FACTORS CONTROLLING CRETACEOUS TURBIDITE DEPOSITION IN THE BETIC CORDILLERA

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ABSTRACT

The Cretaceous, turbiditic materials of the Betic Cordillera are to be found within different contexts. At the Southern Iberian Margin (the External Zones of the Betic Cordillera) the terrigenous turbidites are normally located in the Intermediate Domain, a subsiding area adjoining the southeast of the continental platform (Prebetic) and fed from the Iberian continent. Lesser quantities of turbiditic facies exist locally in a thin-continental-crust area (Subbetic) lying further to the south and southwest. Considerable quantities of Cretaceous terrigenous turbidites were also deposited in the so-called North African "Flysch Trough", a deep elongate basin with an oceanic or sub-oceanic crust substrate. This trough provided a communication between the Tethys and the Atlantic and their sedimentary source areas were the continental reliefs of the African plate and the Mesomediterranean subplate. Both the beginning and the end of turbiditic sedimentation at the Southern Iberian Margin and the North African Flysch Trough, more or less coincided. The terrigenous turbidites occur generally between the Hauterivian and the Albian at times of brusque falls in sea level (Intra-Hauterivian, Intra-Aptian, Intra-Albian), which caused the erosion of the adjacent platforms. There are also other small quantities of turbidites, both terrigenous and carbonate, from various ages during the Cretaceous, connected to local tectonic activity and/or relative falls in sea level.

Key words: Turbidites, Cretaceous, Betic, Rif, Tell, Eustatism, Tectonic, Flysch.

RESUMEN

Los materiales turbidíticos cretácicos de la Cordillera Bética se depositaron en diferentes contextos paleogeográficos. En el Margen Sudibérico, en el que depositaron las Zonas Externas de la Cordillera Bética, las turbiditas terrígenas se presentan preferentemente en el Dominio Intermedio, área subsidente situada al sureste a la plataforma prebética, cuya área fuente era el continente de Iberia. Más localmente se reconocen facies turbidíticas, de escaso volumen y mayoritariamente carbonatadas, en el dominio Subbético, área de sustrato de corteza continental adelgazada ubicada hacia el sur y sureste de la anterior. En el "Surco de los Flyschs Norteafricanos", área alargada con sustrato de corteza oceánica o semioceánica a través del cual existía una vía de comunicación entre el Tethys y el antiguo Atlántico, también se depositó un importante volumen de turbiditas terrígenas, cuya área fuente eran los relieves continentales de la placa africana y de la Subplaca Mesomediterránea. Se reconoce una notable isocronía entre los eventos que provocaron el inicio o el final de la sedimentación turbidítica tanto en el Margen Sudibérico como en el Norteafricano y en el Surco de los Flyschs. Las turbiditas terrígenas se localizan preferentemente entre el Hauteriviense y el Albiense, y se asocian con etapas de descenso brusco del nivel del mar (Intra-Hauteriviense, Intra-Aptiense, Intra-Albiense) que provocaron la erosión de las plataformas adyacentes. Existen, además, otras turbiditas minoritarias, tanto terrígenas como carbonatadas, de edades diferentes dentro del Cretácico, ligadas a efectos de la tectónica local y/o descensos del nivel relativo del mar.

Palabras clave: Turbiditas, Cretácico, Cordilera Bética, Rif, Tell, Eustatismo, Tectónica, Flysch.

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1. INTRODUCTION

Numerous Cretaceous turbiditic formations have been described in Mediterranean Alpine Cordilleras. In the regional geological bibliography these turbidites are commonly referred to as "**flysch**" and in the palaeogeographical reconstructions of one of the most extensive and continuous of the areas in which these materials were deposited the name "flysch trough" has commonly been applied (Didon *et al.*, 1973; Bourgois, 1978; Durand-Delga, 1980; Martín-Algarra, 1987). This misuse of the term flysch has detracted somewhat from its true sense of sinorogenic tectofacies characteristic of the beginning of the closure of deep marine basins before the development of diastrophic orogenic phases, which will later determine the structuring of the basin as a folded cordillera. Thus, numerous Jurassic-Cretaceous Alpine turbiditic formations laid down in tectonically moderately active basins at passive margins under extensive or transtensive conditions have been called flysches, although their deposition took place long before the onset of the compressive orogenic activity per se. This, in fact, is the case with the Cretaceous turbiditic rocks of the Betic Cordillera (irrespective of whether they have been called flysch previously).

In this work we use the term "**turbidite**" in a wide sense, to include not only deposits from turbidity flows (turbidites s.s.) but also other deposits caused by gravity mass resedimentation, such as slumps, debris flows, pebbly sandstones, etc. We also deal with siliciclastic turbidites and carbonate turbidites, both of which interbedded within hemipelagic materials.

In recent years various authors (Mutti, 1985; Mutti and Normark, 1987; Posamentier and Vail, 1988; among others) have stressed the importance of factors other than synsedimentary tectonic activity in the control of turbiditic sedimentation. Such factors include climate, the particular characteristics of the source area, changes in sea level, the palaeogeographical configuration of the basin in question, etc. Special emphasis has been laid on the relationship between turbiditic sedimentation and relative changes in sea level (Shammugan and Moiola, 1984; Mitchum, 1985; Mutti, 1985; Mutti and Normark, 1987; Mutti and Sgavetti, 1987; Kolla and Macurda, 1988; Posamentier and Vail, 1988). Eustatic factors may well be responsible for controlling the form of the basin, the position of the coastline and the erosion base level, and thus the possibility of large quantities of terrigenous sediments reaching the distal areas of the basins and continental margins.

In the Betic Cordillera, the westernmost European Alpine chain (Fig. 1), Cretaceous turbiditic facies are well represented and, in certain palaeogeographical domains (Fig. 2), form thick sedimentary accumulations. An analysis of the spatial- temporal distribution of these facies is of great palaeogeographical interest as it helps not only in the understanding of the morphology of the basin, the nature of the sedimentary contributions and their source, but also gives an insight into the nature of the prevailing sedimentary conditions and their changes throughout time in the zone where the western Tethys and central Atlantic met. Main previous data on the Cretaceous turbiditic rocks in the Betic Cordillera are consist of descriptions of stratigraphic sections and/or palaeogeographical reconstructions of particular areas corresponding to different units (Didon *et al.*, 1973; Kurhy, 1975; Pendón, 1978; Bourgois, 1978; Comas, 1978; Ruiz-Ortiz, 1980, 1981; Comas and Ruiz-Ortiz, 1982; Comas *et al.*, 1982; Company *et al.*, 1982a; García-Hernández *et al.*, 1982a; Martínez del Olmo *et al.*, 1982; Maldonado and Ruiz-Ortiz, 1982; López-Galindo, 1986; Martín-Algarra, 1987; Thurow, 1987; Kuhnt, 1987; Molina, 1987; López-Galindo and Martín-Algarra, 1990a,b; among others). Some other works devoted to general aspects of the Mesozoic Betic Cordillera basin also deal with these materials (Hermes, 1978; Azema *et al.*, 1979; García-Hernández *et al.*, 1980; Vera, 1981, 1988; Vera *et al.*, 1982, Martín-Algarra, 1987).

The aims of this paper are: firstly, to bring together, describe and reinterpret in a summarized form the characteristics of the Cretaceous turbiditic sediments in the Betic Cordillera and sectors close to North Africa; secondly, to draw attention to the isochroneity of the turbiditic sedimentation (and their changes) in various different palaeogeographical domains at the western end of the Tethys; and thirdly, outline their possible relationship with the palaeogeographical and tectonic situation prevailing during the Cretaceous and the synchronous changes in sea level.

2. GEOLOGICAL AND PALAEOGEOGRAPHICAL SETTING

Palinspastic and palaeogeographical reconstructions of the western end of the European Alpine chains during the Cretaceous recognise various major tectonic-palaeogeographic domains (plates or subplates). To the north was the Southern Iberian Paleomargin (Fig. 3), now structured in tectonic units corresponding to the External Zones of the Betic Cordillera. To the south laid the margin adjacent to the African plate (Fig. 3), corresponding to the External Zones of the Rif. Between these plates to the east, where they tended to come together, was a domain which Durand-Delga and Fontboté (1980) named the "Mesomediterranean subplate", and later "Alkapeca" (Bouillin *et al.*, 1986). The tectonic deformation of this subplate gave rise to the formation of the Internal Zones of both the Betic and Rif chains.

As mentioned above, two great geological realms can be recognised in the Betic Cordillera, the External and Internal Zones (cf. Figs. 1 and 2). Between them, at their westernmost point, the Campo de Gibraltar Complex crops out. This comprises a suite of mainly Tertiary rocks (with some Mesozoic at the base), which were deposited in a depression with an oceanic or semi-oceanic substrate (North African Flysch Trough), contained between the African and Iberian plates and the Mesomediterranean subplate (Fig. 3), the structure of

