Journal of
Iberian Geology
AN INTERNATIONAL PUBLICATION OF EARTH SCIENCES

Facies development of ODP Leg 173 sediments and comparison with tectono-sedimentary sequences of compressional Iberian plate margins – a general overview

La sucesión sedimentaria del ODP Leg 173 y su comparación con las secuencias tectonosedimentarias de los márgenes compresivos de la Placa Iberica: revisión general

H.J. Wallrabe-Adams[1], A.V. Altenbach[2], A. Kempe[2], W. Kuhnt[3], P. Schaefer[3]

[1]*Dept. of Geosciences, Univ. Bremen, e-mail, Germany, hwallrabe@uni-bremen.de,*
[2]*Dept. of Palaeontology and Historical Geology, Ludwig-Maximilians Univ. München, Germany,*
a.altenbach@lrz.uni-muenchen.de / andre.kempe@nanogeology.de
[3]*Inst. of Geosciences, Univ. Kiel, Germany, wk@gpi.uni-kiel.de / ps@gpi.uni-kiel.de*

Abstract

Data from several DSDP/ODP-Legs, submersible dives and dredge holes contributed to the knowledge of the general sedimentary development of the northern part of the western Iberian Margin (Galicia Bank, Iberian Abyssal Plain). Most recent data on the Upper Jurassic to Lower Tertiary sedimentary succession were collected during ODP-Leg 173. These results record the development of the margin from the pre-rifting shallow-marine shelf state in the Tithonian, the clastic rifting deposits related to the tilting of the fault blocks developed by crustal thinning, and the first calcareous marine sediments of the Lower Cretaceous which were followed by Cretaceous to early Tertiary deep-marine clays and turbidites. Nearly continuous subsidence characterises this margin until the upper Miocene.

A comparison of a simplified Leg 173 sedimentary sequence with other Iberian margin successions (Lusitanian Basin, Ortegal Spur, Basque-Cantabrian Basin, Pyrenees, Iberian Chain, Betic Cordillera) shows that most facies similarities exist with the Subbetic sediment series of the central Betic Cordillera. In spite of large differences in bio- and lithofacies in other areas, synchronous tectonic events make it possible to correlate tectono-sedimentary sequences around Iberia. The major tectonic events recognisable in nearly all areas are the rifting phase in the late Jurassic (except in the Betic Cordillera), the break-up of the North Atlantic ('break-up unconformity') in the upper Early Cretaceous and the Eurasian Iberian plate collision in the late Eocene (Pyrenean orogenic phase, except in the Iberian Abyssal Plain). Two minor events are less time equivalent and restricted to the northern Iberian Plate (Galicia Bank to Iberian Chain) leading to several unconformities in the Turonian-Coniacian and Maastrichtian-Danian time intervals. The orogenic phase stopped the development at the southern, eastern and north-eastern margins, continuous sedimentation took place at the western and north-western margins.

Keywords: Ocean Drilling Program, Leg 173, Iberian margins, sedimentary cycles, tectonics, Spain

Resumen

Datos procedentes de varios DSDP y ODP Legs, sumergibles y redes de arrastre han contribuido al conocimiento de la evolución sedimentaria general de la parte norte del Margen Ibérico Occidental (Banco de Galicia, llanura abisal Ibérica). De igual modo, datos de la sucesión sedimentaria del Jurásico Superior - Terciario Inferior fueron obtenidos mediante el ODP-Leg 173. Todos estos datos

muestran una etapa pre-rifting de plataforma marina somera durante el Titónico, depósitos clásticos relacionados con movimientos de estiramiento cortical, y la primera etapa de sedimentación marina de tipo calcáreo durante el Cretácico Inferior que fue seguida por otra etapa con depósitos marinos profundos de tipo turbidítico durante el Cretácico y primeras etapas del Terciario. En conjunto, una subsidencia casi continua caracteriza esta margen hasta el Mioceno Superior.

Una comparación simplificada realizada con la secuencia sedimentaria obtenida del leg 173 y otras sucesiones del margen Ibérico (Cuenca Lusitana, Ortegal Spur, Cuenca Vasco-Cantábrica, Pirineos, Cadena Ibérica, Cordillera Bética) muestra que existen fuertes semejanzas con la serie sedimentaria subbética, en la Cordillera Bética central. A pesar de las diferencias significativas en bio- y litofacies en otras áreas, eventos tectónicos sincrónicos permiten correlacionar secuencias tectono-sedimentarias en el entorno de la Península Ibérica. Los eventos tectónicos mayores reconocibles en casi todas las áreas son la fase de rifting durante el Jurásico tardío (excepto en la Cordillera Bética), el 'break-up' del Atlántico Norte ('break-up unconformity') durante el final del Cretácico Inferior, y la colisión de las placas Euroasiática e Ibérica durante el Eoceno tardío (fase orogénica de los Pirineos, excepto en la llanura abisal ibérica). Se observan dos eventos menores que son menos sincrónicos y que están restringidos al norte de la Placa Ibérica (Banco de Galicia - Cadena Ibérica), ocasionando varias disconformidades durante los intervalos Turoniense-Conianiense y Maastrichtiense-Daniense. La fase orogénica paró la sedimentación en los márgenes sur, este y noreste, mientras la sedimentación fue continua en los márgenes occidental y noroccidental.

Palabras clave: Ocean Drilling Program, Leg 173, márgenes ibéricos, ciclos sedimentarios, tectónica, España

1. Introduction

The western Iberian margin is a passive non-volcanic rifted margin with a long rifting history preceding the separation of Iberia from the Grand Banks of North America in the Early Cretaceous (Pinheiro *et al.*, 1996). After the complete separation eastward drift started. Thinning of the continental crust by the formation of tilted fault blocks took place forming a transition zone between the new oceanic crust and the normal continental plate. Continuous cooling of the newly formed lithosphere led to further subsidence and deposition of sediments covering both the new oceanic crust and the continental fault blocks.

Increasing knowledge of the geological development of the western Iberian margin by the results of the Ocean Drilling Program (ODP), especially Legs 149 and 173 (Whitmarsh *et al.*, 1996; Whitmarsh *et al.*, 1998; Beslier *et al.*, 2001), and other works during the last decade, enable us to add the geological history of this part of the margin to the other parts of Iberia exposed on land. Because the structural basement of the Ocean Continent Transition Zone (OCT) was the major target of ODP Leg 173, overlaying sediments were cored from approximately 150m above the basement. Therefore, ODP Leg 173 enlarged the information on the sediment cover of the continental and oceanic basement in the Iberian Abyssal Plain (IAP) by recording the depositional sequences from the late Jurassic (Tithonian) to early Tertiary (Eocene), the most important stratigraphic interval in the structural development of the Iberian plate. But because drilling took place on the top of basement highs, mostly tilted blocks of continental crust, the interesting older and thick sequences in the morphological deeps between the blocks were still unknown (Fig. 1).

With the onset of the initial continental rifting phase in the Triassic, the Iberian plate acted as an independent small plate at the transition zone between the western Tethys and the growing North-Atlantic and the large blocks of Africa and Europe. During the plate motion, which was a combination of eastward movement and rotation, the different margins were influenced by different tectonic regimes, except the western margin, which has been under extensional stress ever since. The tectonic structures and sedimentary sequences at each margin reflect the structural development due to plate motion. Tectono-sedimentary sequences separated by unconformities allow correlating these tectonic and sedimentary events around Iberia.

Aims of this study are:

(1) to describe the basic results of Leg 173 (and relevant data of Leg 149),

(2) to compare the new results of the western Iberian margin with the tectono-sedimentary development on the different Iberian margins as a consequence of plate motion.

In other words, are similarities expected between the different sedimentary basins around Iberia, can they be correlated, and does they reflect the plate tectonic evolution of Iberia respectively the Central North Atlantic/Western Tethys realm?

It is impossible to present here the complex geology of each margin basin. Instead relatively complete generalised successions, showing numerous tectono-stratigraphic units are used as 'type sections' for correlation. We not intend to present a detailed basin correlation.

A simple way to compare completely different sedimentary environments for linking the ODP profiles with land based profiles from Iberia, is to implement tectono-sedimentary phases a continental margin of any
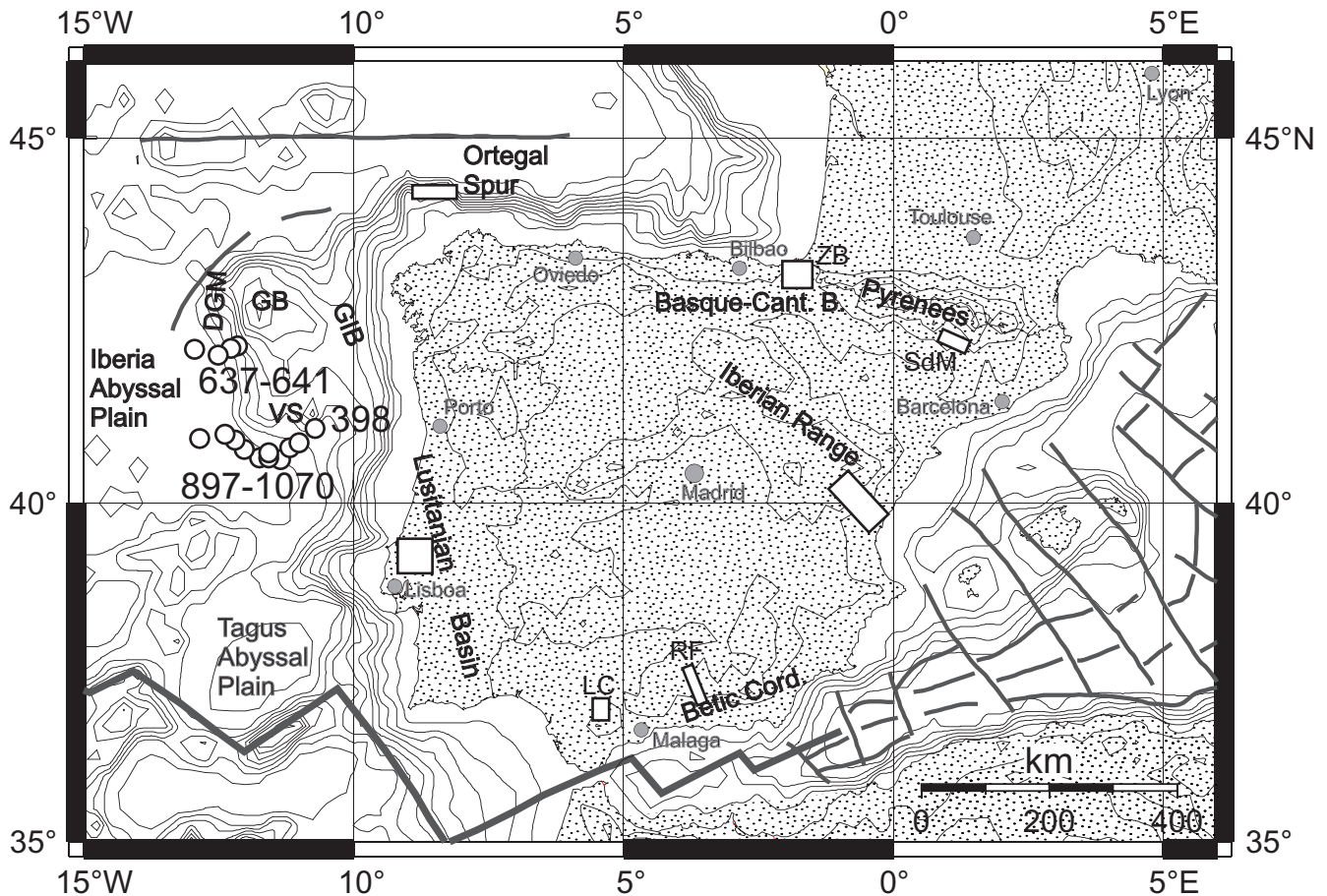
Fig. 1.–Iberia and the surrounding seas with the northwest Iberian DSDP/ODP-Sites and terrestrial study areas. SdM = Sierra de Montsec, RF = Rio Fardes, LC = Las Cabras, ZB = Zumaya Basin, DGM = Deep Galicia Margin, GB = Galicia Bank, GIB = Galicia Interior Basin, VS = Vigo Seamount.

