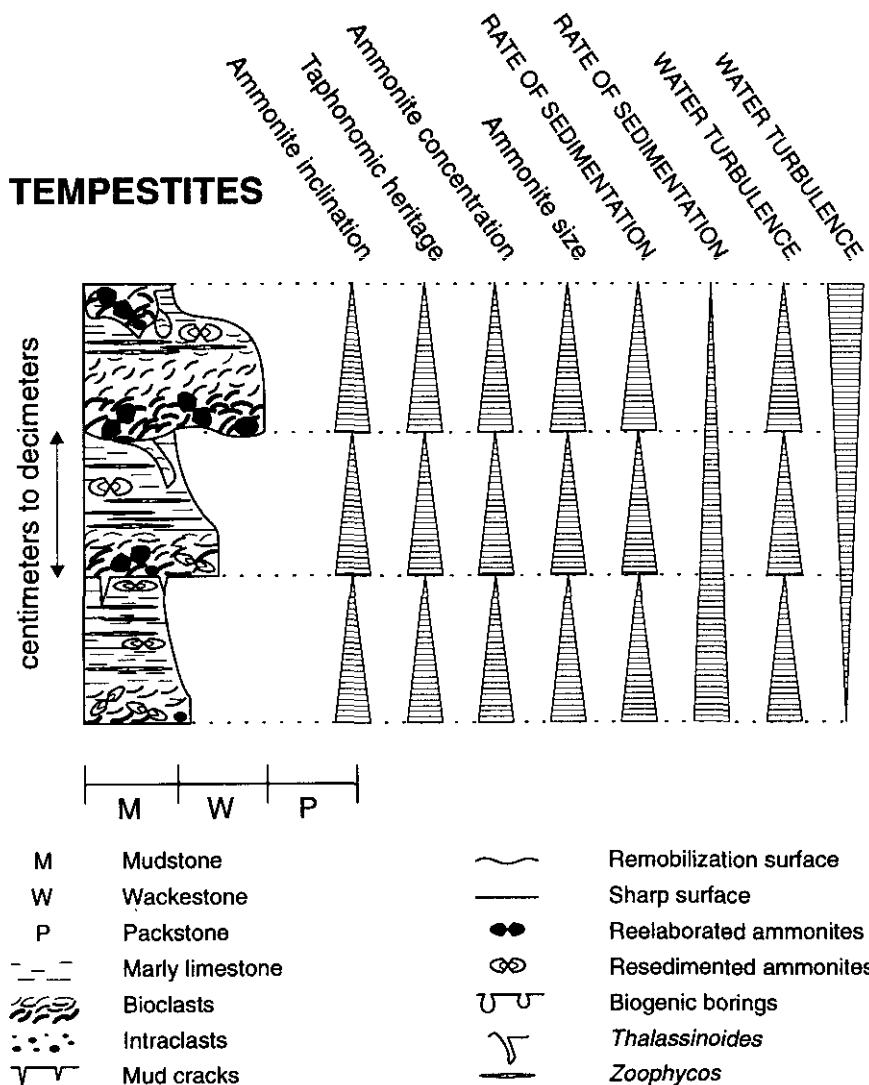
M	Mudstone		Remobilization surface
W	Wackestone		Sharp surface
P	Packstone		Reelaborated ammonites
	Marly limestone		Resedimented ammonites
	Bioclasts		Biogenic borings
	Intraclasts		*Thalassinoides*
	Mud cracks		*Zoophycos*

Fig. 3.–Frequency of different taphonomic characters displayed by ammonites included in tempestites of carbonate outer platform. During the development of a tempestite, in carbonate outer platform environments, the water turbulence and the rate of sedimentation decrease. During the development of such tempestites, consequently, the ammonite size, the ammonite concentration, the taphonomic heritage and the ammonite inclination decrease.

Fig. 3.–Variaciones en diferentes caracteres tafonómicos de los ammonites incluidos en tempestitas de plataforma externa carbonática. Durante el desarrollo de una tempestita, en ambientes de plataforma externa, disminuye la turbulencia y la tasa de sedimentación. En consecuencia, durante el desarrollo de estas tempestitas, disminuye el tamaño de los ammonites, su concentración, su grado de herencia tafonómica y su inclinación.

rized by gradual variations in the rate of sedimentation which are inversely proportional to the degree of turbulence (Fig. 2). In contrast, in the same carbonate epicontinental platforms, events of turbulence, such as storms, lead to the development of deposits formed under conditions of decreasing values of rate of sedimentation and degree of turbulence (Fig. 3). Preservational features and the distribution of ammonites enable the identification of such turbulence events. Ammonites included in tempestites as bioclasts show fining-upwards grading associated with decreasing values of taphonomic heritage and inclination. Tempestites showing fining-upwards grading and erosive or sharp base do not contain ammonites displaying imbricated grouping or preferential azimuthal-orientation (Fernández-López, 1997a).

Elementary taphonomic sequences comprise two or more successive recorded-associations showing gradual variations in their taphonomic characters. The successive recorded associations composing an elementary taphonomic sequence can occur in the same stratigraphic level, since the continuity/discontinuity of the fossil record is not determined by the continuity/discontinuity of the stratigraphical record (Fernández-López, 1986, 1987b, 1995, figure 13).

PARASEQUENCES AND TAPHOSEQUENCES

Carbonate sediments of shallow epicontinental platforms are organized in shallowing-upwards sequences or parasequences, of metric to decimetric thickness, coarsening and thickening upwards, which represent changes in relative depth from subtidal to inter or supratidal environments (Fernández-López 1985b, 1985c, 1997a, 1997b; Fernández-López and Gómez, 1990c; Fernández-López and Meléndez, 1994). These shallowing-upwards sequences or parasequences also represent cyclical variations of fifth-order, for which a time interval of 20.000 to 100.000 years has been estimated, according to Einsele (1992) and Vera Torres (1994); or else c. 100.000 years (Reboulet, 1995); also, 10.000 to 200.000 years according to Miall (1995).

As indicted in the figure 4, shallowing-upwards sequences or parasequences in carbonate outer platform, forming a positive taphosequence and different taphorecords, were formed during a phase of increasing turbulence and decreasing rate of sedimentation. Recorded associations found in positive taphosequences can be grouped in three successive taphorecords: a low turbulence taphorecord (LTT), a moderate turbulence taphorecord (MTT) and a high turbulence taphorecord (HTT). High turbulence
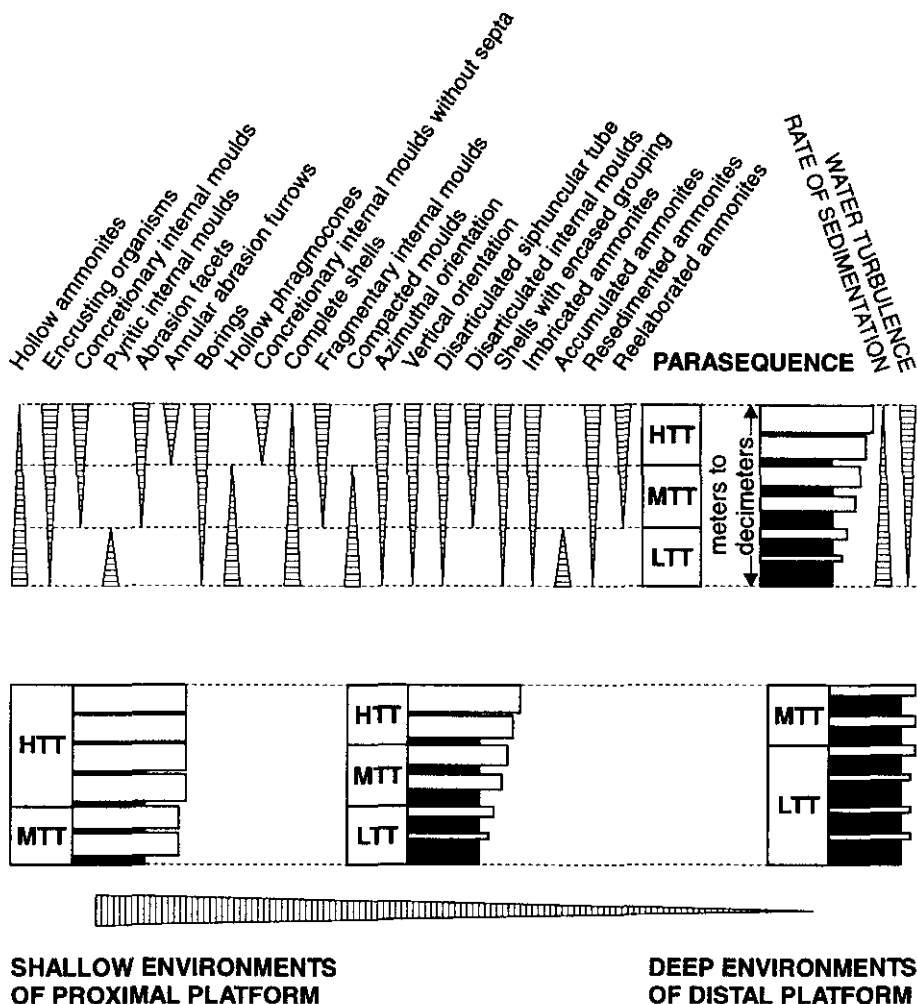
Fig. 4.–Frequency of different taphonomic characters displayed by ammonites included in a shallowing-upwards sequence or parasequence in carbonate outer platform, forming a positive taphosequence and different taphorecords. LTT = low turbulence taphorecord. MTT = moderate turbulence taphorecord. HTT = high turbulence taphorecord.