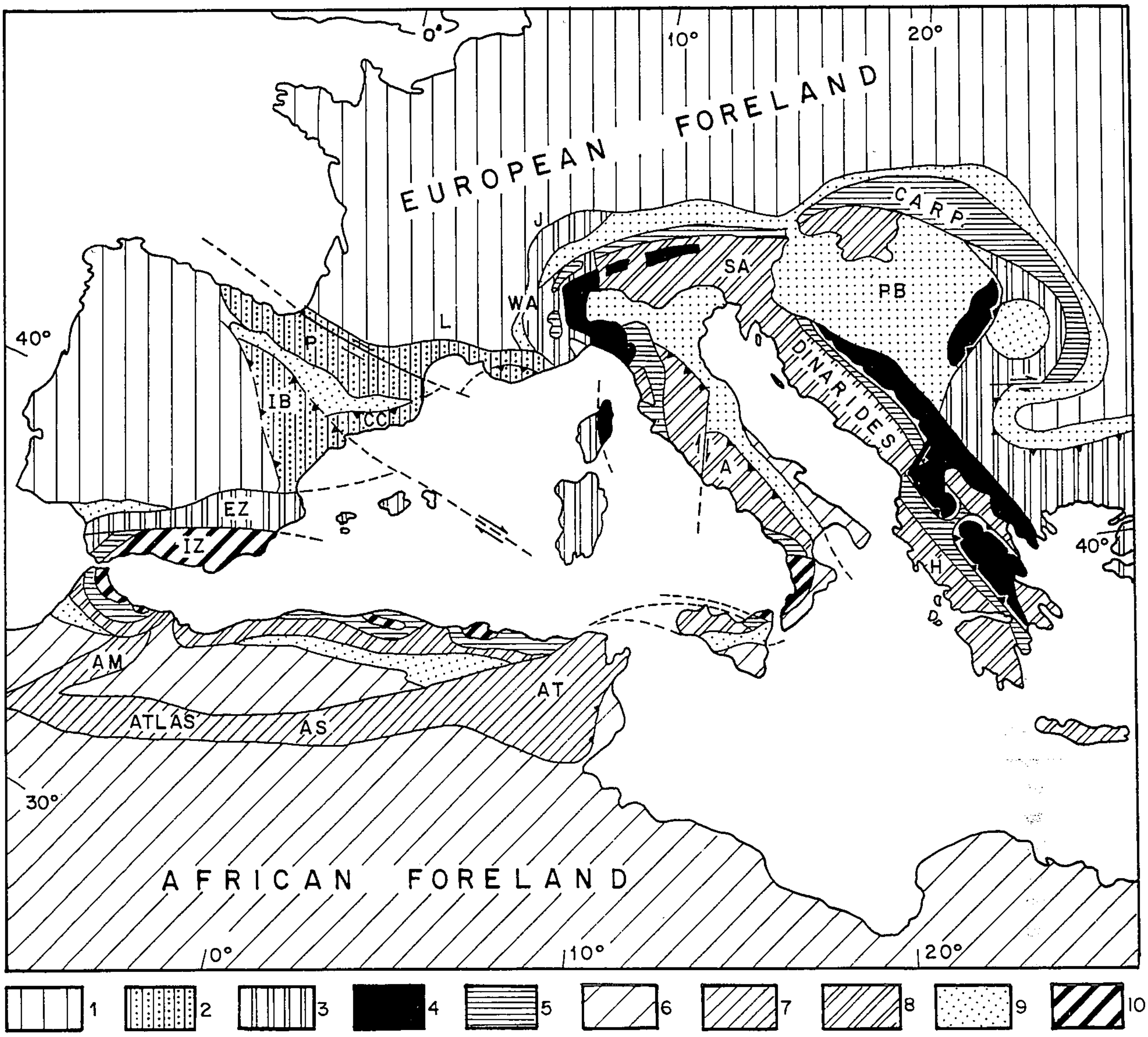

Fig. 1.- Distribution of the Mediterranean Alpine realms according to Ricou *et al.* (1986). Key: 1-2-3: European continent (1.- Foreland, 2.- Intracontinental chain, 3.- Tectonic margin) 4-5: Tethyan ocean (4.- Ophiolitic nappes and related units, 5.- Flyschs nappes). 6-7-8: African Continent (6.- Foreland, 7.- Intracontinental chain, 8.- Tectonic margin). 9.- Molasse foredeep and postorogenic basins. 10.- Internal Zones. Symbols: **EZ**.- Betic External Zones. **IZ**.- Betic Internal Zones. **IB**.- Iberian chain. **CC**.- Catalonian coastal range. **PB**.- Pannonian basin. **AM**.- Middle Atlas. **AS**.- Saharian Atlas. **AT**.- Tunisian Atlas. **A**.- Apennines. **CARP**.- Carpathians. **H**.- Hellenides.

Fig. 1.- Distribución de los dominios alpinos mediterráneos, según Ricou *et al.* (1986). Leyenda: 1-2-3: Continente europeo (1.- Antepaís, 2.- Cadenas intracontinentales, 3.- Margen tectónico). 4-5: Océano del Tethys (4.- mantos ofiolíticos y unidades relacionadas, 5.- Mantos de flysch). 6-7-8: Continente africano (6.- antepaís, 7.-Cadena intracontinental, 8.- Margen tectónico). 9.- Antefosas y cuencas postorogénicas. 10.- Zonas Internas. Abreviaturas utilizadas: **EZ**.- Zonas Externas Béticas. **IZ**.- Zonas Internas Béticas. **IB**.- Cadena Ibérica. **CC**.- Cadena Costerocatalana. **PB**.- Cuenca Panónica. **AM**.- Atlas Medio. **AS**.- Atlas Sahariano. **AT**.- Atlas Tunecino. **A**.- Apeninos. **CARP**.- Cárpatos. **H**.- Helénides.

which today is a complex of thrust nappes. During the Cretaceous, the North African Flysch Trough situated an oceanic or semi-oceanic seaway between the Tethys and North Atlantic.

Cretaceous turbiditic outcrop in southern Spain, forming part of various different tectonic units that make up the Betic Cordillera. They are to be found in two main areas (Fig. 3). One of these was the subsiding realm which lay adjacent and parallel to the edge of the continental platform and the other was the North African Flysch Trough mentioned above.

2.1. *Betic External Zones (Southern Iberian Margin).*

The External Zones are made up of Triassic to Lower Miocene sedimentary materials, which were deposited at the Southern Iberian Paleomargin. The tectonic style of the External Zones of the Betic Cordillera is typical of a sheared-off sedimentary cover (García-Hernández *et al.*, 1980). From the earliest studies of the External Zones (Blumenthal, 1927; Fallot, 1948) two major tectonic and palaeogeographical domains have

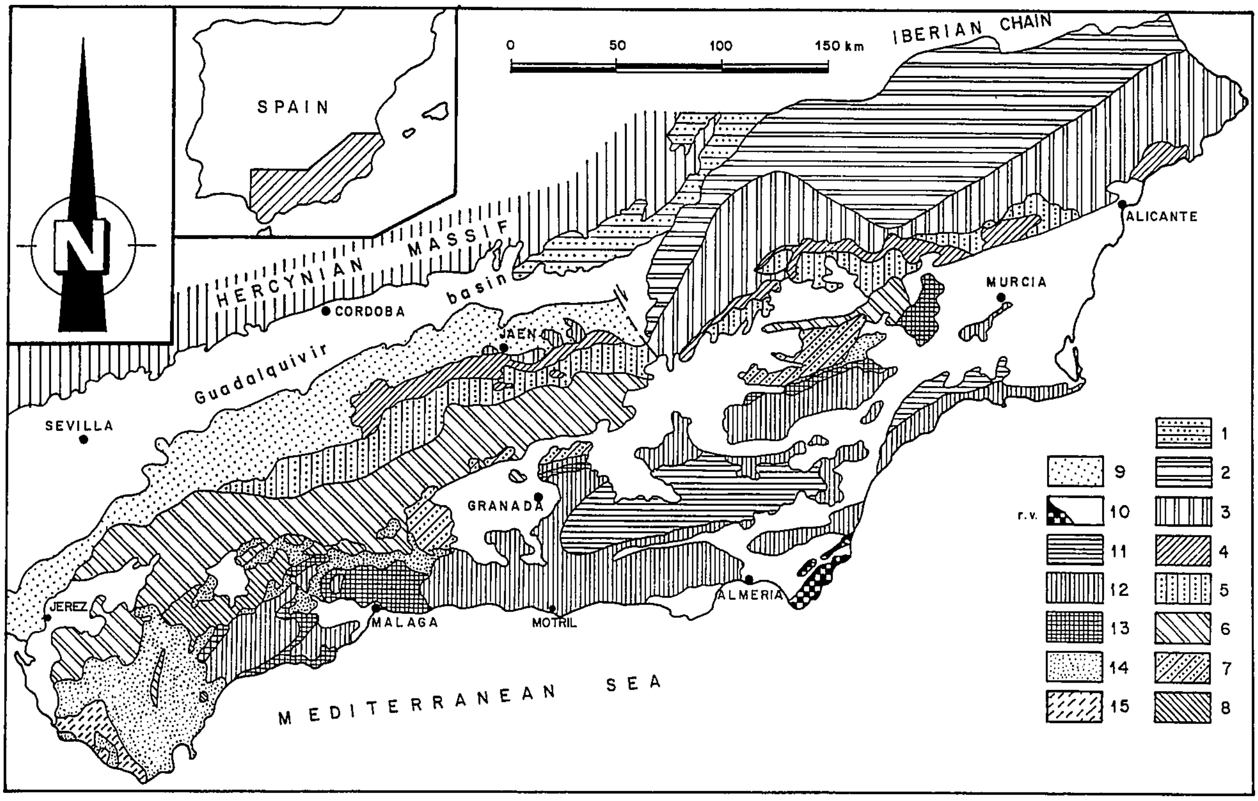

Fig. 2.-Geological sketch map of the Betic Cordillera showing the different geological units, equivalent to palaeogeographic domains. Key: 1.- Non-folded cover (Mesozoic-Tertiary) of the Iberian Massif. 2-3: Prebetic (2.- External Prebetic, 3.-Internal Prebetic). 4.- Intermediate domain. 5-6-7-8: Subbetic (5.-External Subbetic, 6.- Median Subbetic, 7.- Internal Subbetic, 8.- Penibetic). 9.- Miocene syntectonic deposits. 10.- Upper Miocene to Quaternary postorogenic deposits; r.v.- volcanic rocks). 11-12-13: Internal Zones (11.- Nevado-Filabride, 12.- Alpujarride, including Rondaide, 13.- Malaguide). 14.- Flysch units of the campo de Gibraltar Complex. 15.- Almarchal unit of the Campo de Gibraltar Complex (= Tangier unit of the External North African Intrarifian zone).