Fig. 1.–Iberia y áreas circundantes con las localizaciones de DSDP/ODP, y áreas terrestres estudiadas: SdM = Sierra de Montsec, RF = Rio Fardes, LC = Las Cabras, ZB = Cuenca de Zumaya, DGM = Deep Galicia Margin, GB = Banco de Galicia, GIB = Cuenca interior de Galicia, VS = Plataforma de Vigo

microplate may pass through, and which define the tectonic background for related sedimentary deposits. The following five simplified phases (based on the 'Wilson cycle', Wilson, 1966) are solely based on the sedimentary information, reducing the complex regional cycles to the crucial information that is found in every sediment record:

(1) Pre-rift phase. This first phase is characterised by its tectonic stability and continuous sedimentation. Facies changes occur only slowly and without drastic changes. Around Iberia sediments of this phase are typically platform or ramp carbonates.

(2) Rifting (extension) phase. The rifting phase comprises the fracturing of the rigid crustal plate and its subsequent extension. The evolution of grabens and extreme subsidence is typical, but local crustal uplift can although induce increasing relief. Major abrupt facies changes, high sedimentation rates, hiatuses and unconformities characterise this phase. The resulting sediments range

from typical continental clastics (e.g. breccias, olisthostroms, mass flows) to hypersaline sediments, evaporates and shallow marine deposits.

(3) Drift (subsidence) phase. As soon as the production of oceanic crust has started, tectonic activity decreases and thermal subsidence dominates. The following marine sediments cover faults and fill grabens. The facies often shows increasing depths of deposition (deepening upward sequences), sometimes oxygen depleted to anoxic environments ('black shales') occur.

(4) Inversion phase. Beginning compression may stop subsidence and invert extensional structures. First uplift causes the decrease of deposition depth. Changes in sedimentation often induce higher clastic input. Inversion may resemble the following compressional phase but tectonic movements are less intensive compared to the main orogenic phase.

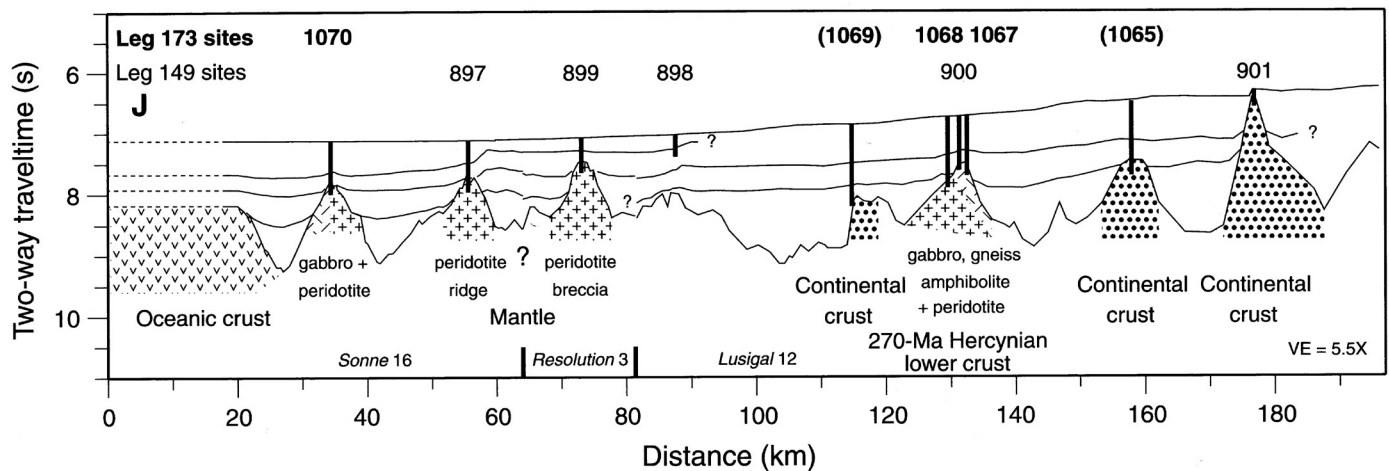(5) Compressional (orogenic) phase. Strong tectonic activity produces hiatuses and coarse clastics. Olist-

Fig. 2.–Composite west to east (from left) cross section through legs 149 and 173 drill sites with a summary of the basement cores. Sites in parentheses are offset a short distance from the profile. J = magnetic Anomaly J. The segments of the Sonne 16, JOIDES Resolution 149/3, and Lusigal 12 seismic reflection profiles used to construct the cross section are indicated (Beslier *et al.* 2001).

Fig. 2.–Sección compuesta oeste-este (desde la izquierda) a través de los legs 149 y 173 con un resumen de los testigos del basamento. Los sitios entre paréntesis están levemente desplazados del perfil. J = anomalía magnética J. Se indican los segmentos de los perfiles de reflexión sísmica Sonne 16, JOIDES Resolution 149/3, y Lusigal 12 que se han usado para construir la sección (Beslier *et al.* 2001).

hostromes, turbidites (flysch) and conglomerates are typical. Subduction related volcanism may occur.

The sedimentary records from around Iberia were interpreted according to these 'Wilson cycles' and compared afterwards.

2. Leg 173 sediments and West-Iberian margin development

2.1. Iberian Abyssal Plain

2.1.1. Facies development of Leg 149/173 sediments, litho- and biostratigraphy

During ODP Leg 173 five holes (1065A, 1067A-1070A; Whitmarsh *et al.*, 1998; Beslier *et al.*, 2001) were drilled in the Iberian Abyssal Plain completing an east-to-west transect of five previously drilled sites (897-901, ODP Leg 149). This transect runs roughly perpendicular to the ocean continent transition (OCT) zone at the western Iberian margin south of the Western Banks (Fig. 1). The cored sediments of Leg 173 range from Lower Cretaceous to Middle Eocene. Some older sediments (Jurassic) build the top of tilted blocks and belong to the continental pre-rift basement (1065A).

Pre-rift rocks have been drilled in Holes 1065A and 1069A forming the top of tilted blocks (Fig. 2). In Hole 1065A Tithonian dark greenish grey to medium dark grey siliciclastic rocks, siltstones and claystones with high content of organic matter (plant debris), were drilled over more than 300m. Rare benthic foraminifers and nan-

nofossils, burrows of *Chondrites*, the occurrence of terrestrial plant debris, and rare current related sedimentary structures such as cross bedding suggest a marine dys-aerobic environment, possibly a shelf basin below wave base (Shipboard Scientific Party, 1998a).

Generally, mass flow deposits (cataclasites, talus-breccias, debris flows) rest directly upon the continental or oceanic basement. These sediments possibly represent a tilting phase (rifting phase) and may be part of the thick sequences filling the deep depressions between the tilted blocks (Fig. 2). These syn-rift deposits are unconformably overlain by marine calcareous muds, consisting of nannofossil oozes and nannofossil chalks, ranging in age between Berriasian – lower Valanginian (Hole 1069A), Valanginian – Barremian (Hole 1068A) and late Aptian (Hole 1070A). At Hole 1070A these sediments are followed by an Upper Cretaceous sequence of coloured clays, silty clays, silts and sands (Unit III, Albian/Cenomanian-Paleocene; Shipboard Scientific Party, 1998b). Unit III has also been drilled at Sites 897 and 899 of Leg 149 (Whitmarsh *et al.*, 1996). The upper part of Unit III is comparable to the deep-sea clays of the following Unit II but lacks the typical turbidite layers so that there is no sharp and distinct boundary between the two Units. All other sites show a hiatus up to the Maastrichtian.

The following Maastrichtian to middle Eocene sequences (Holes 1067A-1070A) consist of red deep marine claystones (sub-CCD) intercalated by calcareous and siliciclastic turbidites and bottom-current influenced deposits. Whereas the sub-CCD claystones show no

lithological change throughout the cored sequence, a significant change in the composition of turbidites occurs in the early Eocene. From the Maastrichtian to the Paleocene/Eocene turbidites are dominated by shallow-water carbonate particles (wackestones and grainstones containing large foraminifers, individual shallow water foraminifers, bryozoans, algae, reworked shallow-water carbonate, calcarenites) with more or less terrestrial influence (quartz). After the Eocene an increasing number of turbidites consist mainly of quartz and mica with minor carbonate (calcareous siltstones) (Wallrabe-Adams, 2001). Sedimentation during Oligocene to Miocene time is characterised by contourites (Milkert *et al.*, 1996a). After the short upper Miocene compressional phase Pliocene to Pleistocene sedimentation is dominated by turbidites (Milkert *et al.*, 1996b).

Biostratigraphic investigations have been carried out on the Upper Cretaceous to Paleogene sub-CCD clays from Holes 1067A, 1069A, and 1070A using benthic agglutinating foraminifera (Kuhnt and Urquhart, 2001). Hole 1069A deep-sea clays range from Late Campanian-Maastrichtian (*Caudammina gigantea*-Zone) to middle Eocene. The upper part of Core 1069A-12R contains an agglutinating foraminifer (*Spiroplectammina spectabilis*), which is characteristic for a microfauna occurring directly after the K/T boundary event. The base of the Eocene is characterised by a maximum of *Glomospira,* a maximum that is a typical stratigraphic marker in the North Atlantic and the western Tethys (e.g. Kaminski *et al.* 1996). The Upper Cretaceous/Paleogene foraminifer record of Hole 1070A seems to be more complete than at other sites: Turonian-Santonian assemblages with *Uvigerinammina jankoi* and Campanian-Maastrichtian assemblages have been found. Hole 1067A (cores 4 and 5) contain Tethyan middle Eocene assemblages with well-preserved typical *Reticulophragmium amplectens*, to our knowledge the first occurrence of these typical forms within the abyssal Atlantic. This fact proves a deep-water connection between the western Tethys and the eastern North Atlantic during the Paleogene through a widely opened Gibraltar seaway, with an outflow of Tethyan deep-water into the North Atlantic.