Fig. 4.–Variaciones en las frecuencias de diferentes caracteres tafonómicos de los ammonites incluidos en las secuencias de somerización o parasecuencias de las plataformas externas carbonáticas, que constituyen tafosecuencias positivas y diferentes taforregistros. LTT = taforregistro de baja turbulencia. MTT = taforregistro de moderada turbulencia. HTT = taforregistro de alta turbulencia.

taphorecords (HTT) are predominant in shallowing-upwards sequences or parasequences developed in shallow environments of proximal platforms. In contrast, low turbulence taphorecords (LTT) are more commonly

formed in shallowing-upwards sequences or parasequences developed in deep environments of the distal platform. In the lower portion of the most complete parasequences, where accumulated elements and pyritic ammonites may be found, complete shells are most common. In this portion, hollow ammonites (*i.e.*, showing no sedimentary infill in the phragmocone) and hollow phragmocones (*i.e.*, without septa) are the dominant fossils, but they are usually compressed by gravitational diagenetic compaction. Resedimented and reelaborated elements become more common to the upper portions of these parasequences, as shells are more completely infill with sediment and tend to acquire an encased pattern of grouping. Towards the top of the sequence, processes of early mineralization are more intense. Reelaborated concretionary internal moulds become dominant. They may display several distinctive features of abrasion, fragmentation, disarticulation, reorientation and regrouping. Such reelaborated elements will show no traces of deformation by gravitational diagenetic compaction, but they may develop abrasion facets formed before the final burial. Ammonite shells and concretionary internal moulds will tend to produce imbricate patterns of grouping and to show azimuthal reorientation. They may also be covered by encrusting organisms and biogenic boring. Siphuncular tubes will usually be disarticulated as a consequence of intense and lasting biostratinomic processes of biodegradation-decomposition and dissolution. Reelaborated concretionary internal moulds will also be preferentially disarticulated along septal surfaces. In the later stage, long episodes of emersion and erosion favour the formation of concretionary internal moulds without septa, as result from dissolution of the septa and subsequent infill of the cavities with sediments during episodes of emersion, and concretionary internal moulds with ellipsoidal abrasion facets and annular abrasion furrows.

During the development of parasequences, the variations in the degree of removal (proportion of resedimented plus reelaborated elements) and taphonomic heritage (proportion of reelaborated elements) of the ammonite associations will depend on the variations in the rate of sedimentation and in the rate of sediment accumulation, rather than on the variations of turbulence. The degree of removal and the degree of taphonomic heritage of the ammonite associations are inversely proportional to the rate of sedimentation and to the rate of sediment accumulation. A decrease in any or both sedimentary rates will produce an increase in the degree of taphonomic removal and taphonomic heritage, leading to the development of a positive taphosequence (Fig. 4). Yet, an increase in the rate of sedimentation or in the rate of sediment accumulation will produce a decrease in

the degree of removal and taphonomic heritage of the preserved association, leading to the development of a negative taphosequence (*cf.* Fernández-López and Suárez-Vega, 1980; Fernández-López 1985b, 1997a, 1997c; Fernández-López, Gómez et Goy, 1985; Fernández-López and Aurell, 1988; Fernández-López, Gómez y Ureta, 1988; Fernández-López and Gómez, 1990b; Fernández-López and Mouterde, 1994). These negative and positive taphonomic sequences, or taphosequences of increasing or decreasing turbulence respectively, enable the identification of shallowing-upwards sequences and infilling sequences of fifth-order respectively (Fernández-López and Gómez, 1991; Gómez and Fernández-López, 1994).

Taphosequences and parasequences can be grouped in sets, which would correspond to longer variations in relative depth. These sets are influenced by the subsidence. They compose stratigraphic cycles of fourth-order, for which a mean duration of 0,08 to 0,5 m.y. has been estimated by Vail *et al.* (1991); or else, 0,1 to 0, 5 m.y. according to Einsele (1992) and Vera Torres (1994); also, 0,4 m. y. according to Reboulet (1995); 0,2 to 0,5 m.y. according to Miall (1995). Sets of parasequences can be progradational, aggradational or retrogradational, according to their stacking pattern (*cf.* Van Wagoner *et al.,* 1988; López Martínez and Fernández-López, 1993; Homewood, 1996).

DEPOSITIONAL SEQUENCES AND DEPOSITIONAL SYSTEMS

Depositional sequences of third order represent relative sea-level changes with an estimated cyclicity of one m.y. (with a range of 0,5 to 5 m.y. according to Vail *et al.,* 1991; Gonnin *et. al.,* 1992, 1993; Jacquin *et al.,* 1992; 0,5 to 3 m.y. according to Einsele, 1992; Graciansky *et al.* 1993; Vera Torres, 1994; Jacquin and Vail, 1995; 1 m.y. in Fels, 1995; 1 to 10 m.y. according to Miall, 1995; 1,5 to 2,5 m.y. in Reboulet, 1995; 1 to 5 m.y. in Rousselle, 1997). Depositional sequences are stratigraphic sequences of greater magnitude than parasequences or sets of parasequences.

A cycle of relative sea-level change, as recognized in sequence stratigraphy, comprises from a relative sea-level fall up to the following relative sea-level fall (Vail *et al.,* 1987; Wilgus *et al.,* 1988; Ferry, 1991; Rioult *et al.,* 1991; Homewood *et al.,* 1992; Burchette and Wright, 1992; Graciansky *et al.,* 1993; Brett, 1995; Jacquin and Vail, 1995). Relative sea-level changes determine relative changes of the potential of accommodation and, in carbonate platforms, relative changes in the production rate of sediments. In carbonate epicontinental platforms, the maximum production

of sedimentary particles takes place to a depth of about a ten of meters undergoing a quick fall thereafter (Wilson, 1975; James, 1983; Wilgus *et al.*, 1988; Einsele, 1992; Handford & Loucks, 1993; Wright and Burchette, 1996). In carbonate epicontinental platforms, relative changes of the potential of accommodation and the variations in the rate of relative sea-level change are two fundamental concepts not only to interpret sequences and sedimentary cycles of the stratigraphical record but also to understand the cyclical and sequential character of the fossil record.

The curve representing the relative changes of the potential of accommodation can be subdivided in four parts to differentiate four successive phases during the development of the third-order depositional sequences (Fig. 5). According to the terms proposed by Jacquin & Vail (1995), four distinctive depositional systems or systems tracts are developed in these four phases of relative sea-level change: 1) lower lowstand systems tract (LLST); 2) upper lowstand systems tract (ULST); 3) backstepping highstand systems tract (BHST or TST); 4) forestepping highstand systems tract (FHST or HST). The whole of these depositional systems correspond to a depositional sequence of third order. Each depositional sequence represents a cycle of eustatic change, and it is bounded by discontinuities produced by relative sea-level falls.
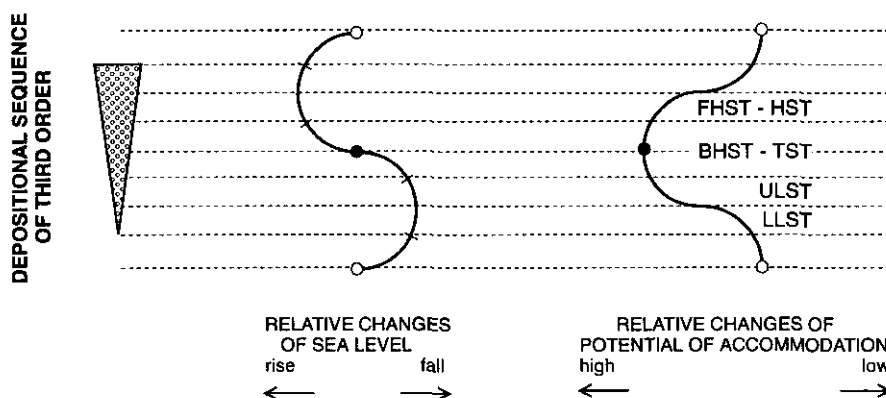

Fig. 5.–Different depositional systems and successive phases which can be distinguished during the development of a depositional sequence of third order. LLST = lower lowstand systems tract. ULST = upper lowstand systems tract. BHST or TST = backstepping highstand (or transgressive) systems tract. FHST or HST = forestepping highstand systems tract.

Fig. 5.–Diferentes sistemas deposicionales y fases sucesivas durante el desarrollo de una secuencia deposicional de tercer orden. LLST = sistema deposicional inferior de bajo nivel. ULST = sistema deposicional superior de bajo nivel. BHST o TST = sistema deposicional retrogradacional de alto nivel. FHST o HST = sistema deposicional progradacional de alto nivel.

Depositional systems or systems tracts of lowstand are not usually re-
presented in carbonate epicontinental platforms. In these depositional si-
ttings, each third-order depositional sequence comprises transgressive de-
posits, of more or less limited thickness, corresponding mainly to highstand
deposits (Baum and Vail, 1988; Brett, 1995; Miall, 1995). In carbonate epi-
continental platforms, the maximum rate of carbonate production takes pla-
ce during the development of the highstand progradational depositional
systems. The highstand retrogradational or transgressive depositional sys-
tems accumulate in the deepest or protected areas and are bounded at the
top by a discontinuity which represents the maximum flooding surface.