Fig. 2.-Mapa geológico esquemático de la Cordillera Bética en el que se muestra la distribución de las diferentes unidades geológicas, equivalentes a dominios paleogeográficos. Leyenda: 1.- Cobertera tabular (Mesozoico-Terciario) del Macizo Hercínico de la Meseta Ibérica. 2-3: Prebético (2.- Prebético Externo, 3.-Prebético Interno). 4.- Dominio Intermedio. 5-6-7-8: Subbético (5.-Subbético Externo, 6.- Subbético Medio, 7.- Subbético Interno, 8.- Penibético). 9.- Materiales del Mioceno sintectónicos. 10.- Materiales postorogénicos (Mioceno superior a Cuaternario); r.v.-rocas volcánicas). 11-12-13: Zonas Internas (11.- Nevado-Filábride, 12.- Alpujárride, incluyendo Rondaide, 13.- Maláguide). 14.- Unidades del Flysch del Complejo del Campo de Gibraltar. 15.- Unidad de Almarchal del Complejo del Campo de Gibraltar (= Unidad de Tánger de las Zonas Externas Norteafricanas, en el Intrarif).

been recognised: the Prebetic and Subbetic (Fig. 2). The allochthonous nature of the Subbetic, with an internal nappe structure, appears as a consistent feature, in contrast to the relatively para- autochthonous character of the Prebetic (Azema *et al.*, 1979; García-Hernández *et al.*, 1980). There are also considerable differences between the Subbetic and Prebetic, both from a stratigraphic and palaeogeographical point of view. During the Cretaceous the Prebetic formed a pericontinental platform bordering the southwest of the old Iberian continent. It was the site of thick, mainly carbonate, sedimentation, interrupted from time to time by the arrival of terrigenous sediments brought down from the Iberian continent by fluviatile and fluvial-delta systems (García-Hernández, 1978; Azema *et al.*, 1979; García-Hernández *et al.*, 1980; Vera, 1988). Basinwards, between the Prebetic and Subbetic, there existed a smaller, individual, palaeogeographical domain (cf. Figs. 2 and 3), which has been called the Intermediate Domain (Foucault, 1960-62; Ruiz-Ortiz, 1980). This domain was fairly deep and acted as a trap for both terrigenous or carbonate sediments, spilling over from the Prebetic platform. It is for this reason that the thickest Cretaceous sediments of the whole Betic Cordillera are to be found here and that they show notable turbiditic phenomena. Finally, in the innermost area of the basin, was the Subbetic, which throughout the Cretaceous was a pelagic zone with mainly marly and marly-calcareous sedimentation, within which local and temporal turbiditic intercalations (mainly carbonates) appear.

These larger domains can in turn be subdivided into smaller subdomains (Azema *et al.*, 1979; García-Hernández *et al.*, 1980; Vera, 1981). Within the Prebetic, for example, there is a domain closer to the continent (External Prebetic), which has been constantly subjected to immersion and re-emersion and thus shows many stratigraphic unconformities and continental, often terrigenous, episodes. Further towards the interior of the basin the Prebetic develops into a second subdomain (Internal Prebetic), in which the stratigra-

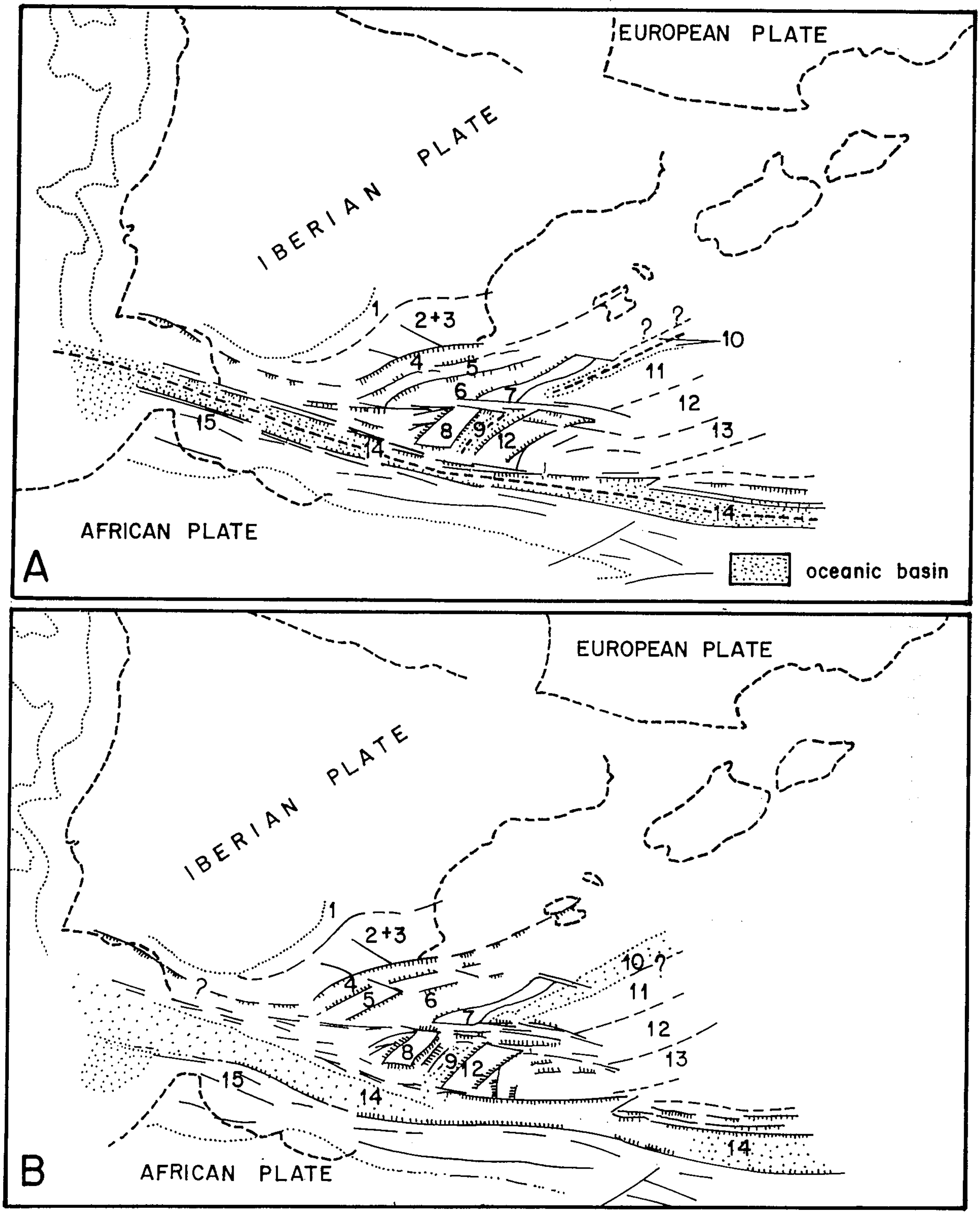

Fig. 3.-Palaeogeographic and palinspastic reconstruction of the westermost Tethys during the Cretaceous, according to Martín-Algarra (1987). A.-Valanginian. B.- Aptian. Key: **1-8: Southern Iberian Margin.** 1: Non-folded cover (Mesozoic-Tertiary) of the Iberian Massif. 2-3: Prebetic (2.- External Prebetic. 3.- Internal Prebetic). 4.- Intermediate Domain. 5-6-7-8: Subbetic (5.- External Subbetic. 6.- Median Subbetic. 7.- Internal Subbetic. 8.- Penibetic). 9.- Deep basin between Penibetic and Rondaides. 10-13: Mesomediterranean subplate. 10.- Oceanic areas in Nevado-Filabride complex. 11.-Nevado-Filabride, 12.-Alpujarride, including Rondaide. 13.-Malaguide. 14.- North African Flysch Trough. 15.- North African Margin (Intrarif = Ketama-Tangier units).

Fig. 3.-Reconstrucción paleogeográfica y palinspástica del extremo occidental del Tethys durante el Cretácico, según Martín-Algarra (1987). A.-Valanginiense B.-Aptiense. Leyenda: **1-8: Margen Sudibérico.** 1: Cobertera tabular (Mesozoico-Terciario) del Macizo Hercínico de la Meseta Ibérica. 2-3: Prebético (2.- Prebético Externo. 3.- Prebético Interno). 4.- Dominio intermedio. 5-6-7-8: Subbético (5.- Subbético Externo. 6.- Subbético Medio. 7.- Subbético Interno. 8.- Penibético). 9.- Cuenca profunda localizada entre el Penibético y los Rondaides. 10-13: Subplaca Mesomediterránea. 10.- Areas oceánicas en el Complejo Nevado-Filábride. 11.- Complejo Nevado-Filábride, 12.- Complejo Alpujárride, incluyendo los Rondaides. 13.- Complejo Maláguide. 14.- Surco de los Flysch Norte-Africanos. 15.- Margen continental Norte-Africano (Intrarif= Unidades de Ketama-Tánger).

phic levels are thicker and more continuous (Foucault, 1971; García-Hernández, 1978; Martín *et al.*, 1985); the length of time not represented by sedimentation decreases and there is a progressive transition towards the pelagic basin (Intermediate Domain and Subbetic).

The morphology of the Subbetic basin was very irregular due to severe Jurassic intracontinental rifting at the Southern Iberian Paleomargin (García-Hernández *et al.*, 1989), which gave rise to high swells and deep troughs. The External Subbetic subdomain was a high swell throughout the Middle- and Upper-Jurassic (Azema *et al.*, 1979; García-Hernández *et al.*, 1980; Vera, 1981, 1988) and was locally emerged during the Lower Cretaceous (Molina, 1987). This swell separated the subsiding basin of the Intermediate Domain from another trough farer from the continent: the Median Subbetic (Fig. 3). During the Uppermost Jurassic and Lower Cretaceous a secondary swell of volcanic origin developed within this latter basin and this had an important effect on the local sedimentation pattern. It determined, for instance, that during the Cretaceous the stratigraphy and palaeogeography of the southern part of the External Subbetic and the northern part of the Median Subbetic were remarkably similar to each other but very different from the southern part of the Median Subbetic (Comas, 1978), a fact which is also borne out by the nature of the sedimentary contributions themselves (López-Galindo, 1986). The internal edge of the margin was made up of yet another swell (Internal Subbetic), which, far from being a homogeneous domain, comprised a chain of humps (Martín-Algarra, 1987) with relatively different stratigraphical characteristics from one site to another: the most westerly of these domains (Penibetic) was that which tended to subside the least and even became emerged and largely karstified during the Lower Cretaceous (González-Donoso *et al.*, 1983; Martín-Algarra, 1987). The boundaries between the Subbetic troughs and swells were especially suitable sites for gravity resedimentation processes and they often contain considerable quantities of turbidites and other reworked sediments, the product of the partial breakup of the heights and talus slopes of the swells. These deposits are practically all carbonates as the siliciclastic sediments deriving from the Iberian continent rarely reached as far as the outermost sectors of the Subbetic.