Palaeobathymetric positions of some localities along the western and southern Iberian margin have been reconstructed using benthic foraminifers (Fig. 3). This reconstruction indicates the partly similar depositional environments at the western and eastern Iberian margins.

2.1.2. Tectonics and subsidence

Tectonic movements of the different segments of the West Iberian Margin (Western Banks, Galicia Internal Basin, Iberian Abyssal Plain) strongly influenced pal-

aeodepth and environment and contribute to regional and local different sedimentation. The general development is governed by the main rifting episodes in Triassic-Liassic, Late Jurassic-Early Cretaceous, and Aptian-Albian times and slight compressional movements during the Late Cretaceous-Eocene and in the Oligocene-Miocene (Réhault and Mauffret, 1979). Generally it is difficult to give a subsidence history because the drilled sediments lie on top of tilted blocks and not in between the blocks and therefore are completely post-rift. Additionally there is no evidence for thick syn-rift sediments in the Iberian Abyssal Plain (Wilson *et al.*, 1996) in contrast to the Deep Galicia Margin (Moullade *et al.*, 1988).

Possible emersion took place between the late Tithonian and early Valanginian as suggested by a piece of strongly oxidized barren sandy claystone (173-1065A-7R, CC, Shipboard Scientific Party, 1998a). This interpretation corresponds with a contemporaneous emersion described by Loreau and Cros (1988) at the Deep Galicia Margin (ODP Site 639).

Beside these uncertain early (?local) uplifts, some steps in subsidence between 150 Ma and 114 Ma and the following "continuous" deepening characterises the western Iberian margin (Moullade *et al.*, 1988). The palaeodepth as indicated by lithology of Leg 173 sediments and the change in the depth of the CCD (Tucholke and Vogt, 1979), supports a rapid subsidence between the Tithonian (~200m water depth) and the lowermost Cretaceous in order of 2500 to 4000m (Table 1). Wilson *et al.* (1996) dated the main rifting event forming the Iberia Abyssal Plain topography as late Tithonian to Berriasian (140 to 134 Ma).

Local differences in subsidence in the Western Banks and the basins are responsible for the development of local sediment facies. ODP Site 398 was located in a branch of the Galicia Interior Basin. Rapid subsidence below the CCD during the Barremian to Cenomanian, initiated the deposition of 'black shales' (Albian) and the deposition of reworked sediment from surrounding highs and from the adjacent continent. A comparable development occurred at the Deep Galicia Margin (ODP Site 641).

Due to the rising CCD since the Hauterivian and the relatively constant level of 2500 to 3000 mbsl until the Campanian (Tucholke and Vogt, 1979) the observed nannofossil chalk points to a palaeodepth of Site 1070 during this time interval much shallower than today. Because the site was located only 15 km east of magnetic anomaly J (slightly older than anomaly M0 = 118 my = lower Aptian = beginning of seafloor spreading between Newfoundland and Iberia), it seams that Site 1070 was located near or possibly at the spreading axis which means near or on the flank of the early mid ocean ridge. This may be
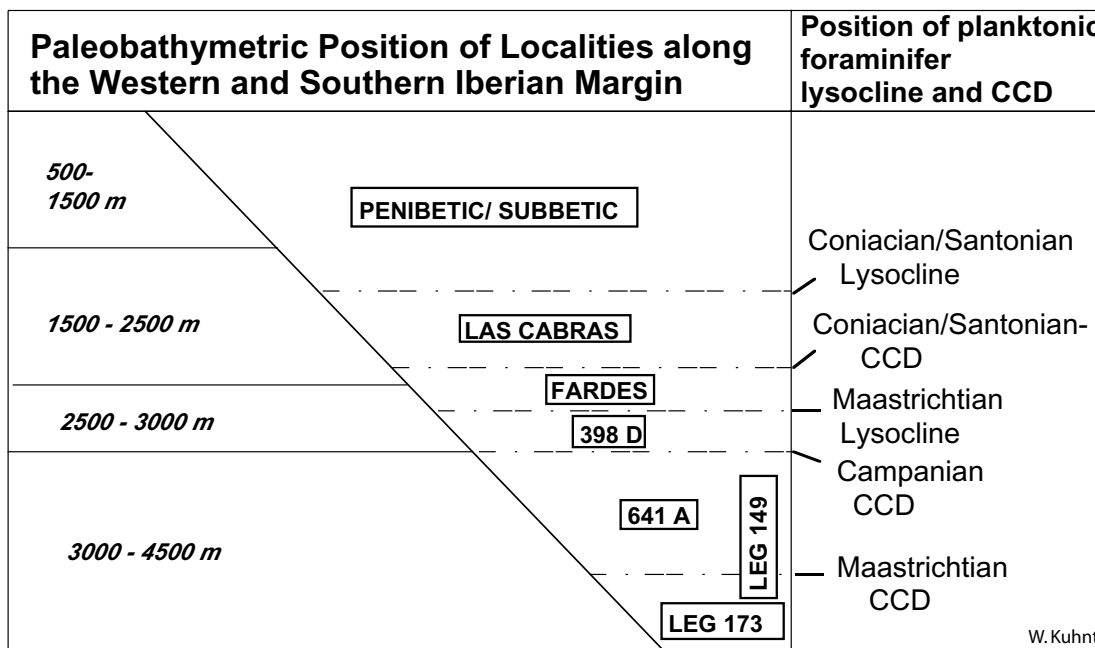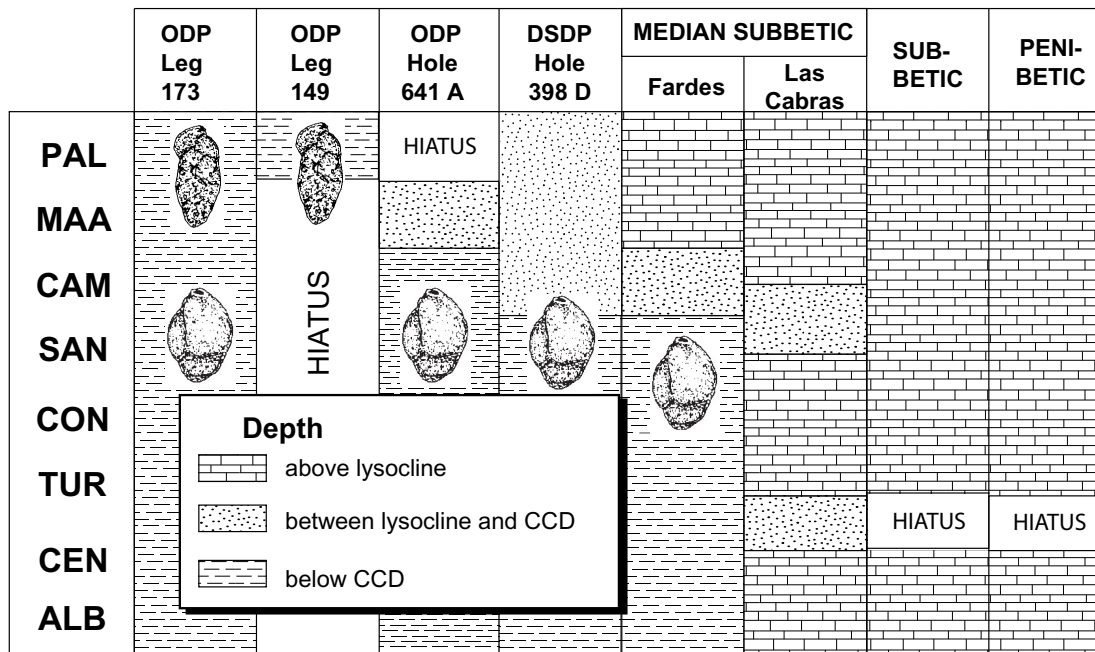
Fig. 3.–Depositional depth of western (DSDP/ODP sites) and southern Iberian margin. Location see Figure 1. For details see Kuhnt and Urquhart (2001).
Fig. 3.–Profundidad de sedimentación en los márgenes ibérico occidental (posiciones DSDP/ODP) y meridional.

supported by the lithology of Unit III which consist of red-brown clay, silt and sand with common volcanic particles and Mn-micronodules and follows the nannofossil chalk (Shipboard Scientific Party, 1998b).

2.2. West Iberia margin

According to Pinheiro *et al.* (1996) the western Iberia Margin is built of several structural features: the main structural highs of the Deep Galicia Margin (the western shelf edge of the Galicia shelf), the Western Banks (including the Galicia Bank, and the Vasco da Gama, Vigo, and Porto seamounts), and the graben structures of the Galicia Interior Basin, the Porto Basin and the Lusitanian Basin (Fig. 1).

Deep Galicia Margin was investigated by ODP Leg 103 with five sites (637-641, Boillot *et al.*, 1988), submersible dives (Boillot *et al.*, 1988a; Mamet *et al.*, 1991)

Biostratigraphic age	Lithology	Site-Cores	Coredepth* (mbsf)	Waterdepth (m)	Palaeodepth (m)
Miocene	Nannofossil chalk	1065A-1R to -6R	309	4770	<4500
Tithonian	Silty claystone	1065A-7R to -35R	>309	4770	<200
Late Campanian-Eocene	Brown claystone with turbidites	1068A-1R to -15R	853	5044	>4000
Maastrichtian-Eocene	Brown claystone with turbidites	1069A-1R to -16R	865.5	5075	>4000
Berriasian-Valanginian	Nannofossil chalk	1069A-16R	868	5075	<4000
Paleocene/Eocene	Brown claystone, rare turbidites	1070A-1R to -3R	619	5322	>4000
Upper Cretaceous (Unit III)	Silty claystone Silt/sandstones	1070-3R to -7R	658	5322	>2500
Aptian	Nannofossil chalk	1070A-7R	658.4	5322	<3000

Notes: * = rounded; mbsf = meters below sea floor

Table 1.–Estimation of palaeo-waterdepth of Leg 173 cores (except Hole 1067A) by lithology and CCD-curve (Tucholke and Vogt, 1979). Biostratigraphy according to Whitmarsh *et al.* (1998) and Kuhnt and Urquhart (2001; Sites 1069, 1070).

Tabla 1.–Estimación de la paleobatimetría del Leg 173 (excepto sondeo 1067A) según litología y curva-CCD (Tucholke y Vogt, 1979). Bioestratigrafía según Whitmarsh *et al.* (1998) y Kuhnt y Urquhart (2001; Posiciones 1069, 1070).

and dredge sites (Dupeuble *et al.*, 1987; Groupe Galice, 1979). At the southern margin of the Western Banks one site was drilled by DSDP Leg 47b (Site 398, Sibuet *et al.*, 1979), located south of Vigo Seamount and northeast of Site 901, as well as some dredge sites exist (Dupeuble *et al.*, 1987). The basement of the West Iberia Margin is continental (Hercynian crystalline rocks, volcaniclastic and sedimentary rocks; Mamet *et al.*, 1991) overlain by upper Jurassic to lowest Cretaceous limestones, which are isochrone with the siliciclastic deposits of the Iberian Abyssal Plain crustal blocks (Sites 901, 1065).