Deposits forming the transgressive or retrogradational depositional
systems typically compose thinning- and fining-upwards sedimentary se-
quences containing condensed recorded associations. They are also classi-
cally known to be formed by condensed sediments. Yet, the degree of se-
dimentary condensation may be very different according to the relative
depth of the platform: condensed sediments are deposited in distal and deep
areas while expanded sediments develop laterally, in proximal and shallow
areas (Fernández-López and Gómez, 1991; Gómez and Fernández-López,
1992, 1994). In both extreme conditions, the discontinuity below these de-
posits containing condensed associations corresponds to the top of the
underlying depositional sequence and represents the boundary between
the two successive depositional sequences (cf. Arnott, 1995).

Depositional systems quickly thin out towards the proximal areas, but
concretionary internal moulds of ammoni tes associated with nondeposi-
tional hiatuses can be incorporated as reelaborated elements in the ulterior
highstand systems tract, giving rise to condensed associations with com-
plete concretionary internal moulds. This would explain the high degree of
taphonomic condensation reached by recorded associations of ammonites
in shallow carbonate epicontinental platforms, even when such associations
are included in mudstone sediments deposited during episodes of maxi-
mum rate of sedimentation. Interpreting these processes of taphonomic
condensation, in carbonate epicontinental platforms, requires taking into
account the relative duration of such taphonomic processes as accumula-
tion, resedimentation and reelaboration (Fig. 1). Accumulation of ammo-
nite shells on the deep sea basins may be practically instantaneous after the
death of the organisms. However, in carbonate epicontinental platforms, accu-
mulation of the ammonite shells can take place several months after the de-
ath (Fernández-López, 1987a, 1997a). Resedimented shells may stay on the
depositional surface for several tens of years, before being buried. Reela-
borated internal moulds of ammonites may stay on the depositional surfa-

ce after being exhumed and before the final burial for more than ten million years, as for many ammonite fossils submitted to reelaboration processes in the Castiliane, Aragonese and Tortosa platforms through the Middle Jurassic (Fernández-López *et al.*, 1996). The highest values of taphonomic condensation in ammonite associations are displayed in shallow epicontinental platforms rather than in deep sea environments. However, the degree of taphonomic heritage (estimated by the ratio of reelaborated elements in the whole assemblage) can reach 100% in both cases (Fernández-López, 1997a).

CONDENSED SECTIONS	PROXIMAL - DISTAL
SEDIMENTS	expanded - condensed
TAPHONOMIC CONDENSATION	high - low
TAPHONOMIC HERITAGE	high - moderate
DEGREE OF PACKING	low - high
STRATIGRAPHIC PERSISTENCE	low - high
TAPHONIC POPULATION OF TYPE 1	absent - present
HOLLOW AMMONITES	abundant - scarce
REELABORATED AMMONITES	rounded - angular
BIOGENIC BORINGS	abundant - scarce
PYRITIC INTERNAL MOULDS	scarce - common
STRATIGRAPHIC GAPS	common - scarce

Table 1.–Differential characters of the condensed sections formed in depositional sequences of third order in proximal or distal areas.
Tabla 1.–Caracteres diferenciales de las secciones condensadas formadas de secuencias deposicionales de tercer orden en áreas proximales o distales.

Condensed sections formed in depositional sequences of third order show different characters in proximal areas in relation to distal areas (Table 1). The degree of taphonomic condensation in ammonite recorded associations reaches the highest values in shallow epicontinental platforms, not in deep basins, though the degree of taphonomic heritage (*i.e.*, the ratio of reelaborated elements to the whole of recorded elements) can, in both cases, reach 100% (Fernández-López, 1997). The degree of packing of ammonite remains (estimated by the difference between the number of specimens and the number of fossiliferous levels subdivided by the number of fossiliferous levels) and the stratigraphical persistence (proportion of fossiliferous levels) display smaller values in proximal than in distal areas.

Condensed sections from distal areas usually contain taphonic population of type 1 (Fernández-López, 1997a). In such areas, phragmocones are normally filled by sediment, and concretionary internal moulds display disarticulation surfaces and fractures with acute margins. Pyritic ammonites are common in certain distal areas. On the other hand, in proximal areas, taphonic populations are usually of type 2 or 3, those of type 1 being not represented. Hollow ammonites (*i.e.*, shells showing no sedimentary infill in the phragmocone) are abundant, reelaborated internal moulds show high values of roundness and sphericity as well as common biogenic borings, and pyritic ammonites are scarce (Fernández-López, 1997). Stratigraphic successions in shallow epicontinental platforms are usually more incomplete than those formed in deep basins (cf. Sadler, 1981; Schindel, 1982; McKinney, 1985; Tipper, 1987; Kowalewaki, 1996). However, despite the abundance and wide range of biostratigraphic gaps in such sequences, registratic gaps are usually not so important in condensed sections of shallow platforms, the registratic succession being usually more than the corresponding biostratigraphic succession.

TRANSGRESSIVE/REGRESSIVE SEDIMENTARY CYCLES

Third-order transgressive/regressive sedimentary cycles represent long-term variations of the relative sea-level, of several million years (from 0,5 to 5 m.y. according to Vail *et al.* 1991; Jacquin *et al.*, 1992; 0,5 to 3 m.y., with an average duration of 0,8 m.y. for the Mesozoic, according to Einsele, 1992; Homewood *et al.*, 1992; Graciansky *et al.* 1993; Vera Torres, 1994; Jacquin and Vail, 1995; 1,5 to 2,5 m.y. in Reboulet, 1995; 1 to 10 m.y. according to Miall, 1995).

Transgressive/regressive sedimentary cycles of third order comprise one or more depositional sequences of third order. Six successive phases can be distinguished within the deepening/shallowing environmental cycles of third-order in carbonate epicontinental platforms, on the basis of the relative changes in the potential of accommodation and in the production rate of sediments (Fig. 6):

1) Incipient deepening phase: open marine environments are restricted to the distal or more depressed areas of the platform, and the accommodation space and the production rate of carbonate begin to increase, after a phase of emersion and regional erosion.
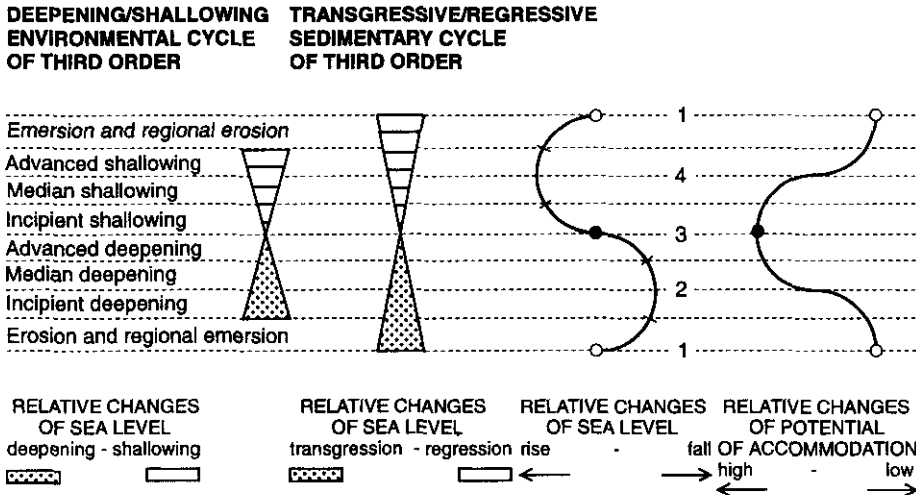
DEEPENING/SHALLOWING
ENVIRONMENTAL CYCLE
OF THIRD ORDER

TRANSGRESSIVE/REGRESSIVE
SEDIMENTARY CYCLE
OF THIRD ORDER

Emersion and regional erosion

Advanced shallowing

Median shallowing

Incipient shallowing

Advanced deepening

Median deepening

Incipient deepening

Erosion and regional emersion

RELATIVE CHANGES
OF SEA LEVEL
deepening - shallowing

RELATIVE CHANGES
OF SEA LEVEL
transgression - regression rise

RELATIVE CHANGES
OF SEA LEVEL

RELATIVE CHANGES
OF POTENTIAL
fall OF ACCOMMODATION
high - low

Fig. 6.–Relative changes of the potential of accommodation (*i.e.*, subsidence and eustasy) and relative changes of sea level, two fundamental concepts of sequence stratigraphy, have conditioned the development of transgressive/regressive sedimentary cycles and environmental cycles of deepening/shallowing in carbonate epicontinental platforms. The curve representing relative changes of sea level during the development of transgressive/regressive sedimentary cycles of third order may be subdivided into four parts to differentiate four successive phases: 1) rapid fall, 2) increasing rate of rise, 3) rapid rise, 4) decreasing rate of rise. From the phase of incipient deepening until that of advanced shallowing, six successive phases can be distinguished in an environmental cycle of deepening/shallowing.

Fig. 6.–Los cambios relativos del potencial de acomodación (*i.e.*, subsidencia y eustasia) y los cambios relativos del nivel del mar, dos conceptos fundamentales de Estratigrafía Secuencial, han condicionado el desarrollo de ciclos sedimentarios transgresivo/regresivos y de ciclos ambientales de profundización/somerización en las plataformas epicontinentales carbonáticas. La curva que representan los cambios relativos del nivel del mar durante el desarrollo de los ciclos sedimentarios transgresivo/regresivos de tercer orden suele ser subdividida en cuatro partes para diferenciar cuatro fases sucesivas: 1) descenso rápido, 2) tasa de ascenso creciente, 3) ascenso rápido, 4) tasa de ascenso decreciente. Desde la fase de profundización incipiente hasta la de somerización avanzada, seis fases sucesivas pueden ser distinguidas en un ciclo ambiental de profundización/somerización.