2.2. *Betic Internal Zones (Mesomediterranean subplate).*

The Internal Zones form a great allochthonous terrane made up of a suite of thrust nappes, which, from bottom to top, can be subdivided into three important complexes: the Nevado-Filabride; the Alpujarride; and the Malaguide (Fig. 1). Cretaceous sediments only occur in the Malaguide and in certain tectonic elements equivalent to some units belonging to the Alpujarride, i.e. the Rondaide (also called the External Dorsal by some authors, Durand-Delga *et al.*, 1970; Durand-Delga, 1973, 1980; Didon *et al.*, 1973; Nold *et al.*, 1980).

During the Jurassic and Cretaceous the Betic Internal Zones, together with their counterparts on the other side of the Straits of Gibraltar, the Rifian Internal Zones, formed part of an allochthonous terrane, the Mesomediterranean subplate (Durand-Delga and Fontboté, 1980). This was a tectonically mobile, continental-crust domain, not subject to subsidence, wedged between the African and European plates and their dependences (Iberia and Adria). It constituted the palaeogeographic precursor to the Internal Zones of the Alpine Cordilleras in the western Mediterranean. The Mesomediterranean subplate was separated from the Southhern Iberian continental Margin to the northwest (i.e. the Betic External Zones) and the North African Margin to the southwest (i.e. External Zones of the Rif and Tell Cordilleras) by deep oceanic or semioceanic basins. The western and southern edges of the Mesomediterranean subplate were narrow, abrupt, continental margins formed by faulting associated with rifting that took place throughout the Jurassic and Lower Cretaceous.

The Alpujarride and Nevado-Filabride domains made up the northern area of the Mesomediterranean subplate but due to the severity of the tectonic deformation and Alpine metamorphism that these rocks have undergone, their Cretaceous history is still not very well understood. Nevertheless, the presence of thin beds of unmetamorphosed, pelagic, Cretaceous sediments, both in the Rondaide (Martín-Algarra, 1987) and the Malaguide (Roep, 1980), does allow us to establish the major features of the palaeogeography of the central-western sector of the Mesomediterranean subplate. During the Cretaceous the Malaguide formed a moderately deep, pelagic platform with very little carbonate sedimentation (only reworked materials around the edges of the domain), which gave way to an abrupt, faulted, slope zone, represented today by the Rondaide units. These units are the vestiges of an Austro-Alpine-type continental margin which bordered the west and northwest of the Malaguide platform and from the Liassic/upper-Dogger to the upper-Paleogene received very little sedimentation (Martín-Algarra, 1987). The best represented Cretaceous sediments on this talus slope are Neocomian and frequently contain breccias and base-of-slope microbreccias.

One sector of the Mesomediterranean subplate to the east of the Malaguide, which probably corresponds today to the Kabylian Internal Zones and possibly also to the Calabrian-Peloritanian Zones was temporarily emerged during the Cretaceous. This sector constituted an important source area for terrigenous materials, which reached both the continental margin and the deep basin to the south in fair quantities, unlike the deposits at the Rondaide margin.

2.3. *Campo de Gibraltar Complex (Flysch Trough).*

This complex contains numerous tectonic units made up largely of turbiditic materials from the Cretaceous and, even more so, from the Tertiary, and is wedged into the contact between the Internal and External Zones. Most of the units that crop out in the southwesternmost part of Spain (Campo de Gibraltar) have their exact counterparts in North Africa, where they belong to the Rifian Flysch Complex. This is the case with the Algeciras, Facinas-Almarchal and Nogales Units on the Iberian side, which correspond to the African Beni Ider, Mellousa (or Internal Tangier) and Tisiren Units respectively (Didon *et al.*, 1973). There are also some units in the Campo de Gibraltar Complex made up entirely of Cretaceous terrigenous sediments, such as the Ubrique and the Corredor del Boyar Flysches that pose greater problems as to their correct correlation.

Cretaceous sediments are much better represented in the flysches of Northern Morocco than they are in those of the south of Spain. Thus, while the Tisiren Unit crops out extensively in the northern Rif, the equivalent Spanish Nogales Unit is only represented by minuscule outcrops. The reasons for this fact are mainly palaeogeographical (Martín-Algarra, 1987): during the uppermost-Jurassic and the Lower Cretaceous deep, narrow, oceanic or semi-oceanic basins opened up between the Mesomediterranean subplate and the Southern Iberian and North African continental margins; the orientation of each of these basins was different and as a consequence they received different quantities of sedimentation (Fig. 3). Between the internal edge of the Southern Iberian Margin (Penibetic) and the western and northwestern edge of the Mesomediterranean subplate (Austro-Alpine-type Rondaide margin), there opened a deep basin, which, together with the two neighbouring domains, was starved and received very little sedimentation. The sedimentation that did occur constituted thin beds of deep-sea clays, which at present times represent the Cretaceous stratigraphic substrate of various units in the Campo de Gibraltar Complex. Where they crop out they are generally highly reworked by mass resedimentation processes and the Alpine tectonism that affected the Betic orogen from the Lower Miocene. This basin, which was orientated approximately NE-SW, in line with the Southern Iberian margin, connected to the S and SW with another longer basin known as the North African Cretaceous Flysch Trough (cf. Fig. 3), in which much greater quantities of Cretaceous sediments were deposited (Durand-Delga, 1980).

The North African Cretaceous Flysch Trough originated at the great transform accident zone which, during the Jurassic and Lower Cretaceous, marked the northern boundary of the African plate (Fig. 3). It ran approximately east-west for some 1,500 kilometres and was the depositional site of both the Betic-Rifean Cretaceous flysches and their more easterly Kabylian and Sicilian counterparts (Chiocchini *et al.*, 1980; Wildi, 1983; Martín-Algarra, 1987). To the east this domain constituted the boundary between the North African margin and the future Kabylian and easternmost regions of the Mesomediterranean subplate, while to the west the Southern Iberian and North African continental margins faced each other on either side of this basin (Fig. 3).

In the North of Africa the thick successions of Cretaceous sediments deposited in the North African Flysch Trough can be subdivided into two palaeogeographical domains: the Mauritanian and the Massylian (Bouillin *et al.*, 1970; Durand-Delga, 1980). The deposits in the Mauritanian area are characteristic of the more internal (northern) sector of the basin: they were mainly the product of the erosion of the Kabylian areas of the Mesomediterranean subplate (Chiocchini *et al., 1980; Raoult et al.*, 1982). The Massylian represented the southern, deep-oceanic sector of the trough and some of its stratigraphic features resemble those of the northern sectors of the External Zones of the North African Cordilleras (Durand-Delga, 1980; Kuhnt and Obert, 1991). The Cretaceous flysches of the Campo de Gibraltar Complex represent the deposits at the western end of the North African Flysch Trough, where the two continental margins directly faced each other. It may be for this reason that some of the units, such as the Ubrique and Corredor del Boyar have certain stratigraphic peculiarities that distinguish them slightly from the Rifian Flysches (Martín-Algarra, 1987).

3. CRETACEOUS TURBIDITES

Both terrigenous and carbonate turbidites were deposited in the Betic Cordillera during the Cretaceous. The thickest succesions of siliciclastic turbidites were laid down during the Barremian, Aptian and Albian in two very distant palaeogeographic domains: the Intermediate Domain and the North African Flysch Trough. The calcareous turbidites and other less important terrigenous sediments are distributed more irregularly both in space and time. In this section a description will be given of the characteristics of the Cretaceous turbidite materials in each of their palaeogeographical contexts.

3.1. *Cretaceous turbidites at the Southern Iberian Margin.*

Both siliciclastic and carbonate turbidites were deposited throughout the Cretaceous at the southern margin of the Iberian plate, which at the present day forms part of the External Zones of the Betic Cordillera. The main accumulation of siliciclastic turbidites took place from the Latest Hauterivian to the Late Albian (Cerrajón Fm., Ruiz-Ortiz, 1980, 1981) in the Intermediate Domain, the most external trough, adjacent to the marginal platform (Prebetic Zone) which acted as a trap for the detritus coming from the continent itself or from the Prebetic platform. Nevertheless, some small intercalations of siliciclastic turbidites do exist in the Internal Prebetic and External Subbetic, the palaeogeographic realms adjacent to the Intermediate Domain.

The remainder of the turbidite deposits are carbonate and are to be found more locally, normally in transition areas between platforms or between swells and adjacent troughs. Deposits of this kind have been described in the Internal Prebetic, the Intermediate Domain and the External Subbetic and also in the Median Subbetic, the Internal Subbetic and the Penibetic at different periods during the Cretaceous.

We shall deal first of all with the deposits in the most external areas of the basin (Internal Prebetic, Intermediate Domain and External Subbetic), where the materials arriving from the continent were mainly siliciclastic, and then we shall go on to describe the carbonate turbidites deposited in the internal parts of the basin (Median Subbetic, Internal Subbetic and Penibetic).

3.1.1. *Cretaceous turbidites in the Intermediate Domain and adjacent sectors.*

As mentioned above, the greatest quantity of turbidites accumulated in the trough corresponding to the Intermediate Domain. It is here that the Cretaceous deposits are thickest along the whole continental margin. To the south of Jaén, for example, the Cretaceous series from the Berriasian to the Cenomanian-Turonian, laminated tectonically by the overthrusting of the External Subbetic, is some 2600 meters thick.

The various turbidite bodies and intercalations, both siliciclastic and carbonate, that crop out in the Intermediate Domain and adjacent sectors are shown schematically in Figure 4, and are correlated with the unconformities and sedimentary cycles already identified in the carbonate materials of the Prebetic platform.

The first turbidite intercalation is a carbonate one; it appears in the Lower Berriasian and crops out locally in the Intermediate Domain. These turbidites appear to have been deposited in a carbonate channel-levee complex (Comas and Ruiz-Ortiz, 1982). They lie directly upon upper-Tithonian, calcareous debrites and other slope deposits and are related to other Upper Jurassic, calcareous turbidite systems in the Intermediate Domain, such as the Toril Formation (Ruiz-Ortiz, 1983). These Jurassic deposits correspond to marginal-basin infillings at a time when the troughs and swells at the Southern Iberian Margin were well distinguished. The source area for the sediments was the Prebetic shelf next to the continent and its talus slope. These lower-Berriasian, calcareous turbidites belonged to the only carbonate turbidite system active in the region at the beginning of the Cretaceous.