2.2.1. Vigo Seamount

South of Vigo Seamount dredged Tithonian limestones consist of partly dolomitized pre-rift platform carbonates deposited in a shelf environment, foraminiferal and algae bearing limestones of an inner shelf, and micritic Calpionellid limestone deposited in deeper environments probably on the deep shelf or upper slope (Dupeuble *et al.*, 1987). At Site 398 a succession from Hauterivian to recent was drilled. It starts with pelagic (above CCD) nannofossil limestones, marlstones and siltstones, followed by turbiditic sand and siltstones slumped beds or debris flows (e.g. with reworked Calpionellid limestones) interbedded with dark shales (Réhault and Mauffret, 1979). Separated by an unconformity, dark sub-CCD claystones ('black shales') of Albian age and upper Albian to lower Cenomanian marlstones with dark claystones have been deposited (Bourbon, 1979). The Upper Cretaceous to lower Paleocene is sharply separated from the footwall by an unconformity. At the base, red zeolitic sub-CCD claystones occur, overlain by pelagic carbonates deposited above CCD. From the Paleocene to Qua-

ternary a rhythmic turbiditic sequence of siliceous marly nannofossil chalk and mudstones with slumps, mud, and debris flows was deposited. An unconformity between the Oligocene and the Miocene is marked by slump deposits. Since the Miocene sedimentation changed to marly nannofossil chalks and foraminiferous nannofossil ooze showing signs of the influence of bottom currents and cyclic sedimentation patterns (Réhault and Mauffret, 1979). One hiatus is noted in the lower Eocene and two in the Miocene.

2.2.2. Deep Galicia Margin

The drilled Deep Galicia Margin sediment successions of Sites 637 to 641 start in the Tithonian with limestones containing sandstone and claystone interbeds followed by dolomitized platform carbonates with marly beds as well as low-relief biohermal mounds and overlain by Early Berriasian sucrosic dolomite possibly deposited as shallow marine echinoid-ooid-skeletal grainstone and packstone. These dolomites were unconformably overlain by middle early Valanginian nannofossil marlstone with calpionellids and very low amounts of foraminifers (Jansa *et al.*, 1988). From the Valanginian to Hauterivian, sandstone and claystone turbidites and, in the later Hauterivian, slumped nannofossil marlstones were deposited. Separated by an unconformity, marlstone/claystones with microturbidite layers of Late Barremian to Early Aptian age and marlstones with conglomerate (clasts of shallow water limestone) of Upper Aptian follow. Overlaying Albian black and dark-green laminated claystones ('black shales') succeeded to calcareous clay and marl in the Upper Albian and Cenomanian, and Cenomanian to Maastrichtian brown clay (Boillot *et al.*, 1988). Late

Miocene to Pleistocene nannofossil ooze unconformably overlay these brown clays. The deposits of the Galicia margin were slightly deformed by tectonism related to the ongoing plate collision between Africa and Eurasia. This process is still active (Muñoz *et al.*, 2003).

2.2.3. Lusitanian Basin

The Lusitanian Basin is the southern onshore prolongation of the Porto and Internal Galicia Basins. Boreholes and outcrops in the Lusitanian Basin prove the rifting and subsidence history of the central section of the western Iberian Margin. Four main rifting episodes led to unconformities separating sedimentary sequences (Wilson *et al.*, 1989; Hiscott *et al.*, 1990, Pinheiro *et al.*, 1996). Rifting started in the Late Triassic to Early Jurassic (Alves *et al.*, 2002) reactivating the tectonic features of the Hercynian basement. This rift was filled with red fluvial sediments overlain by dolomites and evaporites. The following formations up to the Callovian include alternating limestone/shale deposits and shallow water limestones.

The second unconformity in the lower Oxfordian separates the Oxfordian to Berriasian sediment succession, starting with lacustrine carbonates and anhydrite (Leinfelder and Wilson, 1998). The following marginal to fully marine development is shown by a series of carbonates and siliciclastics. This development differs in the southern and northern parts of the Lusitanian Basin and smaller subbasins (Wilson *et al.*, 1989). With an unconformity in the Berriasian, fluvial siliciclastic sandstones and coarser sediments interfingering with shallow water carbonates and shales characterise the Neocomian (Berriasian to Early Aptian). Again fluvial sandstones were deposited after an Early Aptian unconformity, later on (since the Albian) interfingering with shallow marine limestones.

During the Santonian to ? Maastrichtian, sediments are absent, except some siliciclastic sands in the northern part of the basin. This unconformity is possibly related to Santonian-Campanian Pyrenean uplift. Latest Cretaceous to Miocene sediments (dominantly siliciclastic rocks, carbonates in the later Miocene) were encountered in some local basins. The basaltic lavas of the Lisbon volcanic complex are of Paleocene age (Wilson *et al.*, 1989).

2.3. North- and East-Iberian margins (Ortegal Spur, Basque-Cantabrian Basin, Pyrenees and Iberian Chain)

2.3.1. Ortegal Spur

North-east of the Galicia Bank and west of the Basque-Cantabrian Chain (North Galicia Margin), the Ortegal Spur has always remained a shelf or slope environment, which was tectonically influenced by the development of the Bay of Biscay (Boillot *et al.*, 1988b). The extensional regime of the Late Jurassic and Early Cretaceous was followed by a phase of passive margin development during the Late Cretaceous. Convergence started it the Maastrichtian-Paleocene and led to subduction of oceanic crust beneath the northern Iberian margin.

Shallow platform carbonates with sandy or dolomitic tidal intercalations characterise the Middle Jurassic - Berriasian sequence of the Ortegal Spur. Locally occurring carbonates with calpionellids (Tithonian-Berriasian) indicate more open marine conditions. The Lower Cretaceous (Berriasian-Aptian) sandy limestones, siltstones and sandstones show terrestrial influences by containing dominantly quartz, feldspar and mica. Benthic foraminifera and plant debris suggest a shallow-water depositional environment. Following an unconformity ('break-up unconformity', Boillot *et al.*, 1988), the next sedimentary sequence starts with fine-grained dark sandstones rich in plant debris (Late Aptian-Early Albian) overlain by limestones, marlstones, sandstones and interbedded conglomerates deposited on the shelf or the slope (Late Albian-Senonian). A second unconformity (widespread unconformity of the Pyrenean tectonic phase) separates the Cretaceous sequence from Eocene shelf carbonates, which are overlain by Neogene deep-marine silty marls and foraminiferal ooze, associated with breccias and conglomerates.

2.3.2. Basque-Cantabrian Basin

Triassic rifting influenced the Basque-Cantabrian region like the other Iberian margins forming extensional graben structures (Garcia-Mondéjar, 1989, 1996). A short transpressional event (Cimmerian unconformity) occurred in the Upper Triassic (Ziegler, 1990). Further rifting, especially during the Upper Jurassic and Early Cretaceous led to the deposition of very thick fluvio-deltaic sediments („Wealden" facies) comprising more then half of the total thickness (>15.000m) of the Mesozoic-Tertiary sediment succession (Pujalte, 1981; Pujalte *et al.* 1993). According to Schwentke and Kuhnt (1992) the Aptian to Upper Albian sequence is made up of limestones (Urgonian facies, Pascal, 1982; 1983;1985) laterally interfingering with shallow marine siliciclastic and dark calcareous claystones in the deeper part of the basin ('black shales').

The late subsidence stage (Upper Albian to Cenomanian) is characterised by shallow water and fluvio-deltaic sediments (Sandstones, pebbly sandstones and conglomerates and claystones or carbonates) basinward changing to dark fine-grained siliciclastics and black

claystones (black "flysch", Souquet *et al.*, 1985). During Cenomanian/Turonian, locally up to the Lower Campanian, pelagic carbonates and hemipelagic claystones were deposited (marls, clayey limestones and occasionally calcilutite turbidites and mudflows).

Starting in the late Cenomanian and ranging until the Lower Maastrichtian calcareous turbidites and debris flows occur in the northern part of the basin, overlain by dominantly siliciclastic turbidites, which represent a change in depositional system due to local uplifts (Mathey, 1987; Schwentke and Kuhnt, 1992). In the Zumaya and Ulzama subbasins Upper Maastrichtian silty marls of a neritic and pelagic environments were deposited. The following Tertiary sediments consist of shallow water carbonates and marls (Pujalte *et al.*, 1993). Flysch deposits occur in the Zumaya basin in the late Paleocene-early Eocene (siliciclastic turbidites). These flysch series is diachronous starting in other subbasins within the Campanian.

This composite profile varies in the different subbasins according to lithology, thickness, and time of onset and termination of the sequences. An overview over the Cretaceous–Paleogene sedimentary cycles of the Basque-Cantabrian Basin is given by Gräfe (1994, 1998, 1999) and Floquet (1998).

2.3.3. Southern Central Pyrenees

Deeper basinal parts of the Pyrenees tend to a more uniformity in environment and sedimentation than marginal areas (Mathey, 1987). The Southern Central Pyrenean realm has been a shelf environment at the southern margin of the Pyrenean strait through the whole Mesozoic-Tertiary Iberian history. Here, tectonic events and related sedimentary sequences clearly reflect the Iberian plate development resulting in basin-forming and basin-modifying tectonics related to the opening of the Atlantic Ocean and the Bay of Biscay (Puigdefàbregas and Souquet, 1986; Vergés *et al.*, 2002). The succession of the Southern Central Pyrenees (Sierra de Montsec) shows nearly all phases of the tectono-sedimentary cycles and is therefore used to describe the Mesozoic-Tertiary sequence (Wallrabe-Adams *et al.*, 1990). The Sierra de Montsec is located between the 'Outer Sierras', which represent the southern basin margin, and e.g. the Sierra de Prada, representing the basin interior.

Mesozoic continental rifting start in the Upper Triassic (Ziegler, 1990). Claystones and evaporates and carbonates form a typical intercontinental succession. Continuous subsidence led to the formation of fossiliferous marls and limestones during the Liassic and a widespread carbonate platform in the middle and upper Jurassic. This shallow water series is capped by lagoonal limestones

and collapse breccias (Portlandian) with an emersion surface and local karst features (Wallrabe-Adams *et al.*, 1990). Major Pyrenean basins (Parentis Basin, Basque-Cantabrian Basin, Organya Basin) were influenced by rifting periods in late Jurassic-Early Cretaceous and late Barremian-Albian times (Vergés and García, 2001).

The Lower Cretaceous (Hauterivian to Barremian) is characterised by shallow-water carbonates with intercalations of fresh water limestones (Caracean limestone). During the Aptian and Albian shallow water carbonates and marls rich in foraminifers (Orbitolinids) occur. These series was tectonically tilted in the Upper Albian and after a hiatus, represented locally by a hardground, the global Cenomanian transgression deposited again shallow water carbonates. Continuous deepening of the area led to the deposition of neritic carbonates in the Early Turonian, representing the deepest facies in the southern central Pyrenees. At the Turonian/Coniacian boundary uplift led to emersion and a very local deposition of freshwater carbonates. Marine shallow water carbonates with a high terrigenous input, marls and patch reefs characterise the Santonian to Campanian. In the Uppermost Cretaceous (Campanian-Maastrichtian) a widespread carbonate platform was established in the Pyrenean realm (Wallrabe-Adams *et al.*, 1990).