2) Median deepening phase: open marine environments expand towards the proximal and high areas of the outer platform.

3) Advanced deepening phase: the production rate of sediments is insufficient respect to the accommodation space that is generated in the platform. As a consequence, the depositional environments retrograde.

4) Incipient shallowing phase: the production rate of sediments increase more quickly than the potential of accommodation and the rate of sedimentation increases in the deepest areas.

5) Median shallowing phase: open marine environments constraint progressively towards more distal and depressed areas of the outer platform.

6)   Advanced shallowing phase: open marine environments only occupy the most distal or depressed areas of the platform. The potential of accommodation and the production rate of carbonate decrease. Proximal or high areas of the platform are submitted to emersion and erosion processes.

Transgressive/regressive sedimentary cycles of third order comprise relative and cyclical variations of sea level. Yet, environmental deepening/shallowing cycles of third-order, also involving cyclical variations of the potential of accommodation of sediments, can exclusively result from cyclical variations of the subsidence. On the other hand, a high production of sediments can completely infill the space of accommodation generated by a relative rise of sea level, resulting a shallowing phase even during a transgressive phase (Wilgus *et al.*, 1988; Jacquin and Vail, 1995). Transgressive or regressive phases cannot be simply identified by indications of deepening or shallowing. It is necessary to consider as well the time-space relationships between the different environments developed. Open marine environments occupy more coastal and proximal areas of the platforms during the transgressive phases, and more external and distal areas during the regressive phases. Consequently, the transgressive/regressive environmental cycles can be inferred on the basis of the time-space relationships between the different environments which compose the deepening/shallowing environmental cycles. Identification of deepening/shallowing cycles is of utmost importance in interpreting the transgressive/regressive cycles in carbonate epicontinental platforms, where no evidence of coastal onlap is preserved but fossiliferous sediments of outer platform are widely developed, as it occurs often in the European platforms during the Middle Jurassic.

In carbonate epicontinental platforms, relative changes of sea level resulting from eustatic movements and subsidence also led to particular taphonomic cycles: the so-called *deepening/shallowing taphocycles*. Recorded associations of ammonites generated in different phases of these environmental deepening/shallowing cycles show distinctive secondary characters and compose separate taphorecords (cf. Fernández-López, 1987b; 1995). Recorded associations of ammonites comprising an ideal deepening/shallowing taphocycle in carbonate epicontinental platforms can be grouped with taphonomic criteria in taphorecords of different category: incipient-deepening, mean-deepening and advanced-deepening taphorecords, as well as incipient-shallowing, mean-shallowing and advanced-shallowing taphorecords.

BOUNDARIES BETWEEN DEEPENING/SHALLOWING TAPHOCYCLES

The first step to identify the successive deepening/shallowing ta-
phocycles in carbonate epicontinental platforms is to identify the wide-
spread registratic gaps, *i.e.* gaps of the fossil record showing a regional extent,
and affecting the deepest areas of the outer platform (Fig. 9). As it has been
repeatedly shown (Fernández-López, 1984, 1985b, 1986, 1987b, 1991,
1995, 1997; Fernández-López & Gómez, 1990b; Aurell, Meléndez & Me-
léndez, 1993) reelaborated fossils as witnesses of non-deposition or denu-
dation events of the sea floor are valuable instruments to recognize and es-
timate the geochronologic range of stratigraphic gaps. Such episodes are
usually found in carbonate sequences. On the other hand, registratic gaps
may indicate intervals of emersion and regional erosion. They may be
quite common in carbonate epicontinental platforms. Registratic gaps
identified by means of ammonites have generally smaller geochronological
amplitude than the contemporary stratigraphic gaps, and they enable to as-
certain, with greater precision, the episodes of regional emersion in the
platform.

The rate of sedimentation in outer platform areas falls down and some
former subtidal environments can be emerged during a phase of rapid re-
lative sea-level fall. At the same time, the processes of sedimentation and
accumulation of ammonite shells in the more proximal areas of the plat-
form are interrupted. Under such conditions, both the sediments and the
preserved elements undergo some specific modifications because of sub-
aerial exposure and intense early diagenesis. The taphonomic modifications
usually involve reelaboration processes, abrasion and dissolution. The rate
of sedimentation falls down to zero in emerged areas, leading to the deve-
lopment of hardgrounds and rockgrounds. These conditions took place in
the Castiliane, Aragonese and Tortosa platforms during the Murchisonae
Biochron (Aalenian), the Parkinsoni Biochron (Bajocian), the Discus
Biochron (Bathonian) and during the Lamberti and Mariae biochrons (Ca-
llovian/Oxfordian), giving rise to stratigraphic gaps of regional extension in
the Iberian Basin (Fernández-López, 1980, 1985a, 1985b, 1985c; Aurell,
1990; Fernández-López and Gómez, 1990a, 1990b, 1991; Meléndez *et
al.*, 1990; Aurell, Fernández-López & Meléndez, 1995; Ramajo and Me-
léndez, 1996).

Processes of biodegradation-decomposition and dissolution affecting
the scarce ammonite remains which occasionally arrive to the emerged
areas of the outer platform, for example during storm events, are very in-
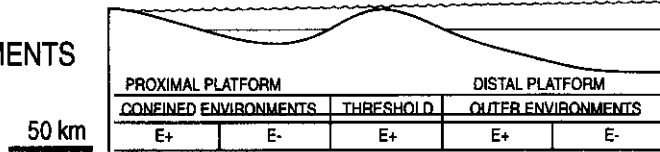tense and rapid. Empty ammonite shells, devoid of soft-parts in the body

chamber, are quickly dissolved in these areas. Partial internal moulds of the body chamber (*i.e.*, hollow ammonites) can be exceptionally formed, indicating very high rate of sediment accumulation. Such sedimentary conditions favour taphonomic reelaboration, so the reelaborated concretionary internal moulds of ammonites may become abundant or even dominant in the recorded-associations formed in these environments. These reelaborated elements will show some specific features such as traces of dissolution and a complex infilling, resulting from multiple episodes of sedimentary infill separated by episodes of cementation. Some of these sediments infilling the shells are siliciclastic, and affect non-displaced elements; hence, they are siliciclastic pseudomorphs. Concretionary internal moulds are usually regrouped, imbricated or verticalized during the reelaboration processes. Concretionary moulds without septa can be formed (Fernández-López, 1997a, figures 11-12). They can also acquire roll and truncational abrasion facets, as well as disarticulation surfaces and fractures.

Once the successive registratic gaps of regional extension have been identified, the time span represented by condensed or by expanded sections, as well as the intervals with condensed associations may be estimated (Fig. 9). A valuable criterion to interpret the environmental deepening/shallowing cycles is the character and geographic distribution of the different taphonic populations of ammonites. Condensed associations containing greater number of taphonic populations of type 1 (TP-1) represent advanced deepening environments. In contrast, condensed associations including only taphonic populations of type 3 (TP-3) represent incipient deepening or advanced shallowing environments.

One or more deepening taphorecords can be developed during the deepening phases in carbonate epicontinental platforms, according to the environmental conditions and on the rate of relative sea-level changes. Deepening taphorecords developed in the most distal areas of the platform usually show more diverse features than those formed in the shallowest most and proximal areas (Fig. 7). They may range from incipient deepening to advanced deepening taphorecords in the most distal areas of the platform. However, taphorecords developed simultaneously in the proximal and shallow areas of the carbonate epicontinental platforms will only range from median deepening to advanced deepening. It means that taphorecords of incipient deepening phases will not be present in shallow or proximal areas of carbonate epicontinental platforms.

Shallowing taphorecords comprise recorded associations younger than those of deepening taphorecords of the same cycle. Shallowing

SEDIMENTARY
PALAEOENVIRONMENTS

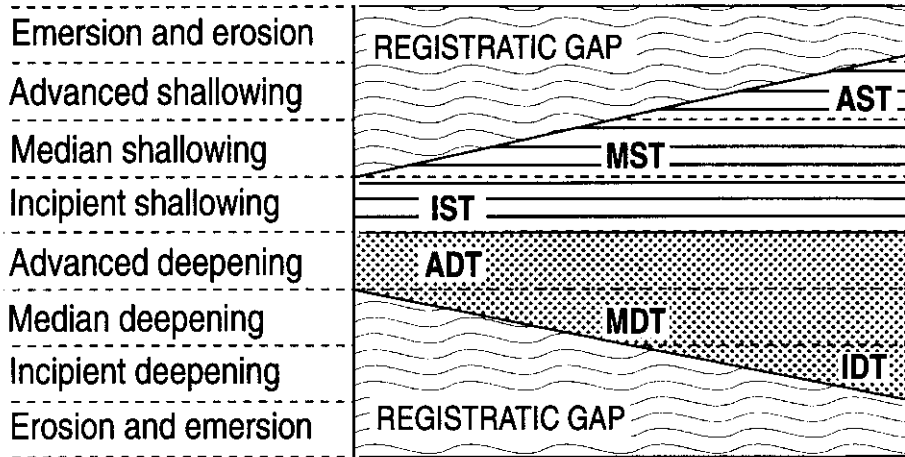| PROXIMAL PLATFORM			DISTAL PLATFORM	
CONFINED ENVIRONMENTS		THRESHOLD	OUTER ENVIRONMENTS	
E+	E-	E+	E+	E-

50 km

DEEPENING/SHALLOWING TAPHOCYCLE

Emersion and erosion	REGISTRATIC GAP
Advanced shallowing	AST
Median shallowing	MST
Incipient shallowing	IST
Advanced deepening	ADT
Median deepening	MDT
Incipient deepening	IDT
Erosion and emersion	REGISTRATIC GAP