Small intercalations of siliciclastic turbidites appears towards the end of the Berriasian. They are made up of beds of fine- to very-fine-grained sandstone with Bouma sequences cut out at the base. Sole marks indicate that the currents ran southwards. In some sections these terrigenous turbidites continue into the Valanginian. Their deposition would correlate with the first arrival of terrigenous materials onto the Prebetic platform (García-Hernández, 1978). In Figures 4 and 6 it can be seen that they are related to unconformity number of the upper Berriasian.

Carbonate and siliciclastic turbidite intercalations have been identified in the lower- and upper-Valanginian respectively. The carbonate turbidites crop out locally in the Internal Prebetic in the form of onlapping sedimentary bodies with thickening-upward sequences. They have been interpreted as being lobes (García-Hernández *et al.*, 1982a), which intercalate within the limestone-marl rhythmites of the Villares Formation. They are composed of calcisiltites and fine calcarenites 5.5 to 7 meters thick and an extension of 25 m to 30 m. They crop out only in the Internal Prebetic and do not reach the Intermediate Domain, which lay further to the south at this time (Fig. 4). The siliciclastic turbidites of the upper Valanginian are much more widely distributed and can be found in stratigraphic sections both in the Internal Prebetic and the Intermediate Domain. It can be seen in Figures 4 and 6 that they are related to unconformity number 2 (intra-Valanginian) and have distal turbidite features similar to those described in the Upper Berriasian.

In the Intermediate Domain there is a thick, extensive lithostratigraphic unit made up of siliciclastic turbidites (Cerrajón Fm.), dating from the upper-Hauterivian at the base and being limited at the top by Lower Cenomanian marls, which, according to the terminology of Mutti and Normark (1987), corresponds to a turbidite complex. In the type section, to the south of Jaén (Ruiz-Ortiz, 1980; Vera *et al.*, 1982), it reaches a thickness of 1200 meters, but this lessens considerably both eastwards and westwards to around 400-500 m. Three separate turbidite systems have been distinguished in this section: the base of the first system coincides with that of the formation and began in the Upper Hauterivian; the second system was active during the Aptian; and the last one dates to the Upper Albian. Between these systems in general there are silty marls with some intercalations of sandstones and calcareous turbidites, while between the second and third systems in particular marly limestones containing Pithonellas and planktonic foraminifers appear. The unconformities related to these turbidite systems are most likely intra-Hauterivian, intra-Aptian and intra-Albian (numbers 3, 5 and 6 in Fig. 4).

The petrology of the sandstones is fairly uniform throughout the Intermediate Domain and is characterized by three notable features: abundance of carbonate allochems (up to 15% in some layers), typical of shallow marine environments (ooids, intraclasts, benthonic foraminifers etc.); presence of cortoids with siliciclastic nuclei; and an almost complete lack of rock fragments and, in places, detrital matrix. These features point to certain conclusions about the origin of the turbidite sediments: firstly, that the source area must have been continental, with outcrops of quartzites and plutonic rocks, similar in fact to areas of the present-day Iberian Meseta; and secondly, that the terrigenous sediments were initially deposited on a shallow, mixed carbonate/siliciclastic platform, from whence they were

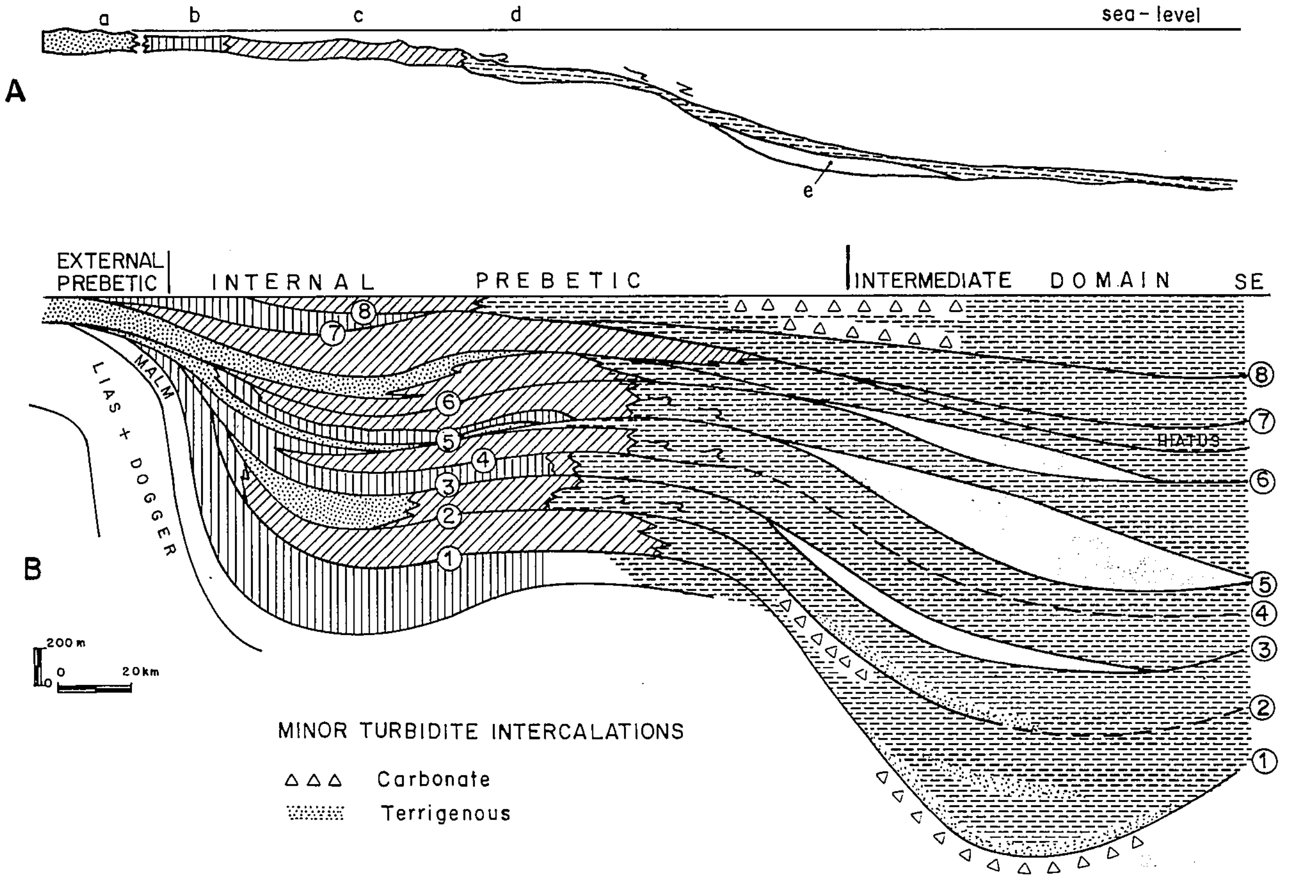

Fig. 4.-Palaeogeographic sketch (A) and chronostratigraphic chart (B) of the most external part of the southern Iberian Margin. Data of the Prebetic according to García-Hernández, 1978; Vera *et al.*, 1982). Key: a.- Fluvio-deltaic and continental facies. b.- Inner platform facies. c.- Outer platform facies. d.- Hemipelagic facies. e.- Terrigenous turbidite systems (stages I and II of Mutti, 1985). Isochronous correlation lines: 1.- Lower Berriasian. 2.- Lower/Upper Valanginian Boundary. 3.- Upper Hauterivian. 4.- Upper Barremian. 5.- Lower/Upper Aptian Boundary. 6.- Middle/Upper Albian Boundary. 7.- Upper Turonian. 8.- Lower/Upper Senonian Boundary.

Fig. 4.-Esquema paleogeográfico (A) y cuadro cronoestratigráfico (B) de la parte más externa del Margen Continental Sudibérico. Elaborado, para el Prebético, a partir de datos de García-Hernández, 1978; Vera *et al.*, 1982). Leyenda: a.- Facies fluvio-deltaicas y continentales. b.- Facies de plataforma interna. c.- Facies de plataforma externa. d.- Facies hemipelágicas. e.- Cortejos sedimentarios de turbiditas terrígenas (estadios I y II de Mutti, 1985). Líneas isocronas de correlación: 1.- Berriasiense inferior. 2.- Límite entre Valanginiense inferior y superior. 3.- Hauteriviense superior. 4.- Barremiense superior. 5.- Límite entre Aptiense inferior y superior. 6.- Límite entre Albiense medio y superior. 7.- Turoniense superior. 8.- Límite entre Senoniense inferior y superior.

transported and redeposited at greater depths some time afterwards.

From a sedimentological study of these turbidites Ruiz-Ortiz (1980, 1981) has proposed a depositional model involving a longitudinal sediment-dispersal pattern, i.e. subparallel to the slope strike. Maldonado and Ruiz-Ortiz (1982) made a comparison between this depositional model for the Cerrajón Formation and the processes occurring in modern turbidite systems in the western Mediterranean and came to the conclusion that the Ebro systems and those of the Valencia trough seem to be analogous to the systems involved in the generation of the Cerrajón Formation.