At the Cretaceous/Tertiary boundary terrestrial influence increased and terrigenous sediments with palaeosols and short marine ingressions ("Garumnian" facies) represent the Lower Tertiary (Danian to Eocene). This succession is unconformably overlain by coarse clastic deposits (molasse) indicating the folding of the Pyrenean orogen phase. The end of deformation has been dated as late Oligocene (Meigs *et al.*, 1996)

2.3.4. Iberian Chain

Pre-rift sediments of the Iberian Chain are Jurassic platform carbonates. These carbonates were capped by an erosional surface and a discordance reflecting tectonic movements (?Young Cimmerian phase).

The structural development of the Iberian Chain started in the Lower Cretaceous with the formation of small local grabens. These grabens became wider and a typical aulacogene developed (Alvaro *et al.*, 1979), trending SE-NW onto the Iberian block. From the late Cenomanian to the latest Santonian or Campanian a shallow marine connection between the Iberian aulacogene and the Basque-Cantabrian basin existed (Castilian Ramp and South Iberian Ramp), bordered by the Iberian Meseta in the SW and the Ebro High in the NE (Floquet, 1991, 1998; Salas and Casas, 1993). Salas and Casas (1993) reinterpreted the eastern Iberian basin as a rift in contrast top a "traditional" aulacogene.
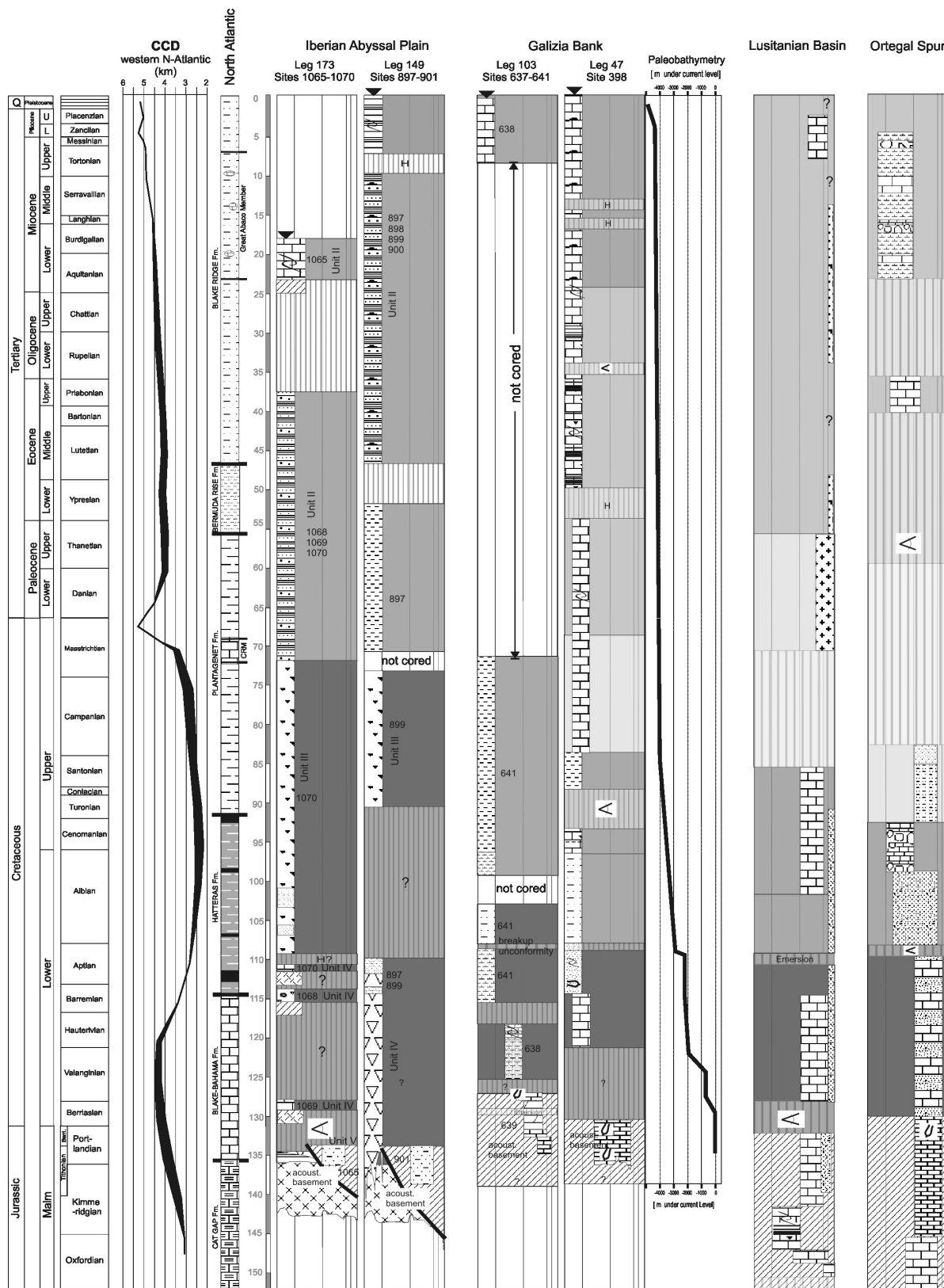
Fig. 4.–Generalised sediment successions around Iberia. Source of data: CCD curve from Tucholke and Vogt (1979); North Atlantic sediment record after Jansa *et al.* (1979); Iberian Abyssal Plain after Beslier *et al.* (2001) and Milkert *et al.* (1996); Galizia Bank after Shipboard Scientific Party (1987), Jansa *et al.* (1988) and Rehault and Mauffret (1976); Paleobathymetry after Boillot *et al.* (1989) and Synatlan database; Lusitanian Basin after Wilson *et al.* (1989) and Hiscott *et al.* (1990); Ortegal Spur after Boillot *et al.* (1987); Basque-Cantabrian Basin (Zumaya) after Schwentke and Kuhnt (1992), Garcia-Mondejar (1989) and Gräfe (1999); S-Pyrenees (Sierra del Montsec) after Puigdefàbregas and Souquet (1986) and Wallrabe-Adams *et al.* (1990); Iberian Chain after Vilas *et al.* (1983) and Valladares *et al.* (1996); Betic Cordillera (Median Subbetic) after Reicherter *et al.* (1994) and Chacón and Martín-Chivelet (this volume); sea level curve from Haq *et al.* (1987).
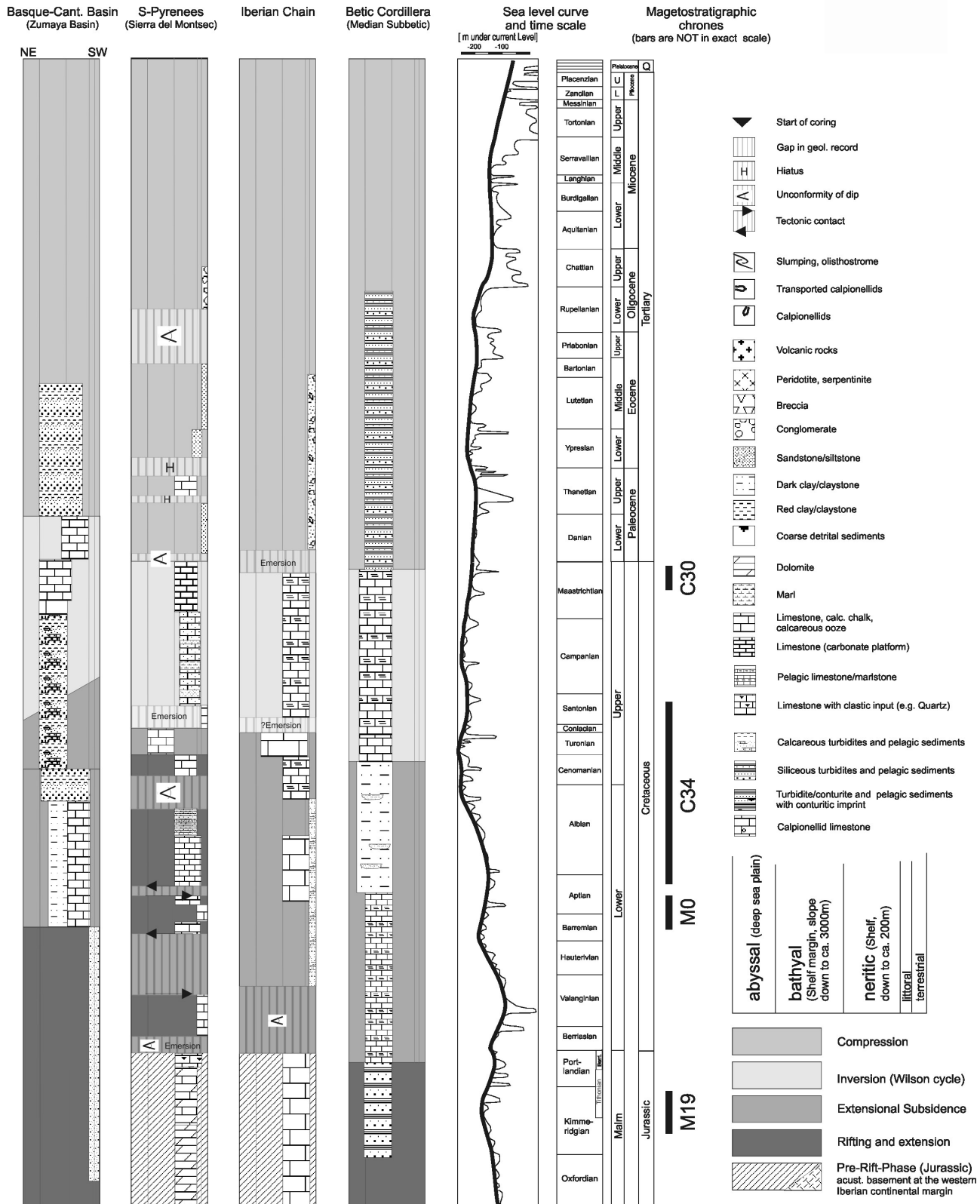
Fig. 4.–Sucesiones sedimentarias generales del entorno de la Península Ibérica. Fuentes: Curva CCD (Tucholke y Vogt,1979); registro sedimentario del Atlántico Norte (Jansa *et al*, 1979); llanura abisal de Iberia (Beslier *et al.*, 1979, Milker *et al.*, 1996); Banco de Galicia según Shipboard Scientific Party (1987), Jansa *et al.* (1988) y Rehault y Mauffret (1976); Paleobatimetría según Boillot *et al.* (1989) y la base de datos de Synatlan; Cuenca Lusitánica según Wilson *et al.* (1989) y Hiscott *et al.* (1990); Promontorio de Ortegal según Boillot *et al.* (1987); Cuenca Vasco-Cantábrica (Zumaya) según Schwentke y Kuhnt (1992), Garcia-Mondejar (1989) y Gräfe (1999); Pirineos meridionales (Sierra del Montsec) según Puigdefàbregas y Souquet (1986) y Wallrabe-Adams *et al.* (1990); Cadena Ibérica según Vilas *et al.* (1983) y Valladares *et al.* (1996); Cordillera Bética (Subbético medio) según Reicherter *et al.* (1994) y Chacón y Martín-Chivelet (este volumen); curva del nivel del mar de Haq *et al.* (1987).