Fig. 7.–Taphorecords of ammonites developed in carbonate epicontinental platforms during an environmental deepening/shallowing cycle show more diverse characters in distal and depressed areas than in proximal and shallow areas. Taphorecords of incipient deepening and those of advanced shallowing were only developed in distal and deep areas of the platform. IDT = incipient-deepening taphorecord. MDT = median-deepening taphorecord. ADT = advanced-deepening taphorecord. IST = incipient-shallowing taphorecord. MST = median-shallowing taphorecord. AST = advanced-shallowing taphorecord. Fig. 7.–Los taforregistros de ammonites desarrollados en las plataformas epicontinentales carbonáticas durante un ciclo ambiental de profundización/somerización presentan caracteres más variados en las áreas distales y deprimidas que en las áreas proximales y someras. Los taforregistros de profundización incipiente y los de somerización avanzada sólo se desarrollaron en las áreas distales y profundas de las plataformas carbonáticas. IDT = taforregistro de profundización incipiente. MDT = taforregistro de profundización media. ADT = taforregistro de profundización avanzada. IST = taforregistro de somerización incipiente. MST = taforregistro de somerización media. AST = taforregistro de somerización avanzada.

taphorecords reach greatest development in the most distal areas of the platform, where the record of the whole environmental change from incipient to advanced shallowing taphorecords is more complete. Accordingly, in the proximal and shallow areas of the carbonate platforms for the same time span, only incipient to mean shallowing taphorecords are developed.

INCIPIENT-DEEPENING TAPHORECORDS

Incipient-deepening taphorecords represent the first phase of the deepe-ning/shallowing taphocycles. They·are generated in the distal or more de-pressed areas of the outer platform, when the space accommodation and the production of carbonate begin to increase, after a phase of emersion and re-gional erosion. Sediments are quickly cemented, and firmgrounds, showing traces of dessication and local weathering, are dominant. Rates of sedimen-tation are usually very low, but rates of sediment accumulation may be very variable. At the same time, stratigraphic and registratic gaps are still deve-loped in the proximal areas of the outer platform. Such palaeogeographic conditions were developed in the Castiliane, Aragonese and Tortosa plat-forms during the Bradfordensis, Concavum, Discites, Laeviuscula and Pro-pinquans biochrones (Aalenian-Bajocian; Fernández-López, 1985c; Fer-nández-López and Gómez, 1990a, 1990b, 1991; Fernández-López *et al.*, 1996), as well as during the Zigzag Biochron (early Bathonian; Fernández-López, Meléndez y Suárez-Vega, 1978; Fernández-López and Aurell, 1988; Fernández-López *et al.*, 1988, 1996; Lardiés, 1990) and during the Bullatus Biochron (early Callovian; Sequeiros and Meléndez, 1987; Aurell, Meléndez y Meléndez, 1990; Fernández-López & Meléndez, 1995b, 1996).

After a phase of regional emersion and when the rate of relative sea-le-vel fall in the outer platform becomes minimal or zero, the shells of am-monites can still be preserved as accumulated elements in the most distal or depressed areas, but they will tend to be quickly resedimented (Fig. 8). The importation of shells by nekroplanktic drift is usually low, although they can locally form high concentrations. Taphonic populations of type 3, composed of resedimented or reelaborated elements, are dominant. The de-gree of packing (estimated by the difference between the number of spe-cimens and the number of fossiliferous levels with respect to the number of fossiliferous levels) in the preserved associations of ammonites may also be very variable. Ammonite associations show very low values of stratigra-phic persistence (proportion of stratigraphic levels with ammonites) and scarce

Fig. 8.–Characteristic features of the different taphorecords of ammonites composing a deepening/sha-llowing taphocycle in carbonate epicontinental platforms. IDT = incipient-deepening taphorecord. MDT = median-deepening taphorecord. ADT = advanced-deepening taphorecord. IST = incipient-sha-llowing taphorecord. MST = median-shallowing taphorecord. AST = advanced-shallowing taphorecord. Fig. 8.–Caracteres de los diferentes taforregistros de ammonites que componen un tafociclo de pro-fundización/somerización en las plataformas epicontinentales carbonáticas. IDT = taforregistro de profundización incipiente. MDT = taforregistro de profundización media. ADT = taforregistro de profundización avanzada. IST = taforregistro de somerización incipiente. MST = taforregistro de so-merización media. AST = taforregistro de somerización avanzada.

DEEPENING/SHALLOWING TAPHOCYCLE
IN CARBONATE EPICONTINENTAL PLATFORMS
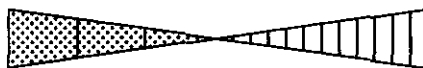
○　　' IDT ' MDT ' ADT ● IST ' MST ' AST '　　○

MECHANISMS OF TAPHONOMIC ALTERATION and results:

BIODEGRADATION-DECOMPOSITION
Body chambers with soft-parts
Shells with periostracum
Siphuncular tubes with connecting rings

ENCRUSTATION
Intrathalamous encrustings
Extrathalamus encrustings
Stromatolite laminae

SEDIMENTARY INFILL
Phragmocones with sedimentary infill
Siliciclastic pseudomorphs

SINSEDIMENTARY MINERALIZATION
Calcareous concretionary internal moulds
Phosphatic concretionary internal moulds
Glauconitic concretionary internal moulds
Pyritic internal moulds
Silicified concretionary internal moulds

ABRASION
Internal moulds with truncational facets
Internal moulds with roll facets
Internal moulds with ellipsoidal facets
Internal moulds with annular furrows

BIOEROSION
Internal moulds with biogenic borings

SINSEDIMENTARY DISSOLUTION
Shells without septa (hollow phragmocones)
Periostraca without septa neither wall
Concretionary internal moulds without septa

TAPHONOMIC DISTORTION
Shells with opened fractures
Shells with closed fractures
Complete shells
Incomplete phragmocones
Fragmentary internal moulds
Moulds with discontinuous compaction
Moulds with continuous compaction
Hollow ammonites (phragmocones without sedimentary infill)

REORIENTATION
Shells with azimuthal reorientation
Internal moulds with azimuthal reorientation
Vertical shells
Vertical concretionary internal moulds

DISARTICULATION
Disarticulated aptychus
Shells without aptychus
Disarticulated siphuncular tubes
Disarticulated internal moulds

DISPERSAL
Taphonic populations of type 1
Taphonic populations of type 2
Taphonic populations of type 3

REGROUPING
Encased shells
Imbricated shells
Imbricated internal moulds

REMOVAL
Accumulated elements
Resedimented elements
Reelaborated elements

lateral continuity. Biostratinomic processes of biodegradation-decomposition are intense. Ammonite shells usually lack soft-parts and aptychus in the body chamber, as well as periostracum or connecting rings. Siphuncular tubes tend to be disarticulated. Among the resedimented and buried shells, the phragmocones without sedimentary infill are common, indicating very rapid processes of sedimentary infill and high rate of sediment accumulation. Hollow ammonites maintain their original volume, showing no traces of distortion by gravitational compaction, as a result from rapid early cementation. Shells can also show microbial laminae, developed during the resedimentation, and skeletal remains of very diverse encrusting organisms, indicative of lasting and intense processes of nekroplanktic drift. Resedimented shells and reelaborated internal moulds may be overgrown by calcareous stromatolitic laminae, and sometimes by phosphatic and/or ferruginous coatings. Reelaborated internal moulds may display roll and truncational abrasion facets; more seldom, associated with hard and homogeneous substrates, they may show ellipsoidal abrasion facets or annular furrows. Preserved elements are usually reoriented and regrouped, forming encased or imbricated patterns, even when they are included in sediments of channeled facies or deposited by events of turbulence. In such environmental conditions positive taphosequences may be formed. Condensed associations included in the base of the parasequences usually show high values of taphonomic condensation, and some preserved elements display traces of subaerial exposure, erosion and transportation. These reelaborated elements can be even older in age than the underlying parasequence.

MEDIAN-DEEPENING TAPHORECORDS

Median-deepening taphorecords are formed in the outer platform under oxygenated marine water conditions and when the rate of relative sea-level rise is sufficiently slow as to allow an increase in the production of carbonate. Such conditions promote the development of bioconstructions and hinder the process of lateral accretion. This deepening phase tends to coincide with the aggradation phase of sedimentary cycles of third order (cf. Jacquin and Vail, 1995). The rate of sediment accumulation is usually high, although the rate of sedimentation can be very variable in the different areas. According to the morphology of the sea floor, the outer platform can have restricted conditions in the proximal areas or generalized open-sea conditions. Environmental conditions will generally be characterized by a lower turbulence than during the phase of initial deepening, the influence of the swell and the storms on the sea floor being also lower. These palaeo-

geographic conditions were developed in the Castiliane, Aragonese and Tortosa platforms during the Humphriesianum and Niortense biochrones (Bajocian; Fernández-López, 1985c; Fernández-López and Mouterde, 1985; Fernández-López *et al.*, 1996), as well as during the Progracilis Biochron (Bathonian; Fernández-López *et al.*, 1978; Lardiés, 1990) and the Gracilis Biochron (early Callovian; Sequeiros and Meléndez, 1987).