Turbiditic intercalations similar to the materials of the Cerrajón Formation and possibly genetically related to them have been identified in the Internal Prebatic and the External Subbetic. In general they are thin-bedded turbidites intermittently intercalated within the pelagic carbonate materials. They correspond to the fine fraction (usually the carbonate fraction) of the turbidites from the Cerrajón Formation and were carried here by dilute turbidity currents. Small turbidite intercalations have been described in the Internal Prebetic during the upper-Barremian, Aptian and Albian (García-Hernández *et al.*, 1982b; Leret *et al.*, 1982), which may correspond to overbank flows and other local processes. The most important accumulations of turbidites outside the Intermediate Domain are those of the Argos Formation in the External Subbetic (Van Veen, 1969). This formation consists of rhythmic beds of lightish-coloured calcisiltites and marls, containing intercalations of turbidite calcarenites, which vary from some centimetres to decimetres in thickness and are even more than a metre in places. Texturally they are packstones made up of bioclasts of echinoids, bryozoans, moluscs and benthic foraminifers such as orbitolinids. The non-carbonate fraction rarely exceeds 50% and is composed of quartz, quartzite and chert fragments, mi-

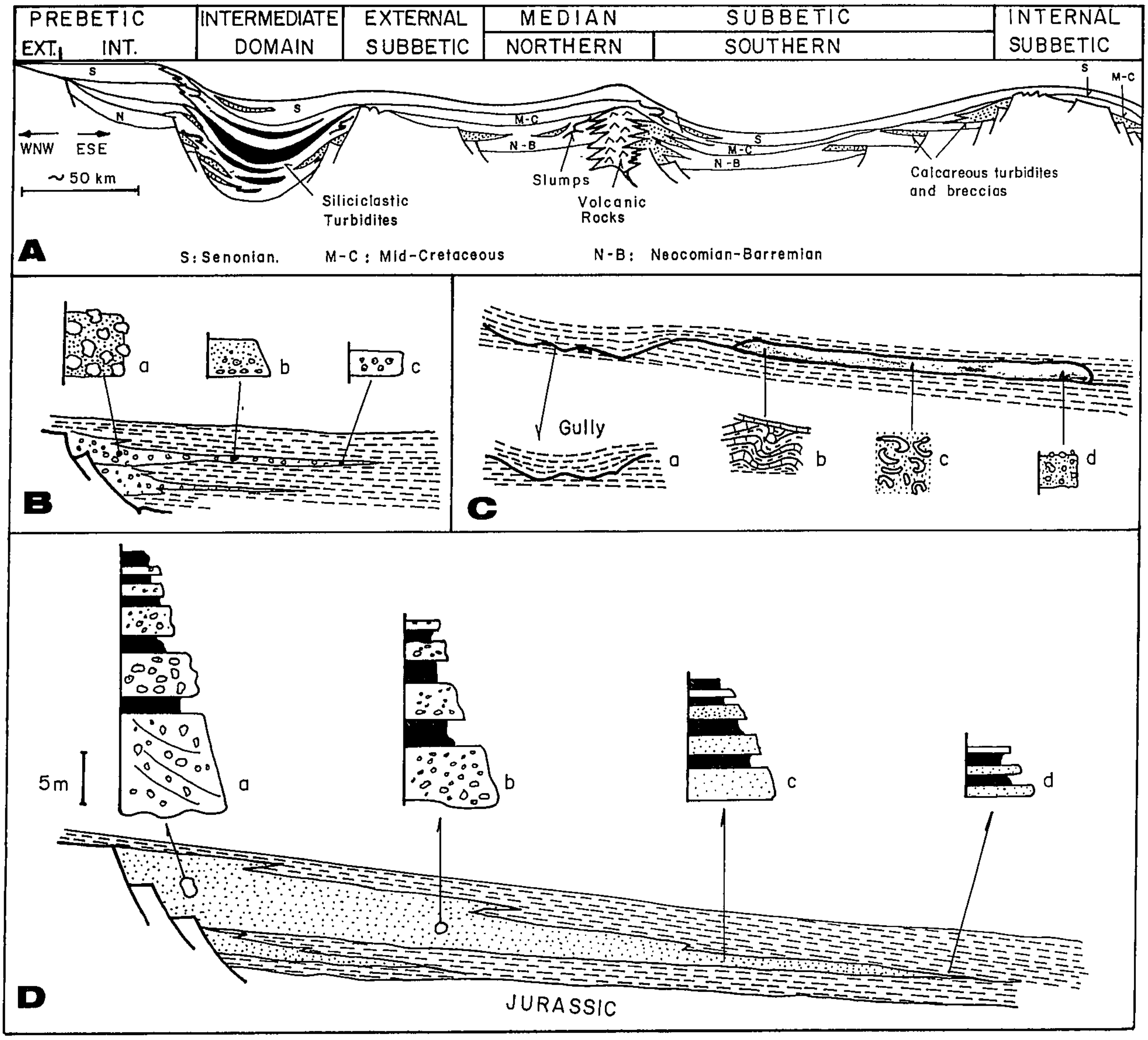

Fig. 5.-Turbidites in the Southern Iberian Margin during Cretaceous. **A**.- Palaeogeographic position of siliciclastic and carbonate turbidites in the Southern Iberian Margin during Cretaceous. **B**.- Facies associations within a single cretaceous carbonate turbidite body linked to a fault scarp in Jurassic oolitic limestones (Internal Subbetic, according to Vera *et al.*, 1990; Aguado *et al.*, 1991). Key: a.- disorganized clast-supported calcareous breccias; b.- Gradded calcareous microbreccias with ooliths; c.- Oolitic turbidite calcarenites. **C**.- Facies associations in mass-flow deposists induced within Lower-Cretaceous marly-limy rhythmites of the Northern Median Subbetic. Key: a.- slump scars; b.- slump with internal structure. c.- evolved slump with chaotic internal structure. d.- intraformational breccias (pebbly mudstones). **D**.- Thinning- and fining-upward sequences in Mid- to Upper Cretaceous calcareous turbidites and breccias of the transition from Northern to Southern Median Subbetic (Fardes Fm.) Facies changes from massive unsorted or roughly sorted calcareous breccias (a), to graded breccias (b), to turbiditic microbreccias and calcarenites (c), and, finally, to fine-grained and thin-bedded, calcareous turbidites (d).

Fig. 5.-Turbiditas del Margen Sudibérico durante el Cretácico. **A**.- Posición paleogeográfica de las turbiditas siliciclásticas y calcáreas en el contexto del Margen Continental Sudibérico durante el Cretácico. **B**.- Asociaciones de facies dentro de un cuerpo simple de turbiditas calcáreas (turbiditas oolíticas), genéticamente relacionado con un escarpe de fallas en el que afloran calizas oolíticas del Jurásico medio (Subbético Interno, según Vera *et al.*, 1990; Aguado *et al.*, 1991). Leyenda: a.- Brechas calcáreas desorganizadas, que presenta soporte de clastos; b.- Microbrechas calcáreas con oolitos redepositados; c.- Calcarenita turbidítica oolítica. **C**.- Asociaciones de facies características de depósitos de flujo en masa dentro de la ritmita calizas/margas del Cretácico inferior del Margen Sudibérico. Leyenda: a.- cicatriz de *slump*; b.- *slump* con una estructura interna visible. c.- *slump* con estructura interna caótica. d.- Ruditas intraformacionales. **D**.- Secuencias estratodecrecientes y granodecrecientes en turbiditas calcáreas del Cretácico medio y superior en el sector de tránsito entre el Subbético medio septentrional y meridional (Fm. Fardes). Cambios de facies desde brechas calcáreas con escasa o nula selección (a), a brechas granuloclasificadas (b), a microbrechas turbidíticas y calcarenitas (c), y, finalmente, a turbiditas calcáreas de grano fino y finamente estratificadas (d).

cas, feldspars and heavy minerals. The grain size ranges from coarse to very-fine sand. Van Veen (1969) dated this formation in the type section as very Late Barremian-Middle Aptian, but Kuhry (1972) gives evidences favouring a later age to the top in some sections. Therefore this formation correlates with the Cerrajón

Fm. of the Intermediate Domain, which has a wider chronostratigraphic extent. The calcareous turbidites of the Argos Fm., with important amounts of siliciclastics, and bioclasts of shallow water environments only present in the Prebetic, should have the same sources as the turbidites of the Cerrajón Fm., from which the should be distal equivalents. The greater concentration of carbonate grains in the turbidites of Argos Fm., should be a function of the different hydrodynamic behaviour of the carbonate versus the siliciclastic grains (Stow, 1986).

Finally, in the Senonian carbonate turbidites are to be found as local, thin intercalations within pelagic rocks in the Internal Prebetic and the Intermediate Domain. They are found associated with slumps and mass slides of pelagic limestones, characteristic of talus-slope environments. Company *et al.* (1982a) describe them in the Campanian-Maastrichtian of S^a Aixorta, in the eastern sector of the cordillera, where they interpret them as being transition deposits between the marginal platform and the basin proper, deposited at between 400 m and 500 m. The lower levels of these turbidites lie upon unconformity number 8 in Figures 4 and 8 (upper Senonian). Nevertheless, they also appear higher up in this same depositional sequence (Fig. 4).

So, in the most external part of the continental margin, the turbidites are mainly concentrated in the Cerrajón Fm. (Late Hauterivian / Latte Abbian) of the Intermediate Domain. The deposits are siliciclastic but with a significant content of carbonate grains. In the Internal Prebetic the talus-slope deposits contain small intercalations of turbidites, while in the External Subbetic intercalations of distal turbidites occur in a basin-plain environment. The base of slope and basin-plain environments, where the greater part of the gravity-flow deposits collected, is partially represented in the Intermediate Domain, although much of it is missing due to the masking effects of thrust-sheet tectonics in the Betic Cordillera.

3.1.2. *Cretaceous turbidites in the Subbetic.*

The terrigenous turbidites in the Argos Fm., genetically related to those of the Cerrajón Fm. in the Intermediate Domain, have already been described. Apart from these, all the Subbetic turbidites are carbonate and local in extension (Fig. 5). They are often found as slumps, mass slides, and coarse conglomerate and/or breccia facies with finer calcarenite and/or calcisiltite, turbidite facies intercalations (Figs. 5B, 5C and 5D). These sediments came from the faulted edges of pelagic swells on both a local and regional scale (Fig. 5A). Tectonic activity played an essential role in their generation in two ways: firstly by creating fault scarps in which older, Jurassic and Cretaceous rocks cropped out, and then by triggering gravity flow sedimentation. Anaerobic conditions prevailed in the depths of the confined areas of the pelagic basin, where darkish sediments were deposited and within which some turbidite beds are intercalated. The greatest quantities of turbidites were deposited during the Aptian-Albian and Coniacian-Santonian.