The environment of the epicontinental sediment rock series of the Iberian Chain alternates between terrestrial and shallow marine conditions (Vilas *et al.*, 1983). From the Valanginian-Hauterivian up to the Cenomanian, regressive and transgressive phases led to a series of dominantly terrigenous sediments with some shallow marine carbonates. Extensive and widespread shallow marine carbonate sedimentation with continental influences was established in the Cenomanian. In the Turonian this depositional systems reached its deepest conditions with ammonites and planktonic foraminifera environments (Vilas *et al.*, 1983; Valladares *et al.* 1996). The Late Cretaceous deposits represent transgressive-regressive short-term and long-term cycles (Floquet, 1998). At the end of the Cretaceous terrestrial conditions reappeared diachronously from the late Santonian up to the Campanian.

2.4. South-Iberian margin (Betic Cordillera)

The southern Iberian margin is represented in the external zones of the Betic Cordillera. Together with its prolongation, the Moroccan Rif, it is the remnant of the Betic Seaway (Gibraltar Seaway) connecting the western Tethys and the Atlantic Ocean during the Mesozoic and Paleogene. This seaway existed since the Upper Jurassic following the Triassic to Lower Jurassic rifting phase.

The Median Subbetic represents the deepest pelagic environment of the Betic Seaway showing great similarities with the North Atlantic palaeoceanographic conditions (Reicherter *et al.*, 1994). For this reason profiles of this zone (Rio Fardes, Las Cabras; Figs. 3 and 4) are used for comparison with the other margins.

As in large marginal areas of Iberia, Upper Triassic rocks (shales, evaporates) are the first sediments related to the beginning of the continental rift phase. Shallow marine carbonate platforms in the Lower Jurassic locally collapsed in the Middle and Late Jurassic and the depressions were filled with pelagic limestones, marls, calcareous turbidites and radiolarites. During the Lower Cretaceous deposition of pelagic limestones and marl/limestone alternations persisted, intercalated by debris flows and slumped sediments indicating tectonic movements. In the Albian dark claystones ('black shales') were deposited (Reicherter *et al.*, 1994) as well as siliciclastic and calcareous rocks (Martín-Chivelet, 1996). Such turbidites also characterise the Cenomanian to Turonian sediments which again contain organic-rich deposits (Reicherter *et al.*, 1994). Pink to red deep-sea clays and pelagic lime/marlstones were deposited in the basins during the major part of the Upper Cretaceous (Coniacian to Maastrichtian). At the Cretaceous/Tertiary boundary the clastic input increases (calciturbidites, mass flows

with components of crystalline basement rocks) forming a 'flysch'-facies.

Comparable environments describe Chacón and Martín-Chivelet (this volume) for the Caravaca region were four rapid facies changes (middle Campanian to earliest Paleocene) correlate probably with the onset of the plate convergence.

Continental collision between Africa and Iberia during the Miocene formed the nappe system of the Betic Cordillera.

3. Comparison of margin development according to tectono-sedimentary sequences around Iberia

In the following a comparison of the margin successions around Iberia is given, using important unconformities and generalised sedimentary sequences bounded by these unconformities. The generalized tectono-sedimentary conditions based on the more detailed descriptions in chapter 2 (see here for references). All interpreted profiles are shown in Figure 4.

3.1. Iberian Abyssal Plain

For the Iberian Abyssal Plain three tectono-sedimentary phases can be distinguished: the pre-rift phase, a rifting- and extension phase, and a phase of extensional subsidence.

The shelf related sediments that form the tilted blocks have been assigned to pre-rift origin. The mostly fine-grained clastic deep-sea deposits which range from Berriasian to Maastrichtian and unconformably overlie the blocks, therefore represent the rifting and following extension phase of the west Iberian margin (Fig. 4). From the Maastrichtian upward the deposits record a more stable environment with continuous deep-sea sedimentation. This last phase can be characterised as extensional subsidence phase. Signs of compressional events are widely missing at the Iberian Abyssal Plain, except the general tilting of the Galician Bank and some light regional flexuring of sediment and a hiatus of 2.3 Ma in some cores (Sites 897, 898, and 899), which is thought to be the result of a middle Miocene compressional phase in the Rif-Betic mountains.

3.2. Galicia Bank

At the Galicia Bank pre-rift sediments range up to the Berriasian. Rifting sequences start with the Valanginian discordance and indicate a drastic deepening that lasts until the break-up unconformity of the Aptian (Fig. 4). After this break-up, continuous deepening is documented

by deep-sea clay with minor clastic input. The first tectonic compression is marked by the renewed sedimentation of calcareous material coinciding with a rise of the sedimentary setting in the Santonian. Therefore it is been labelled as an inversion phase (Fig. 4). The stronger tectonic activity of Maastrichtian to Oligocene times caused more disturbed sediments with olisthostroms and higher clastic input. It is thus thought to represent compressional events of the Pyrenean orogeny. In the upper Oligocene sedimentation changes to uniform contouritic chalk deposition. Because no significant sedimentation gaps, unconformities or tectonic events are recorded from that time on, we postulate the beginning of the final extensional phase in the upper Oligocene (Boillot *et al.*, 1988b).

3.3. Lusitanian Basin

In the Lusitanian Basin stable platform conditions last only until the Oxfordian, when rapid deepening and siliciclastic sedimentation marks the beginning of the rifting phase (Hiscott *et al.*, 1990; Wilson *et al.* 1989). Rifting resulted in the uplift of the Lusitanian Block so that terrigenous sediments were deposited up to the Aptian. The Aptian emersion is thought to mark the culmination of the rifting phase. The renewed deepening of the sedimentary environment is assigned to the following subsidence phase. The wide gap that lasts from the Santonian to the Maastrichtian and the following Paleocene volcanic rocks stand for new tectonic activity and represent the inversion phase in the Lusitanian basin (Fig. 4, Hiscott *et al.*, 1990; Wilson *et al.* 1989). Compression lasts from the upper Paleocene until today and is represented by terrigenous clastics.

3.4. Ortegal Spur

Calcareous shelf related sedimentation at the Ortegal Spur ranges up to the Berriasian, where it is replaced by a near-coast environment with a periodic clastic influence (Boillot *et al.* 1989b). We interpret these clastics to represent the rifting phase at the Ortegal Spur. The following phase of subsidence starts with the Aptian break-up unconformity and lasts until the Cenomanian, when a rapid change of facies depth occurs (Fig. 4). This change stands for the beginning of an inversion phase with an unclear duration. The huge sedimentary gap after the youngest Campanian sediments is thought to represent the orogenic (Pyrenean) phase which led to the subduction of the Bay of Biscay crust in the Tertiary, coinciding with an increasing sedimentation depth. We suggest a compressional phase that starts in the Paleocene as found in the Pyrenees and the Betic Cordillera.

3.5. Basque-Cantabrian Basin

In the Basque-Cantabrian Basin the Upper Jurassic up to the Barremian is represented by terrestrial clastics. In the Aptian shallow carbonates of the Urgonian facies are deposited. The rifting phase in the Basque-Cantabrian Basin is terminated at the Aptian-Albian unconformity (Gräfe, 1999). The sedimentary environment of the following subsidence phase lies much deeper. In the Basque Massifs, the subsidence phase stopped in the early Cenomanian when a strong clastic influence can be observed (Schwentke and Kuhnt, 1992). In the southern part of the basin tectonic subsidence is terminated in the Coniacian/Santonian (Gräfe, 1999). Beginning of compression leads to flysch deposition in the Maastrichtian (Mathey, 1987). Sedimentation of coarse clastic material starts in the upper Paleocene and marks the onset of the tectonic inversion phase of the basin (Fig. 4, Paleocene to Miocene, Gómez *et al.*, 2002).

3.6. Southern Pyrenees

In the Southern Pyrenees the pre-rift - stable shallow marine conditions stopped in the lowest Berriasian, when an emersion initiated a phase of undulating facies depth with minor unconformities. The beginning of the following subsidence is rather difficult to determine, but the first distinct sign of a change in the sedimentation mode is recorded by the successive deepening of the environment at the Cenomanian – Turonian boundary. Inversion begins with the emersion in the Coniacian and ends with the terrestrial sediments of the Paleocene which represent the beginning of the compressional phase (Puigdefàbregas and Souquet, 1986).

3.7. Iberian Chain

In the mid plate Iberian Chain shelf carbonate sedimentation is cut by a broad unconformity comprising the Berriasian to Valanginian, which coincides with the start of the rifting episode around the Iberian microplate (Fig. 4). Long sequences of terrestrial sediments were produced that lasts until the upper Albian. They were replaced by shelf sequences that stand for the following phase of extensional subsidence (Flouqet, 1998). Inversion starts with shallow marine series ranging from the Coniacian to the upper Maastrichtian. The compressional phase is initiated with an emersion at the Maastrichtian–Paleocene.

3.8. Betic Cordillera

In the prebetic zone of the Betic Cordillera, shelf conditions are documented in the sediments throughout the Cretaceous (Martín-Chivelet *et al.*, 2002). Two large tectonic unconformities occur in this shelf series in the

early Campanian and the early Maastrichtian. In the penibetic zone shelf sediments are not present. Clastic sediments that represent the rifting phase date from the upper Oxfordian to the upper Aptian when a complete change in the facies is recorded with deep sea clays that constitute the phase of extensional subsidence ranging up to the Cenomanian. This subsidence phase corresponds with the circum-Iberian events at this time and is interpreted as a transtensional stage in the tectonic regime by Reicherter and Pletsch (2000) (compare also Fig. 4). Inversion is documented by the clastic sequences from Cenomanian to Maastrichtian. Compression starts with the coarse clastic material of the Paleocene.

3.9. Tectonic phases and sequence development

Following the first rifting events in the Triassic creating graben and halfgraben structures, the Iberian margins were dominated by shallow marine conditions resulting in widespread carbonate platform/ramp development. Locally slightly deeper deposits (fossiliferous marlstones) occur. An exception of this general scenario was the southern Iberian margin were a deep strait between Iberia and Africa connected the western Tethys and the Central-Atlantic. In the upper Jurassic rifting continued and the opening of the North-Atlantic began (Chrone M19), leading to block faulting and thinning of the continental crust of Iberia and America (Grand Banks) resulting in the formation of the young southern North-Atlantic basin. This very short rifting phase (Tithonian-Berriasian) is visible in the sequences of the western and north-eastern Iberian margin (Fig. 4). In contrast to the western margin, were subsidence is documented by the deepening of the lithofacies, compression and uplift characterise the change from marine to terrestrial influenced sediments in the Pyrenees and the Iberian Chain.During the break-up phase (anomaly 'J', Chrone M0), the complete separation of Iberia and Grand Banks in the Aptian and local deep subsidence, occur leading to the deposition of dark organic-rich sediments (black shales, Galicia Bank, Ortegal Spur, Basque-Cantabrian Basin, Betic Cordillera). Other areas seem to be uninfluenced (NE-Iberia). But this may be due to the generally shallow marine stable shelf conditions in NE-Iberia which show only limited reactions with minor shallowing or deepening tendencies.