A depth of several tens of meters is reached in the distal areas during this phase of slow relative sea-level rise. Ammonite associations will spread throughout the most proximal and shallow areas of the outer platform. The importation of shells by nekroplanktic drift is high, as a result from the increase in the space of accommodation. Taphonic populations of types 3 and 2 are dominant among these associations. Patterns of shell distribution are usually of grouped type, and the degree of packing as well as the stratigraphic persistence of the recorded associations of ammonites are very variable in the different areas. The degree of taphonomic heritage and the degree of removal displayed by the successive ammonite associations decrease quickly when the rate of production of sediments exceeds the rate of relative rise of sea level. However, these indices do not show meaningful variations if the rate of production of sediments matches the rate of relative sea-level rise. Positive taphosequences become much more clearer when the rate of sedimentation decreases. In the proximal areas, coinciding with the boundaries of the parasequences, condensed associations showing traces of subaerial exposure can still be generated during this phase.

In outer environments, the rate of sediment accumulation is usually high, but the rate of sedimentation may be very variable in the different areas. Accumulated shells are scarce, the resedimented shells being dominant. Locally, coinciding with the boundaries of the successive parasequences, reelaborated internal moulds with roll and truncational abrasion facets are formed. Biostratinomic processes of biodegradation-decomposition are less intense than in the phases of incipient or advanced deepening. Ammonite shells usually lack soft-parts and aptychus in the body chamber, but they can maintain the periostracum and the connecting rings during the burial. Hollow ammonites and partial internal moulds of the body chamber, indicative of a very high rate of sediment accumulation, are abundant. Resedimented shells may be overgrown by intrathalamous and extrathalamous, encrusting organisms. Reelaborated internal moulds are usually covered by stromatolitic laminae. Concretionary internal moulds can be carbonated, phosphatic or glauconitic. Silicified internal moulds, associated with sediments deposited in conditions of high rate of sediment accumulation but low rate of sedimentation, may locally be common.

Restricted environments may be common in the proximal areas during this phase. The rate of sedimentation and the rate of sediment accumulation are both generally high in these protected environments. Reelaborated fossils are here very scarce and limited to the boundaries between successive parasequences. Accumulated shells may become quite common in the areas of lower turbulence. Biostratinomic processes of biodegradation-decomposition can be retarded by the deficiency in shortage of oxygen. Ammonite shells usually lack soft-parts in the body chamber, but they can still maintain the periostracum and the connecting rings. Siphuncular tubes are usually articulated. Among the recorded elements, partial internal moulds of the body chamber and hollow ammonites, indicative of very high rate of sediment accumulation, are dominant. Resedimented shells and reelaborated moulds are usually covered by stromatolitic laminae. Concretionary internal moulds are usually carbonated. In the most confined environments, pyritic internal moulds and shells without septa (*i.e.*, hollow phragmocones) can be formed by early dissolution near the water/sediment interface.

ADVANCED-DEEPENING TAPHORECORDS

Advanced-deepening taphorecords developed in carbonate epicontinental platforms characterize the last stadiums of the deepening phases. They acquire the maximum development in the most distal and deepest areas of the outer platform, where oxygenated environments prevail but the production rate of sediments is insufficient in relation to the accommodation space generated. Consequently, the rate of sediment accumulation decreases and the depositional environments retrograde. The rate of sedimentation and the rate of sediment accumulation are both usually low. Parasequences show a less distinctive development than in the previous phases. Thresholds and depressed areas can be distinguished, but they do not show important breaks or abrupt transitions. Lateral variations of the environmental conditions are generally gradual. The sea floor in the outer platform remains below the fair weather and the storm wave base levels during these maximum deepening episodes. Such palaeogeographic conditions were reached in the Castiliane, Aragonese and Tortosa platforms during the Niortense Biochron (Polygyralis Subchronozone, late Bajocian; Fernández-López, 1985c; Fernández-López *et al.*, 1996).

The outer platform constitutes a carbonate ramp whose maximum depth can vary from several tens to a hundred meters during this last deepening

phase. The final episodes of this deepening phase correspond to the maximum deepening stadiums in the platform. Though the concentration of ammonite shells tends to be less important than in the previous phase, taphonic populations of type 1, 2 and 3 may be produced. The occurrence of taphonic populations of type 1 is indicative of autochthonous biogenic production, showing no signs of sorting by nekroplanktic drift. Ammonite associations show relatively low values of packing, but relatively high values of stratigraphic persistence. Biostratinomic processes of biodegradation-decomposition are intense. Ammonite shells usually lose the soft-parts, aptychus and periostracum before the burial. Siphuncular tubes are usually disarticulated. Remains of intrathalamous or extrathalamous, encrusting organisms develop preferentially on the shells of taphonic populations of type 2 or 3. The degree of removal and the degree of taphonomic heritage acquire relatively high values. Complete concretionary internal moulds of the body chamber and phragmocone, indicative of low rate of sediment accumulation, are abundant. Remobilization levels are common, often enclosing phosphatic or carbonated concretionary moulds. Pyritic internal moulds are formed only locally. Reelaborated internal moulds show usually disarticulation surfaces with sharp margins. Fragmentary internal moulds can also occur, but bearing no signs of rounding, encrustation or bioerosion, because of the low degree of turbulence near the water/sediment surface. However, concretionary internal moulds and shells can locally be regrouped and imbricated or azimuthally reoriented. Episodes with predominance of background sedimentation give rise to coarsening-upwards recorded associations included in fine grained sediments showing no evidence of basal discontinuity. In contrast, events of turbulence lead to fining-upwards recorded associations included in coarser deposits with an erosive base (Fernández-López, 1997a, figure 15).

INCIPIENT-SHALLOWING TAPHORECORDS

Incipient-shallowing taphorecords represent the first stadium of the shallowing phases developed in carbonate epicontinental platforms. In such great depth conditions, the sea floor of the outer platform remain below the fair weather and the storm wave base levels. The first deposits have wide geographical distribution and are aggradational or scarcely progradational. The increase of terrigenous supply leads to a correlative quick increase of the sedimentation rate, resulting in the development of marly, expanded successions. The rate of sedimentation is high in the deepest areas, but the rate of sediment accumulation can be very variable. Such conditions were

developed in the Castiliane, Aragonese and Tortosa platforms during the
Humphriesianum, Niortense and Garantiana biochrones (Blagdeni, Bacula-
ta, Dichotoma and Subgaranti subchronozones, Bajocian; Fernández-Ló-
pez, 1983, 1985c, 1986, 1987a; Fernández-López and Mouterde, 1985; Fer-
nández-López *et al.*, 1996; Fernández-López and Meléndez, 1995a, 1996).

The totally deluged outer platform, with predominance of softgrounds,
constitutes a homogeneous carbonate ramp that tends to be deeper than se-
veral tens of meters, with relatively stable environments during the phase
of incipient shallowing. Taphonic populations of type 1, 2 and 3, with re-
latively high values of packing and stratigraphic persistence, are formed.
The occurrence of taphonic populations of type 1 is indicative of autoch-
thonous biogenic production, showing no signs of sorting by nekroplanktic
drift. In the areas of greater depth, the successive recorded associations can
be expanded associations, their stratigraphically successive elements re-
presenting contemporary organisms. Biostratinomic processes of biode-
gradation-decomposition can be inhibited by rapid burial. Buried shells
usually lack sedimentary infill in the phragmocone and are preserved as ho-
llow ammonites, still maintaining the soft-parts, periostracum and co-
nnecting rings. Siphuncular tubes are usually articulated. Remains of in-
trathalamous or extrathalamous, encrusting organisms are only developed
on some preserved elements of taphonic populations of type 2 or 3. In the
taphonic populations of type 1, preserved elements lack usually encrusting
organisms or stromatolitic laminae in these distal areas of the platform. In-
ternal moulds can be carbonated or pyritic. Carbonate concretionary inter-
nal moulds are only formed, during the early diagenesis, in areas of mini-
mum sedimentation rate. Reelaborated elements are very scarce or absent.
Accumulated shells may be locally common. The degree of removal can be
variable, but the degree of taphonomic heritage will be from very low to
zero. Signs of abrasion and bioerosion on shells and internal moulds are
very scarce. The septa and wall of the shell can disappear by early disso-
lution, while the periostracum may still remain, giving rise to compressed
elements showing continuous deformation by gravitational diagenetic
compaction. Disarticulated aptychii may be locally common. Ammonite
shells will normally appear dispersed in the sediment, showing no pattern
of imbricated or encased regrouping. Taphosequences and successive as-
sociations of ammonites will not display sharp changes in preservation.

In shallow areas, successive recorded associations of ammonites can be
condensed. Biostratinomic processes of biodegradation-decomposition are
more intense than in deep areas. Sedimentary infilled phragmocones and
signs of encrustation will be more common. Internal moulds can be both car-

bonated, phosphatic or glauconitic. Reelaborated elements are increasingly abundant, whilst accumulated shells will become progressively scarce. The degree of removal and the degree of taphonomic heritage will be increasingly high. Evidence of abrasion and bioerosion may be common both in shells and concretionary internal moulds. Preserved elements can maintain the original volume and form as a result from early cementation, showing no evidence of gravitational deformation by diagenetic compaction. Disarticulated aptychii may be common. Shells and concretionary internal moulds can display imbricated or encased patterns. Taphosequences and successive associations of ammonites will not generally display sharp changes in preservation.