In the Carretero Fm., made up of lower-Cretaceous, pelagic, limestone-marl rhythmites, slumps and other slope processes are common and give rise to debris deposits made up on the whole of pelagic limestone clasts and, locally, beds of aptychi. In various parts of the Subbetic deposits known as "aptychus microbreccia", calcareous turbidites containing large quantities of aptychus fragments, have been described. The greatest accumulations of slumps and pelagic detritus are found in the original transition areas between troughs and swells in the basin (Figs. 5A and 5C). The gravity flows that generated these sediments (Fig. 5C) were related to tectonic fault activity and/or halokynesis in the Triassic Keuper facies (red clays containing gypsum and other salts), which conditioned the topography of the floor of the basin (Sanz de Galdeano, 1973; Nieto, 1990).

During the Senonian the reworking of carbonate deposits also took place in small sub-basins in the easternmost External and Median Subbetic. Van Veen (1969) has described intercalations of calcarenites and calcareous conglomerates containing large quantities of Inoceramus fragments in the Jorquera Fm. (Maastrichtian/early-Eocene) of the External Subbetic, in an area between La Puebla de Don Fadrique (Province of Granada) and Caravaca (Province of Murcia).

One of the best examples of a carbonate turbidite formation in the Subbetic, is that of the Fardes Fm. (Comas, 1978; Hernández-Molina *et al.*, 1991). The rocks are turbidite calcarenites and conglomerates, intercalated within anaerobic hemipelagites. These sediments accumulated from the Albian to the Santonian, but the record of the Early Cenomanian and the Turonian is scarse or absent. The lithology of the turbidite beds in the Fardes Fm. varies from coarse conglomerates and breccias containing large blocks to fine calcarenites and calcisiltites (Fig. 5D). The conglomerate and breccia clasts derive both from the erosion of older Jurassic and Cretaceous formations and that of coetaneous sediments. In some olistostrome beds allolistoliths of different ages, up to several hm^2 in size crop out. The finer calcarenite and calcisiltite facies are composed of carbonate allochems (intraclasts, ooids, bioclasts) with a small siliciclastic contribution (never more than a 5%). These turbidites are intercalated between green and red hemipelagites, composed of bentonitic clays, slightly carbonate clays with radiolaritic sediments (Comas, 1978; Comas *et al.*, 1982; Vera *et al.*, 1982). The turbidites and olistostromes of the Fardes Fm. came from the erosion the eastern Internal Subbetic, a conclusion that can be reached if me takes into account the age and facies of clasts (Hernández-Molina, 1992). Besides, the Median Subbetic basin was almost certainly confined, with a relatively high CCD caused by the chemistry of the sea water and the active vulcanism in the region at that time (López-Galindo, 1986). The thicker olistostrome beds reflect the episodes of greater instability in the adjacent talus slopes.

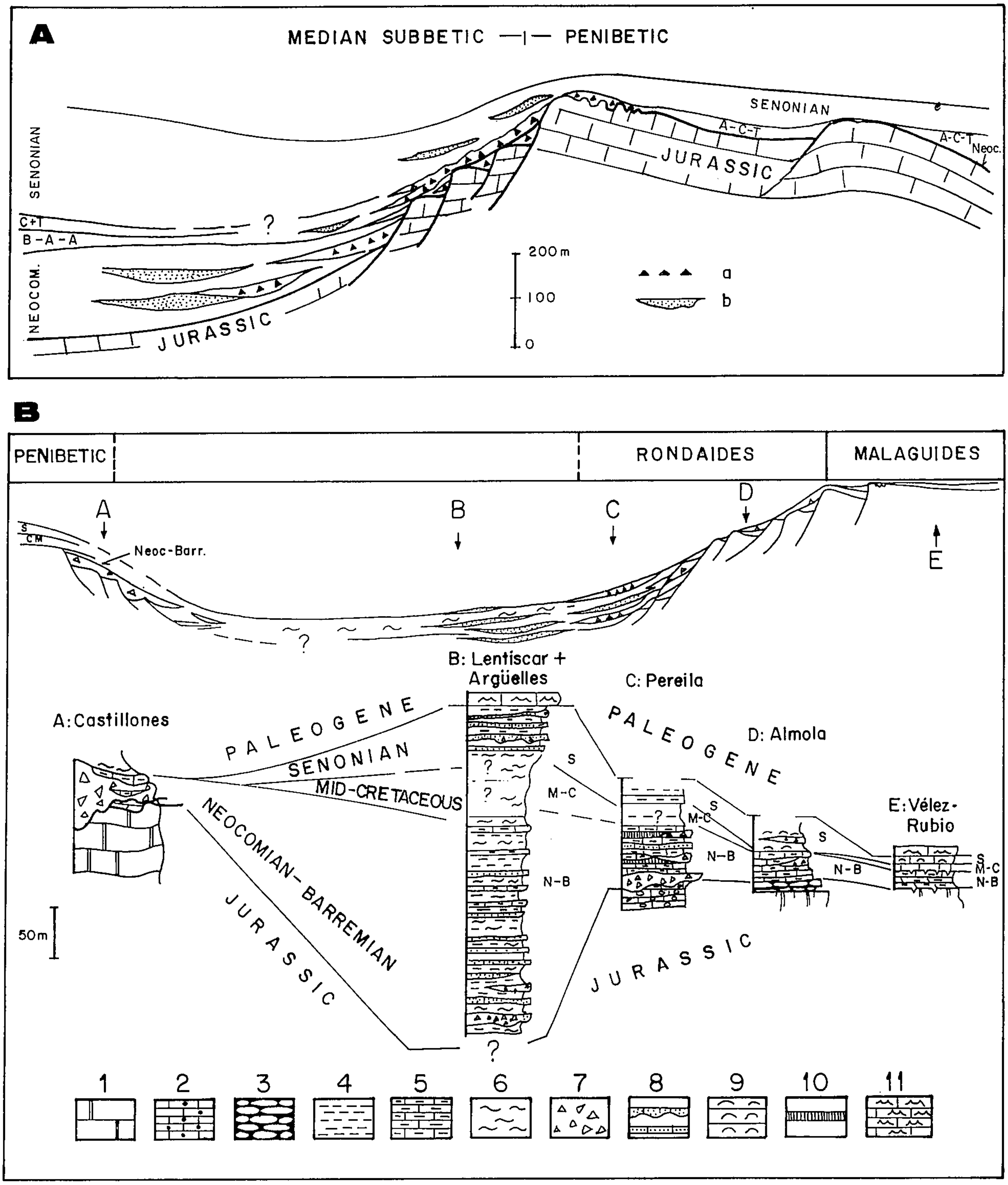

Fig. 6.-Turbidites in the Southern Iberian Margin during Cretaceous. **A.**- Stratigraphic and palaeogeographic position of turbidite deposits in the transitional area from the Median Subbetic to Western Internal Subbetic (Penibetic). Key: a.- clast-supported, carbonate breccias (upper slope) and pebbly mudstone (lower slope). b.- Calcareous microbreccias and turbiditic calcarenites. B-A-A.- Barremian-Aptian-Albian. A-C-T: Albian-Cenomanian-Turonian. **B.**- Palaeogeographic position of turbidite deposits in the deep basin in between the Penibetic (Southern Iberian Margin) and the Rondaides and Malaguides (western margin of the Mesomediterranean subplate). Key: 1.- Jurassic platform limestones. 2.- Cherty limestones. 3.- Nodular limestones. 4.- Gray to green marls. 5.- Gray-green and white marly limestones. 6.- Variegated clays. 7.- Unsorted carbonate breccias. 8.- Carbonate turbidites and microbreccias (Aptychus microbreccias in the Neocomian). 9.- Red marls and marly limestones with Globotruncana. 10.- Siliceous marls and radiolarites. 11.- Paleocene turbiditic Microcodium limestones.

Fig. 6.-Turbiditas en el Margen Continental Sudibérico durante el Cretácico. **A.**- Localización estratigráfica y paleogeográfica de los depósitos de turbiditas en el área de tránsito entre el Subbético medio al Penibético (Subbético Interno Occidental). Leyenda: a.- Brechas calcáreas, granosoportada (facies de talud superior) y ruditas intraformacionales (*pebbly mudstones*) (facies de talud inferior). b.-

In the same way, in the Aptian-Albian and also in the Coniacian and Santonian of the Internal Subbetic to the north of Vélez-Blanco (Almería province), resedimented conglomerates and calcareous turbidites, mainly composed of ooliths and other Jurassic and Cretaceous carbonate clasts (Fig. 5B), have been found intercalated in dark anoxic marls (Kuhry, 1975; Vera *et al.*, 1990; Aguado *et al.*, 1991). The generation of these deposits can best be understood in the context of an unstable sedimentary basin in which severe scarps of tectonic origin created gravity flows, thus filling in the depressions and smalls basins (half-graben) originated also by tectonic activity (Aguado *et al.*, 1991)

Finally, reworked intercalations also occur at the boundary between the Penibetic and the western Median Subbetic (Fig. 6A). They are carbonate and derive from the erosion of the Jurassic-Cretaceous section of a rugged, steep part of the basin, formed by the rifting that affected the Southern Iberian Margin throughout the Jurassic. Witness to this are the frequent intercalations of breccias and microbreccias deriving from Jurassic-Cretaceous materials, often lying unconformably upon the Liassic-Dogger carbonate formations beneath. The most important of these are Neocomian (from the upper-Berriasian onwards) and contain aboundant aptychi. These formations are on the whole clayey-marly and contain laterally discontinuous beds of breccias and microbreccias, the bottoms of which are often erosional or channelled out and the facies sequences usually poorly organized. These Neocomian materials are well represented in various sections of the Corredor del Boyar and Alta Cadena and also in the Sierra del Pinar (Peyre, 1974; Bourgois, 1978; Martín-Algarra, 1987). In these areas intercalations of Albian-Cenomanian and upper-Senonian breccias and calcareous turbidites also occur, although more sporadically.

Thus, the Subbetic turbidites are very different in composition and nature from those deposited in the more external areas of the continental margin. They were clearly related to tectonically active regions during the Cretaceous and filled small sub-basins at various times during this period.