The north-eastern Iberian margin again underwent a compressional phase as the result of the combination of a south-eastward drift and an anticlockwise rotation of the Iberian plate. The plate movement started in the Aptian-Albian (Chrone 34), the rotation centre was located between the central Pyrenees and the Basque massifs (Engeser and Schwentke, 1986). Due to the extensional conditions west of the rotation centre subsidence characterised this area (opening of the Bay of Biscay) and in opposite, east of the rotation centre, compression led to the deposition of sediments of shallow marine to terrestrial environments (Pyrenees). Large global sea level changes like the Cenomanian transgression may overprint local tectonic movement in the eastern Pyrenees, causing the deepest facies conditions in the early Turonian (outer shelf environment).

Northward motion of the Iberian plate in the Campanian-Early Maastrichtian (Chrone C30) again initiated compressional conditions at the northern Iberian margin. The terrestrial Garumnian facies characterise this phase in the Pyrenees and the Iberian Chain.

Continuous northward movement stopped the marine sedimentation at the north-eastern margin (Basque-Cantabrian Basin, Pyrenees), eastern margin (Iberian Chain), and the southern margin (Betic Cordillera) by folding and uplift of the orogens.

4. Conclusions

Tectono-sedimentary sequences and related unconformities in the orogens around Iberia are the result of the tectonic development of the independent plate. With respect to the accessible stratigraphic resolution and the local completeness of the sedimentary record, a general correlation of the margin sequences is possible. Nearly time equivalent similar or opposed trends in facies development in the basins around Iberia show the local transgressional or regressional regime caused by the phases of continental plate motion. The correlation of sequences and the reconstruction of the Iberian plate movement by geophysical sea floor observations help to establish a detailed history of Iberian plate tectonics and palaeogeography of the Central North Atlantic/Western Tethys realm since the Triassic.

Interesting and important targets for future drilling at the western Iberian margin are the older (earliest Cretaceous) sediments between the tilted blocks of the Iberian Abyssal Plain basement. These sediments must be deposited with very high sedimentation rates (mass flows, rock fall) because of the high thickness filling the whole relieve in the short time interval between the Tithonian to Berriasian-Valanginian.

like to thank ODP for inviting him to Leg 173.

This manuscript has benefited from the careful review and very helpful comments of J. Martín-Chivelet and M. Floquet.

References

Alvaro, M., Capote, R, Vegas, R. (1979): Un modelo de evolución geotectónica para la cadena Celtibérica. *Acta Geologica Hisp*anica, 14: 172-181.

Alves, T.M., Gawthorpe, R.L., Hunt, D.W., Monteiro, J.H. (2002): Jurassic tectono-sedimentary evolution of the Northern Lusitanian Basin (offshore Portugal). *Marine and Petroleum Geology*, 19: 727-754.

Beslier, M.-O., Whitmarsh, R.B., Wallace, P.J., Girardeau, J. (eds.) (2001): *Proceedings of the Ocean Drilling Program, Scientific Results,* 173 [Online]. Available from World Wide Web: http://www-odp.tamu.edu/publications/173_SR/173sr.htm. [Cited 2004-03-10]

Boillot, G. Comas, M.C., Girardeau, J., Kornprobst, J., Loreau, J.-P., Malod, J., Mougenot, D., Moullade, M. (1988a): Preliminary results of the Galinaute cruise; dives of the submersible Nautile on western Galicia margin, Spain. In: G. Boillot *et al.* (eds.): *Proceedings of the Ocean Drilling Program, Scientific Results,* 103: 37-51, Ocean Drilling Program, College Station, TX.

Boillot, G., Malod, J.-A., Dupeuble, P.-A., Groupt, C. (1988b): Mesozoic evolution of Ortegal Spur, north Galicia margin: comparison with adjacent margins. In: G. Boillot *et al.* (eds.): *Proceedings of the Ocean Drilling Program, Scientific Results,* 103: 107-115, Ocean Drilling Program, College Station, TX.

Boillot, G., Winterer, E.L., Meyer, A.W. *et al.* (1988): *Proceedings of the Ocean Drilling Program, Scientific Results.*, 103: 828 p., Ocean Drilling Program, College Station, TX.

Bourbon, M. (1979): Petrographic and sedimentological study of the Cretaceous-Paleocene sequence of Hole 398D. In: J.C. Sibuet, W.B.F. Ryan *et al.* (eds.): *Initial Reports of the Deep Sea Drilling Program*, 47 Part 2: 419-427, U.S. Government Printing Office, Washington, DC.

Chacón, B., Martín-Chivelet, J. (2005): Major palaeoenvironmental changes in the Campanian to Palaeocene sequence of Caravaca (Subbetic zone). *Journal of Iberian Geology*, this volume.

Dupeuble, P.-A., Boillot, G., Mougenot, D. (1987): Upper Jurassic-Lowerst Cretaceous limestones dredged from the western Galicia margin. In: G. Boillot *et al.*, (eds.): *Proceedings of the Ocean Drilling Program, Initial Reports, (Pt. A)*, 103: 99-105, Ocean Drilling Program, College Station, TX.

Engeser, T., Schwentke, W. (1986): Towards a new concept of the tectogenesis of the Pyrenees. *Tectonophysics*, 129: 233-242.

Floquet, M. (1991): La plateforme Nord-Castillane au Crétacé supérieur (Espagne). *Mémoire géologique de l'Université de Dijon*, 14: 1-925.

Floquet, M. (1998): Outcrop cycle stratigraphy of shallow ramp deposits: the Late Cretaceous series on the Castilian Ramp (Northern Spain). In: P.C. de Graciansky, J. Hardenbol, T. Jacquin, P.R. Vail (eds.): Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. *SEPM, special publication,* 60: 343-361, SEPM, Tulsa.

Garcia-Mondéjar, J. (1989): Strike-Slip Subsidence of the Basque-Cantabrian Basin of Northern Spain and its relationship to Aptian-Albian opening of Bay of Biscay. In: A.J. Tankard, H.R. Balkwill (eds.): Extensional Tectonics and Stratigraphy of the North Atlantic Margins. *American Association of Petroleum Geologists, Memoir,* 46: 395-409, AAPG, Tulsa.

Garcia-Mondéjar, J (1996): Plate reconstrucion of the Bay of Biscay. *Geology*, 24 (7): 635-638.

Gradstein, F. M., J. Ogg, (1996): A Phanerozoic time scale. *Episodes,* 19 (1, 2): 3-5.

Gräfe, K.-U. (1994): Sequence stratigraphy in the Cretaceous and Paleogene (Aptian to Eocene) of the Basco-Cantabrian Basin (N. Spain). *Tübinger geowissenschaftliche Arbeiten,* 18: 1-418.

Gräfe, K.-U. (1998): Sequence stratigraphy on a carbonate ramp: the Late Cretaceous Basco-Cantabrian Basin (Northern Spain) In: P.C. de Graciansky, J. Hardenbol, T. Jacquin, P.R. Vail (eds.): Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. *SEPM, special publication,* 60: 337-345, SEPM, Tulsa.

Gräfe, K.-U. (1999): Sedimentary cycles, burial history and foraminiferal indicators for systems tracts and sequence boundaries in the Cretaceous of the Basco-Cantabrian Basin. *Neues Jahrbuch für Geologie-Paläontologie, Abhandlungen*, 212 (1-3): 85-130.

Gómez, M.; Vergés, J., Riaza, C. (2002): Inversion tectonics of the northern margin of the Basque Cantabrian Basin. *Bulletin de la Société géologique de France*, 173 (5): 449-459.

Groupe Galice (1979): The continental margin off Galicia and Portugal; acoustical stratigraphy, dredge stratigraphy, and structural evolution. In: J.C. Sibuet, W.B.F. Ryan *et al.* (eds.): *Initial Reports of the Deep Sea Drilling Program*, 47: 633-662, U.S. Government Printing Office, Washington, DC.

Haq, B.U., Hardenbol, J., Vail, P.R. (1987): Chronology of Fluctuating Sea Levels Since the Triassic. *Science*, 235: 1156-1167.

Hiscott, R.N., Wilson, R. C. L., Gradstein, F. M., Pujalte, V., García-Mondéjar, J. Boudreau, R. R., Wishart, H. A. (1990): Comparative stratigraphy and subsidence history of Mesozoic rift basins of the North Atlantic. *American Association of Petroleum Geologists, Bulletin*, 74(1): 60-76.

Jansa, L.F., Comas, M.C., Sarti, M. Haggerty, J.A. (1988): Late Jurassic carbonate platform of the Galicia margin. In: G. Boillot *et al.* (eds.): *Proceedings of the Ocean Drilling Program, Scientific Results,* 103: 171-190, Ocean Drilling Program, College Station, TX.

Kaminski, M.A., Kuhnt, W., Radley, J.D. (1996): Paleocene-Eocene deep water agglutinated foraminifera from the Numidian Flysch (Rif, Northern Morocco): their significance for the palaeoceanography of the Gibraltar gateway. *Journal of Micropaleontology*, 15: 1-19.

Kuhnt, W., Urquhart, E. (2001): Tethyan flysch-type benthic foraminiferal assemblages in the North Atlantic: Cretaceous to Paleogene deep water agglutinated foraminifers from the Iberia Abyssal Plain (ODP Leg 173). *Revue de Micropaléontologie*, 44 (1): 27-59.

Leinfelder, R.R., Wilson, R.C.L. (1998): Third-order sequences in an Upper Jurassic rift-related second-order sequence, central Lusitanian Basin. In: P.C. de Graciansky, J. Hardenbol, T. Jacquin, P.R. Vail (eds.): Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. *SEPM, special publication,* 60: 507-525, SEPM, Tulsa.

Loreau, J.P., Cros, P. (1988): Limestone diagenesis and dolomitization of Tithonian carbonates at ODP Site 639 (Atlantic Ocean, west of Spain).In: G. Boillot *et al.* (eds.): *Proceedings of the Ocean Drilling Program, Scientific Results,* 103: 105-143, Ocean Drilling Program, College Station, TX.

Mamet, B., Comas, M.C., Boillot, G. (1991): Late Paleozoic basin on the West Galicia Atlantic margin. *Geology*, 19: 738-741.

Martín-Chivelet, J. (1996): Late Cretaceous stratigraphic patterns and subsidence history of the Betic Continental Margin (Jumilla-Yecla region, SE Spain). *Tectonophysics*, 265: 191-211.