MEDIAN-SHALLOWING TAPHORECORDS

The rate of sedimentation in outer platform environments is generally lower during the phases of median shallowing than during those of incipient shallowing. Early cementation processes may be common in the proximal areas of the platform, though the rate of sediment accumulation may be high in distal areas. Depositional systems show progradational or retrogradational stacking patterns and scarce thicknesses. Carbonate bioconstructions can be also developed during this shallowing phase in the oxygenated and proximal environments, whilst microfilament facies tend to be dominant in the most distal and deepest areas. Conditions of higher turbulence will result in an increase of storms and wave action. Such palaeogeographic conditions were developed in the Castiliane, Aragonese and Tortosa platforms during the Opalinum Biochron (Aalenian; Fernández-López, 1985c; Fernández-López and Gómez, 1990a, 1990b; Goy *et al.*, 1994; Fernández-López *et al.*, 1996), during the Garantiana Biochron and at the beginning of the Parkinsoni Biochron (Tetragona and Acris subchronozones, late Bajocian; Fernández-López, 1985c, 1987a; Fernández-López and Mouterde, 1985; Fernández-López *et al.*, 1996), as well as during the middle Bathonian (Fernández-López *et al.*, 1978; Lardiés, 1990) and the Anceps Biochron (middle Callovian; Sequeiros and Meléndez, 1987; Aurell *et al.*, 1990, 1995; Fernández-López *et al.*, 1996).

Recorded associations of ammonites can still develop in every area of the outer platform during this phase, when the relative sea level can reach some tens of meters of depth. The autochthonous production of ammonite shells may fall down to zero, but the importation of shells can locally give rise to high concentrations. Taphonic populations of types 3 and 2 are generally dominant in these associations. Patterns of distribution of shells

are usually regrouped. Rates of sediment accumulation are high, but the rate of sedimentation can be very variable from some areas to others. Concretionary internal moulds can be calcareous, phosphatic or glauconitic. Accumulated elements are virtually absent. Some associations may show patterns of regrouping and reorientation. Changes in taphosequences are generally sharper than in the previous phase of incipient shallowing.

In proximal areas, condensed associations are common in the base of taphosequences, which can be positive or negative. The degree of removal and taphonomic heritage is higher in the uppermost and most proximal recorded associations. Accumulated element are absent. Reelaborated elements, showing roll and truncational facets, may be locally dominant. Biostratinomic processes of biodegradation-decomposition are usually intense. Ammonite shells commonly lack the soft-parts and aptychus in the body chamber, as well as the periostracum and connecting rings. Among the recorded elements, partial internal moulds of body chamber (*i.e.*, hollow ammonites) are dominant, as a consequence of the high rate of sediment accumulation. Shells and concretionary internal moulds show abundant and diverse remains of encrusting organisms, as well as stromatolitic laminae. Concretionary internal moulds may be carbonated, phosphatic or glauconitic. Silicified concretionary moulds can also be locally formed.

ADVANCED-SHALLOWING TAPHORECORDS

Advanced-shallowing taphorecords represent the last phase of the deepening/shallowing taphocycles. They are formed in environments characterized by low rate of sedimentation. Early cementation processes are common. Progradational units of scarce thickness are developed in distal areas of the platform. These units towards the continent pinch out and develop erosive unconformities. Such palaeogeographic conditions were developed in the Castiliane, Aragonese and Tortosa platforms during the Opalinum Biochron (early Aalenian; Fernández-López, 1985c; Fernández-López and Gómez, 1990a, 1990b; Goy *et al.*, 1994; Fernández-López *et al.*, 1996), during the Parkinsoni Biochron (Bomfordi Subchronozone, late Bajocian; Fernández-López, 1985c, 1987a; Fernández-López *et al.*, 1996), as well as during the Retrocostatum (Bathonian; Fernández-López *et al.*, 1978; Lardiés, 1990), Coronatum and Athleta biochrons (Callovian; Gómez, 1979; Sequeiros, Cariou et Meléndez, 1984; Fernández-López *et al.*, 1985; Sequeiros and Meléndez, 1987; Meléndez, 1989; Aurell, 1990; Aurell *et al.*, 1990, 1995; Lardiés, 1990; Fernández-López and Meléndez, 1995a, 1990b, 1996; Fernández-López *et al.*, 1996).

When the relative rise of sea level ceases or when the relative sea level starts to fall, the preserved associations of ammonites can be limited to the most distal areas of the outer platform or wider areas, depending on the morphology of the sea floor. In these ammonite associations, taphonic populations of type 3, composed either of resedimented or reelaborated elements, are dominant. Biostratinomic processes of biodegradation-decomposition are generally intense during this phase. Ammonite shells lack the soft-parts and aptychus in the body chamber, as well as periostracum. Siphuncular tubes are disarticulated.

In distal areas, the recorded associations of ammonites are dominated by resedimented elements with very variable values of packing and very high values of stratigraphic persistence. The partial internal moulds of the body chamber (*i.e.*, hollow ammonites), indicative of very rapid sedimentary infill and high rate of sediment accumulation, are dominant. Hollow ammonites maintaining their original volume and form also are common, as a result from the low rate of sedimentation and rapid early cementation. Ammonite shells can present microbial laminae, developed during the resedimentation processes, and skeletal remains of very diverse encrusting organisms, indicative of intense and lasting processes of nekroplanktic drift. Positive taphosequences are usually well develop. Reelaborated elements enclosed in the condensed associations found in the base of the parasequences can display different signs of subaerial exposure, erosion and transport, and they can be even older than the previous parasequence.

Ammonite recorded-associations of the most shallow and proximal areas are usually condensed associations of scarce lateral continuity. The successive recorded associations show sharp changes in preservational features. Calcareous, phosphatic or glauconitic concretionary internal moulds showing multiple sedimentary infill phases are dominant among the recorded elements. Calcareous, phosphatic and/or ferruginous, stromatolitic laminae, as well as encrusting organisms (in particular, serpulids, bryozoans and oysters) are generally developed on resedimented shells and reelaborated moulds. Reelaborated internal moulds can show roll and truncational abrasion facets, as well as ellipsoidal abrasion facets or annular furrows. Concretionary internal moulds without septa also are formed by early dissolution during the processes of reelaboration. Preserved elements are usually reoriented and regrouped, forming encased or imbricated patterns during the episodes of smaller rate of sediment accumulation. The recorded associations, in turn, may show normal grading when they are included in sediments deposited by events of turbulence.

MEGASEQUENCES AND SUPERCYCLES

Megasequences or supercycles of second order represent long-term variations, several million years long (over 5 m.y. according to Vail *et al.*, 1991; Rousselle, 1997; over 3 m.y. according to Jacquin and Vail, 1995; 3 to 50 m.y. according to Einsele, 1992; Graciansky *et al.*, 1993; Vera Torres, 1994; over 2.5 m.y. in Reboulet, 1995; 10 to 100 m.y. according to Miall, 1995).

Five deepening/shallowing taphocycles were developed during the Middle Jurassic, in the Castiliane, Aragonese and Tortosa platforms

(Fig. 9): four median-deepening taphocycles (during the early Aalenian, the middle Aalenian-early Bajocian, the Bathonian and the Callovian) and one advanced-deepening taphocycle (during the late Bajocian).

The successive recorded associations of ammonites composing an ideal deepening/shallowing taphocycle can be grouped in two *megataphosequences*, each one of those showing gradual variations in their secondary characters: a *deepening megataphosequence* and a *shallowing megataphosequence* (Fig. 9). Each megataphosequence can comprise one or several taphosequences. The boundary between the shallowing and the deepening megataphosequences, between deepening/shallowing taphocycles, corresponds at most to a registratic gap which is usually associated with a widespread stratigraphic gap of regional extension in the platform. However, an incipient or mean shallowing taphorecord can be followed by a median or advanced deepening taphorecord representing a new megataphosequence and a different taphocycle. The different megataphosequences of the same order should be integrated in a megataphosequence of higher order, on the basis of the amplitude of the registratic gaps and the development of the successive taphorecords, in interpreting the relationships between successive megataphosequences and taphocycles, as well as to ascertain the episodes of maximum deepening.

The major discontinuities in the Middle Jurassic correspond to the middle Aalenian (Murchisonae Biochron) and to the late Callovian (Lamberti Biochron). Two further minor regional discontinuities correspond to the late Bajocian (Parkinsoni Biochron) and to the late Bathonian (Discus

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Fig. 9.–Zonal diagram showing the maximum thickness, the stratigraphic and registratic gaps, condensed sections, expanded sections, condensed associations, types of taphonic populations, taphorecords, taphocycles and megataphosequences of ammonites identified in the Middle Jurassic of the Iberian Basin (Castiliane, Aragonese and Tortosa platforms). SM = shallowing megataphosequence. DM = deepening megataphosequence. TP-1 = taphonic population of type 1. TP-2 = taphonic population of type 2. TP-3 = taphonic population of type 3. IDT = incipient-deepening taphorecord. MDT = median-deepening taphorecord. ADT = advanced-deepening taphorecord. IST = incipient-shallowing taphorecord. MST = median-shallowing taphorecord. AST = advanced-shallowing taphorecord. 2nd PT = peak transgression of second order. 2nd PR = peak regression of second order.

Fig. 9.–Esquema zonal de las potencias, lagunas, secciones condensadas, secciones expandidas, asociaciones condensadas, tipos de poblaciones tafónicas, taforregistros, tafociclos y megatafosecuencias de ammonites identificadas en el Jurásico Medio de las plataformas Castellana, Aragonesa y de Tortosa. SM= megatafosecuencia de somerización. DM = megatafosecuencia de profundización. TP-1 = población tafónica de tipo 1. TP-2 = población tafónica de tipo 2. TP-3 = población tafónica de tipo 3. IDT = taforregistro de profundización incipiente. MDT= taforregistro de profundización media. ADT = taforregistro de profundización avanzada. IST = taforregistro de somerización incipiente. MST = taforregistro de somerización media. AST = taforregistro de somerización avanzada. 2nd PT = pico transgresivo de segundo orden. 2nd PR = pico regresivo de segundo orden.