Martín-Chivelet, J. Berástegui, X., Rosales, I., Vilas, L., Vera, J.A., Caus, E., GrÄfe, K.-U., Segura, M., Puig, C., Mas, R., Robles, S., Floquet, M., Quesada, S., Ruiz-Ortiz, P.A., Fregenal-Martínez, M.A., Salas, R., García, A., Martín-Algarra, A., Arias, C., Meléndez, N., Chacón, B., Molina, J.M., Sanz, J.L. Castro, J.M., García-Hernández, M., Carenas, B., García-Hidalgo, J., Gil, J., Ortega, F. (2002): Cretaceous. In: W. Gibbons, M.T. Moreno (eds.): *Geology of Spain*, 255-292, Geological Society, London

Mathey, B. (1987): Les flyschs Crétacé supérieur des Pyrénées Basques. *Mémoire géologique de l'Université de Dijon*, 12: 1-399.

Meigs, A.J., Vergés, J., Burbank, D.W. (1996): Ten-million-year history of a thrust sheet. *Geological Society of America, Bulletin*, 108 (12): 1608-1625.

Milkert, D. Alonso, B., Liu, L., Zhao, X., Comas, M., de Kaenel, E. (1996a): Sedimentary facies and depositional history of the Iberia Abyssal Plain. In: R.B. Whitmarsh *et al.* (eds.): *Proceedings of the Ocean Drilling Program, Scientific Results,* 149, 685-704, Ocean Drilling Program, College Station TX.

Milkert, D., Weaver, P.P.E., Liu, L., (1996b): Pleistocene and Pliocene turbidites from the Iberia Abyssal Plain. In: R.B. Whitmarsh *et al.* (eds.): *Proceedings of the Ocean Drilling Program, Scientific Results,* 149: 281-294, Ocean Drilling Program, College Station TX.

Moullade, M., Brunet, M.F., Boillot, G. (1988) : Subsidence and deepening of the Galicia margin; the paleoenvironmental control. In: G. Boillot *et al.* (eds.): *Proceedings of the Ocean Drilling Program, Scientific Results,* 103: 733-740, Ocean Drilling Program, College Station, TX.

Muñoz, A., Acosta, J., Uchupi, E. (2003): Cenozoic tectonics on the Galicia margin, northwest Spain. *Geo-Marine Letters*, 23: 72-80.

Pascal, A. (1982): Systemes biosedimentaires Aptiens *et albiens* (Urgoniens) de la marge cantabrique (Espagne). In : J. Philip (ed.): *Formations carbonatees; dynamique, successions paleoecologiques.* Journees plenieres de la RCP 510 , 9; 3: 257-258, Editions de l'Universite de Provence, Aix-en-Provence, France.

Pascal, A. (1983): L'Urgonien, systemes biosedimentaires et tectonogenese. In : P.Rat *et al.*, (eds.): Vue sur le Cretace Basco-cantabrique et Nord-Iberique; Une marge et son arriere-pays, ses environnements sedimentaires. *Mémoire géologique de l'Université de Dijon,* 9: 45-76.

Pascal, A. (1985): Les systèmes biosédimentaires Urgoniens (Aptien-Albien) sur la marge nord-ibérique. *Mémoire géologique de l'Université de Dijon*, 10: 1-569.

Pinheiro, L.M., Wilson, R.C.L., dos Reis, R.P., Whitmarsh, R.B., Ribeiro, A. (1996): The western Iberia Margin: a geophysical and geological overview. In: R.B. Whitmarsh *et al.* (eds.): *Proceedings of the Ocean Drilling Program, Scientific Results,* 149: 3-21, Ocean Drilling Program, College Station TX.

Puigdefàbregas, C., Souquet, P. (1986): Tecto-sedimentary cycles and depositional sequences of the Mesozoic and Tertiary from the Pyrenees. *Tectonophysics*, 129: 173-203.

Pujalte, V. (1981): Sedimentary suxccession and paleoenvironments within a fault-controlled basin: The "Wealden" of the Santander area, northern Spain. *Sedimentary Geol*ogy, 28: 293-325.

Pujalte, V., Robles, S., Robador, A., Baceta, J.I., Orue-Etxebarria, X. (1993): Shelf-to-basin Palaeocene palaeogeography and depositional sequences, western Pyrenees, north Spain. In: H.W. Posamentier, H.W. Summerhayes, C.P. Haq, B.U., Allen, G.P. (eds.): *Sequence Stratigraphy and Facies Associations.* International Association of Sedimentologists, special publication, 18: 369-395, Blackwell, Oxford.

Réhault, J.-P., Mauffret, A. (1979): Relationship between tectonics and sedimentation around the northwestern Iberian margin. In: J.C. Sibuet, W.B.F. Ryan *et al.* (eds.): *Initial Reports of the Deep Sea Drilling Program*, 47 Part 2: 663-681, U.S. Government Printing Office, Washington, DC.

Reicherter, K.R. Pletsch, T., Kuhnt, W., Manthey, J., Homeier, G., Wiedmann, J. Thurow, J. (1994): Mid-Cretaceous paleogeography and paleoceanography of the Betic Seaway (Betic Cordillera, Spain). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 107 (1-2): 1-33.

Reicherter, K.R., Pletsch, T.K. (2000): Evidence for a synchronous circum-Iberian subsidence event and its relation to African-Iberian collision in the Upper Cretaceous. *Terra Nova*, 12: 141-147.

Salas, R., Casas, A. (1993): Mesozoic extensional tectonics, stratigraphy and crustal evolution during the Alpine cycle of the eastern Iberian basin. *Tectonophysics*, 228: 33-55.

Schettino, A., Scotese, Ch. (2002): Global kinematic constraints to the tectonic history of the Mediterranean region and surrounding areas during the Jurassic and Cretaceous. In:

Rosenbaum, G., Lister, G.S., (eds.): *Reconstruction of the Evolution of the Alpine-Himalayan Orogene,* Journal of the Virtual Explore*r*, 8: 149-168.

Schwentke, W., Kuhnt, W. (1992): Subsidence history and continental margin evolution of the Western Pyrenean and Basque Basins. *Palaeogeography, Palaeoclimatology, Palaeoecolog.,* 95: 297-318.

Shipboard Scientific Party (1998a): Site 1065. In: R.B. Whitmarsh, M.-O. Beslier, P.J. Wallace *et al.* (eds.): *Proceedings of the Ocean Drilling Program, Initial Reports,* 173: 65-104, Ocean Drilling Program, College Station TX.

Shipboard Scientific Party (1998b): Site 1070. In: R.B. Whitmarsh, M.-O. Beslier, P.J. Wallace *et al.* (eds.): *Proceedings of the Ocean Drilling Program, Initial Reports,* 173: 265-294, Ocean Drilling Program, College Station TX.

Sibuet, J.-C., Ryan, W.B.F. *et al.* (eds.) (1979): *Initial Reports of the Deep Sea Drilling Program*, 47 Part 2*:* 1-881, U.S. Government Printing Office, Washington, DC.

Souquet, P., Debroas, E.-J., Boirie, J.M., Pons, P., Fixari, G., Roux, J.C., Dol, J., Thieuloy, J.-P., Bonnemaison, M., Manivit, H., Peybernés, B. (1985): Le groupe du flysch noir (Albo-Cénomanien) dans les Pyrénées. *Bulletin des Centres de Recherche Exploration-Production Elf-Aquitaine*, 9 (1): 183-252.

Tucholke, B.E., Vogt, P.R. (1979): Western North Atlantic: sedimentary evolution and aspects of tectonic history. In: B.E. Tucholke *et al.* (eds.): *Initial Reports of the Deep Sea Drilling Program*, 43*:* 791-825, U.S. Government Printing Office, Washington, DC.

Valladares, I., Recio, C., Lendínez, A. (1996) Sequence stratigraphy and stable isotopes (delta^{13}C, delta^{18}O) of the Late Cretaceous carbonate ramp of western margin of the Iberian Chain (Soria, Spain). *Sedimentary Geology,* 105: 11-28.

Vergés, J., Fernàndez, M., Martínez, A. (2002): The Pyrenean orogene: pre-, syn-, and post-collisional evolution. In: G. Rosenbaum, G.S. Lister, G.S. (eds.): *Reconstruction of the Evolution of the Alpine-Himalayan Orogene*. Journal of the Virtual Explorer, 8: 57-76.

Vergés, J., García Senz, J.M. (2001): Mesozoic evolution and Cenocoic inversion of the Pyrenean rift. In: P.A. Ziegler, W. Cavazza, A.H.F. Robertson, S. Crasquin-Soleau (eds.): *Peri-Tethys Memoir 6: Pery-Tethyan Rift/Wrench Basins and Passive Margins.* Mémoires du Muséum National d'Histoire Naturelle, 186: 187-212, MNHN, Paris.

Vilas, L., Alonso, A., Arias, C., Garcia, A., Mas, J. R., Rincon, R., Melendez, N. (1983): The Cretaceous of the Southwestern Iberian Ranges (Spain). *Zitteliana*, 10: 245-254.

Wallrabe-Adams, H.-J. (2001): Data Report: Lithology and microfacies of Upper Jurassic to Lower Tertiary sediments of Sites 1068 and 1069. In: R.B. Whitmarsh, M.-O. Beslier, P.J. Wallace *et al.* (eds.): *Proceedings of the Ocean Drilling Program, Initial Reports*, CD-ROM, Ocean Drilling Program, College Station, TX.

Wallrabe-Adams, H.-J., Brinnel, P., Altenbach, A.V. (1990): Zur Geologie des Grenzbereiches der Decken von Montsec und Gavarnie (Raum Rio Noguera Ribagorzana, Nordspanien). Translated Title: The geology of the boundary zone of the Montsec and Gavarnie nappes, Rio Noguera Ribagorzana area, northern Spain. *Zeitschrift der deutschen geologischen Gesellschaft*, 141: 113-127.

Whitmarsh, R.B., Sawyer, D.S., Klaus, A., Masson, D.G. (eds.) (1996): *Proceedings of the Ocean Drilling Program, Scientific results,* 149: Ocean Drilling Program, College Station, TX.

Whitmarsh, R. B., Beslier, M.-O., Wallace, P. J. *et al.* (1998): Return to Iberia. *Proceedings of the Ocean Drilling Program, Initial Reports*, 173, Ocean Drilling Program, College Station, TX.

Wilson, J.T. (1966): Did the Atlantic close and then re-open? *Nature*, 211 (5050): 676-681.

Wilson, R.C.L., Hiscott, R.N., Willis, M.G., Gradstein, F.M. (1989): The Lusitanian Basin of west-central Portugal; Mesozoic and Tertiary tectonic, stratigraphic, and subsidence history. In: A.J. Tankard, H.R. Balkwill (eds.): Extensional tectonics and stratigraphy of the North Atlantic margins. American Association of Petroleum geologists, Memoir, 46: 341-361, AAPG, Tulsa.

Wilson, R.C.L., Sawyer, D.S., Whitmarsh, R.B., Zerong, J., Carbonell, J. (1996): Seismic stratigraphy and tectonic history of the Iberia Abyssal Plain. In: R.B. Whitmarsh *et al.* (eds.): *Proceedings of the Ocean Drilling Program, Scientific Results,* 149: 617-633, Ocean Drilling Program, College Station TX.

Ziegler, P.A. (1990): *Geological Atlas of Western and Central Europe*, 238 p., Geological Society, London.