Biochron). Ammonite taphorecords of the Opalinum Biozone represent the
last terms of a shallowing megataphosequence which started in the late To-
arcian. Three deepening megataphosequences were developed during the
Murchisonae-Niortense biochrones (middle Aalenian-late Bajocian), Zig-
zag-Progracilis biochrones (Bathonian) and Bullatus-Gracilis biochrones
(Callovian).

The maximum deepening and the maximum relative sea-level rise
were reached during the Niortense Biochron (late Bajocian). The episodes
of maximum shallowing, that represent maximum relative sea-level fall,
correspond to the middle Aalenian (Murchisonae Biochron) and of the
late Callovian (Lamberti Biochron) discontinuities. The ammonite recor-
ded-associations comprised between these two biochrons represent a su-
pertaphocycle of second order in the Iberian Basin. The development of
this second-order supercycle was probably influenced by global eustatic
changes (cf. Hallam, 1988; Haq *et al.*, 1988; Norris & Hallam, 1995).
However, regional tectonic processes could compensate the effects of eus-
tatic changes in some epicontinental platforms (cf. Fernández-López & Gó-
mez, 1990; Underhill & Partington, 1993; Aurell *et al.*, 1995; Fernández-
López *et al.*, 1996).

Taphocycles and megataphosequences established with ammonites
enable the identification of sedimentary cycles of third-order (the so-call
transgressive/regressive cycles) and megasequences of second order res-
pectively. The development of such megataphosequences, as well as the
development of the sedimentary cycles of third order, depends on the re-
lative changes of the potential of accommodation and on the sediment
production. The shallowing megataphosequences will be more distinctive
as far as the accommodation space generated by eustatic fluctuations and
subsidence will be lower and the sediment supply will be higher. The dee-
pening megataphosequences, in turn, will be more distinctive when both
the accommodation space and the sediment production are higher. The
identification of deepening/shallowing taphocycles is of utmost impor-
tance in interpreting the transgressive/regressive cycles of Mesozoic epi-
continental platforms, when no evidence of the coastal onlap can be ob-
served but the fossiliferous sediments of outer platform are widely
developed.

On the other hand, as the development of third-order depositional se-
quences and systems tracts or depositional systems depends on the deve-
lopment of the third-order transgressive/regressive cycles, the identification
of deepening/shallowing taphocycles can be also used to recognize third-
order sequences and depositional systems. Median and advanced-deepe-

ning taphorecords are found in aggradational and retrogradational sequences respectively. Incipient and mean-shallowing taphorecords, in turn, are found in infilling sequences and in progradational sequences respectively. In the same way, elementary stratigraphic sequences and parasequences can be identified and delimited on the basis of taphonomic criteria, such as elementary taphonomic sequences and taphosequences.

From the palaeoecological point of view it is worthy of note the slight diachronism observed between the deepening/shallowing taphocycles established by ammonites, the third-order transgressive/regressive cycles and the second-order supercycles developed in shallow platforms with respect to the relative abundance of ammonite taphonic populations of type 1 (Fig. 10). The maximum abundance of taphonic populations of
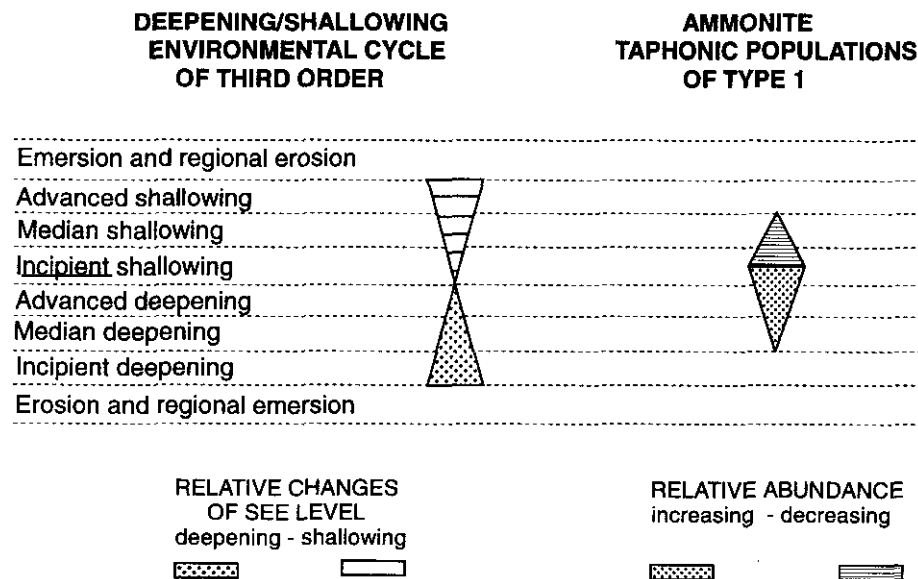
DEEPENING/SHALLOWING ENVIRONMENTAL CYCLE OF THIRD ORDER	AMMONITE TAPHONIC POPULATIONS OF TYPE 1
Emersion and regional erosion	
Advanced shallowing	
Median shallowing	
Incipient shallowing	
Advanced deepening	
Median deepening	
Incipient deepening	
Erosion and regional emersion	

RELATIVE CHANGES OF SEE LEVEL deepening - shallowing	RELATIVE ABUNDANCE increasing - decreasing

Fig. 10.–Diachronism observed between the deepening/shallowing taphocycles established by ammonites and the relative abundance of taphonic populations of type 1 in carbonate epicontinental platforms. The maximum abundance of taphonic populations of type 1 is not recorded in the sediments formed during the advanced-deepening phase but in the sediments of the incipient-shallowing phase, when marine environments in the platforms reached the maximum values of depth and stability.

Fig. 10.–Diacronismo observado entre los tafociclos de profundización/somerización establecidos con ammonites y la abundancia relativa de poblaciones tafónicas de tipo 1 en plataformas epicontinentales carbonáticas. La máxima abundancia de poblaciones tafónicas de tipo 1 no se encuentra en los sedimentos formados durante las fases de profundización avanzada sino en los sedimentos de somerización incipiente formados cuando los ambientes de plataforma alcanzan los máximos valores de profundidad y estabilidad.

type 1 is not recorded in the sediments formed during the advanced-deepening phase but in the sediments of the incipient-shallowing phase, when marine environments in the platforms reached the maximum values of depth and stability. This fact also shows the greater capacity of response of the biosedimentary systems to relative changes of sea level, with respect to the eudemic populations of ammonites.

CONCLUSIONS

Recorded associations of ammonites formed in carbonate epicontinental platforms can be grouped on the basis of taphonomic criteria in taphorecords of different categories: incipient, mean or advanced-deepening, as well as incipient, mean or advanced-shallowing. On the basis of the changes in the preservation state of the successive recorded association of ammonites, it is possible to distinguish taphocycles, megataphosequences and supertaphocycles resulting from relative changes of sea level. A deepening/shallowing taphocycle comprises two or more successive recorded associations showing cyclical variations in their secondary characters, as a result from a cycle of relative change of sea level. A deepening/shallowing taphocycle comprises two megataphosequences: a deepening and a shallowing one. The successive megataphosequences of the same order should be integrated in a megataphosequence of higher order to interpret the maximum deepening episodes. Deepening/shallowing taphocycles and megataphosequences established by means of ammonites enable the identification of depositional sequences of third order and stratigraphic supercycles of second order respectively.

The identification of deepening/shallowing taphocycles is of utmost importance in interpreting the transgressive/regressive cycles of Mesozoic epicontinental platforms, when no evidence of the coastal onlap is observed but the fossiliferous sediments of outer platform are widely developed. Using the palaeontological data in sequence stratigraphy analysis in shallow marine platforms requires the prior identification of taphonomic sequences and cycles. The successive recorded associations composing several successive taphorecords generated in different environments can form a condensed association enclosed in a single stratigraphic level.

Five environmental deepening/shallowing cycles were developed in the Castiliane, Aragonese and Tortosa platforms during the Middle Jurassic: four median-deepening cycles (during the early Aalenian, the middle Aalenian-early Bajocian, the Bathonian and the Callovian) and one advanced-

deepening cycle (during the late Bajocian). Ammonite taphorecords of the Opalinum Biozone represent the last terms of a shallowing megataphosequence beginning in the late Toarcian. Three deepening megataphosequences were developed during the Murchisonae-Niortense biochrones (Aalenian-late Bajocian), Zigzag-Progracilis biochrones (Bathonian) and Bullatus-Gracilis biochrones (Callovian). The maximum deepening and the maximum relative sea-level rise were reached during the Niortense Biochron (late Bajocian). The sediments of the Polygyralis Subchronozone belong to a second-order peak transgression. Episodes of maximum shallowing during the Middle Jurassic, representing maximum relative sea-level fall, correspond to the discontinuities of the middle Aalenian (Murchisonae Biochron) and late Callovian (Lamberti Biochron). The Murchisonae and Lamberti biochrons conform two second-order peak regressions. The recorded associations of ammonites comprised between these two biochrons represent a second-order supertaphocycle in the Iberian Basin. The sediments of the Middle Jurassic between these two stratigraphic discontinuities, from the middle Aalenian until the upper Callovian, also represent an stratigraphic supercycle of second order in the Iberian Basin.

ACKNOWLEDGEMENTS

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