3.2. *Turbidites in the North African Flysch Trough and adjacent areas.*

Some of the units of the Campo de Gibraltar Complex, such as the Nogales, Facinas-Almarchal, Ubrique and Corredor del Boyar units, are made up entirely of Cretaceous sediments, mainly turbidites (Fig. 7). Furthermore, some units consisting mostly of Tertiary materials, such as the Algeciras Unit, have a thin base of Cretaceous sediments. As mentioned above, all of them, with the notable exception of the Ubrique and Corredor del Boyar Units, are merely prolongations to the north of the Straits of Gibraltar of other ones much better represented in the Northern Rif, and thus can be assigned to some of the palaeogeographic domains of North African. So, the Almarchal Unit is equivalent to the Senonian of the Internal Tangier Unit; the Facinas Unit, which must be considered as the stratigraphic substratum of the Senonian of Almarchal, is strictly equivalent to the Albo-Aptian of the Mellousa Unit; and, finally, the Nogales and Algeciras Units are the spanish equivalent of the Mauritanian Tisiren-Beni Ider Moroccan ensemble of units. The ideal stratigraphic sections of the Betic Cretaceous flysches and that of their North African counterparts are represented in Figure 7.

3.2.1. *A deep basin between the Penibetic and the Rondaides.*

This basin was starved throughout the Cretaceous. Its sediments are in fact hardly recognisable, due to extensive deformation and lamination, because they form the tectonic base of various nappes otherwise composed of thick Tertiary turbidites. Elsewhere, they have been redeposited in mass in Burdigalian to Middle Miocene tectosedimentary complexes (mélanges: Martín-Algarra, 1987), the interpretation of which within the framework of the geology of the region is somewhat open to dispute (cf. Bourgois, 1978; Olivier, 1984). The deposits from the talus slopes adjacent to this basin, which separated it from and the inner edge of the Southern Iberian Margin on one side, and the outer margin of the Mesomediterranean subplate (Rondaides) on the other, are better preserved, forming as they do part of tectonic units outside the Campo de Gibraltar complex itself. They are to be found in the Castillones Unit, which constituted the internal edge of the Penibetic, and the Lentiscar, Argüelles and Pereila-type Units, which accounted for the lowest part of the continental talus slope formed by the Rondaide units (Martín-Algarra, 1987).

The Lower Cretaceous of the Castillones Unit (Fig. 6B) is a jumble of megabreccias, containing blocks up to more than a metre in size, which fossilizes a Jurassic palaeorelief, extensively reworking Jurassic carbonate rocks of similar age and facies to the underlying materials. These breccias are associated with Neocomian

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Microbrechas calcáreas y calcarenitas turbidíticas. B-A-A.- Barremiense-Aptiense-Albiense. A-C-T: Albiense-Cenomaniense-Turoniense. **B.**- Posición paleogeográfica de los depósitos turbidíticos de la cuenca profunda localizada entre el Penibético (Margen Subibérico) y los Rondaides y Malaguides (Margen occidental de la Subplaca Mesomediterránea). Leyenda: 1.- Calizas liásicas de plataforma marina somera. 2.- Calizas con sílex. 3.- Calizas nodulosas. 4.- Margas verdes y grises. 5.- Calizas margosas grises-verdosas y blancas. 6.- Arcillas versicolores. 7.- Brechas calcáreas de tamaño de cantos muy variado. 8.- Turbiditas calcáreas y microbrechas (microbrechas de Aptychus en el Neocomiense). 9.- Calizas margosas y margas rojas con Globotruncana. 10.- Margas silíceas y radiolaritas. 11.- Calizas de Microcodium turbidíticas del Paleoceno.

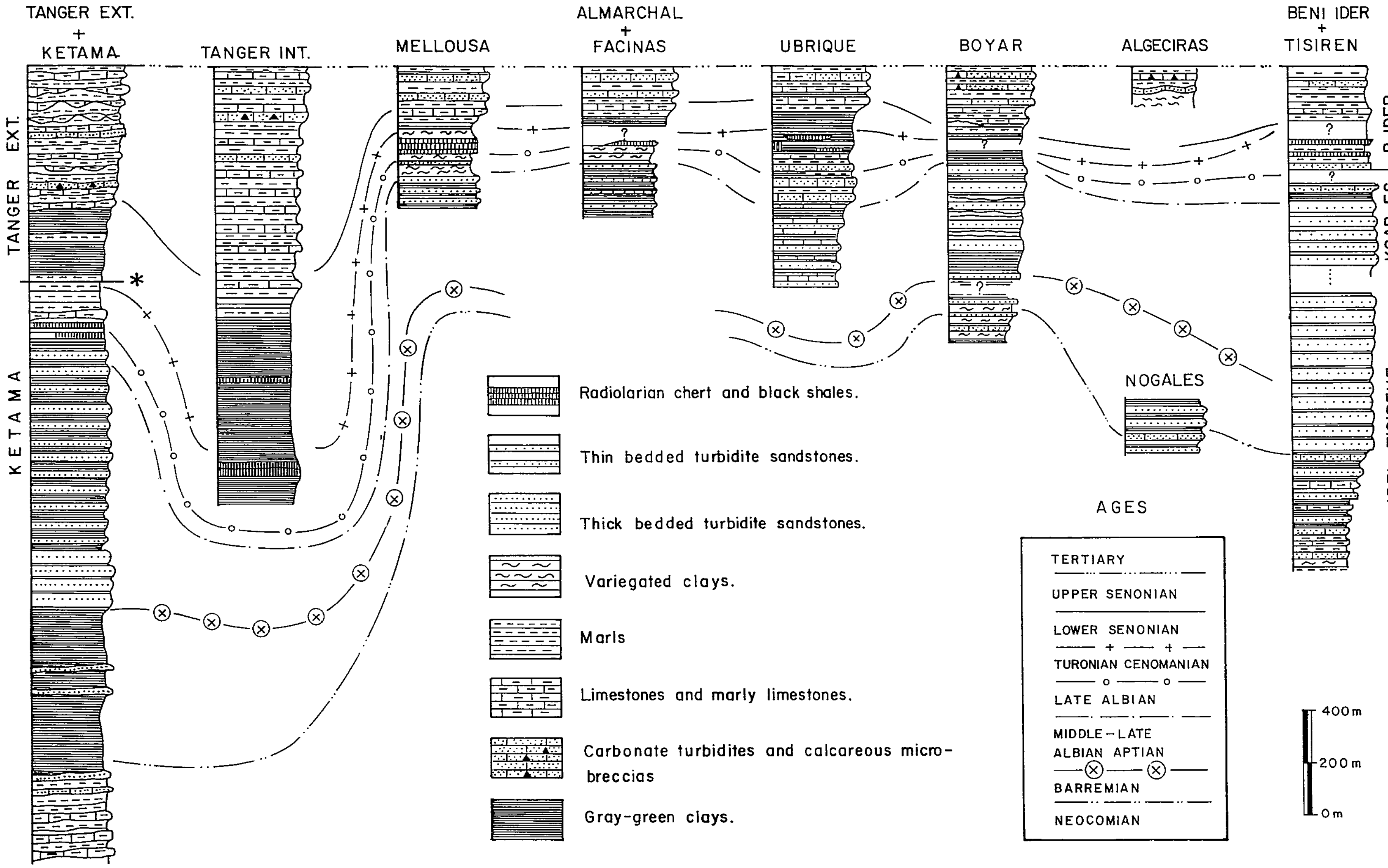

Fig. 7.-Synthetic stratigraphic columns of Cretaceous Flysches around the Straits of Gibraltar (African data adapted from Wildi, 1983).
Fig. 7.-Columnas estratigráficas sintéticas de los Flyschs cretácicos a ambos lados del Estrecho de Gibraltar (los datos de África según Wildi, 1983).

marly, hemipelagic sediments which are themselves at times reworked. The facies are typical of a abrupt talus slope of tectonic origin, which marked the transition between the high swell of the Penibetic and this deep basin.

Cretaceous sedimentation in the Rondaides is very scarce and is represented only locally, by thin, laterally discontinuous, marly-limestone beds. Only in the units closest to the basin itself, such as the Pereila-type Units (Martín-Algarra, 1987), do the Cretaceous sediments attain any notable thickness. Here the Neocomian deposits are composed of carbonate breccias and microbreccias, deriving principally from the various Jurassic facies of the same units, which contain an abundance of aptychi (*Complexe à Aptychus* for the French authors). This type of sedimentation is to be found in various tectonic elements occupying different palaeotopographical positions along the talus slope. The grain size diminishes basinwards and marly intercalations become more and more frequent. The coarse-grained beds are massive, lenticular in shape, and sometimes channelized, whilst the fine-grained beds are thinner, better sorted and normally graded, and may show Bouma sequences, although these are generally incomplete. There is no clearly defined organisation of the thickness in the sections studied. These deposits seem to be best represented in the Valanginian and Hauterivian, but a precise dating is difficult because of resedimentation. In the upper-Hauterivian-Barremian of some units (e.g. Lentiscar and Camarote), intercalated within clayey-marley sediments, there are thin, terrigenous, turbidite layers composed of fine-grained feldspathic and micaceous sandstones of Mauritanian affinity, containing calcareous clasts and carbonate cement. In some tectonic elements, such as the Argüelles Unit, there is an upper-Senonian sequence of alternating whitish-pink marls with planktonic foraminifera, calcareous microbreccias and breccias, and intermittent fine-grained-sandstone levels composed mainly of angular quartz and carbonate fragments, which exhibit the upper intervals of the Bouma sequence. Just as did the Neocomian materials of the Castillones Unit, these deposits derived mainly from Jurassic rocks reworked and carried lower down to the base of an abrupt talus slope, probably of tectonic origin.

3.2.2. *Turbidites in the intra-Rifian and Massylian realms.*

The northern limits of the North African Margin of Morocco corresponded to the intra-Rifian Zone, widely represented today in the northern Rif by the Ketama and External Tangier units (Didon *et al.*, 1973). Before the Alpine tectonic events both units probably formed part of one single stratigraphic section, as the former is made up of a thick pelitic-sandstone succession dating to the Lower Cretaceous (*Flysch Albo-Aptien* for the French authors) and covered by marly Cenomanian-Turonian deposits, while no rocks earlier than the Cenomanian have been reported in the latter. The Senonian of the Internal Tangier Unit [formerly considered as the innermost intra-rifian element (Didon et al., 1973) and now as an element of the Massylian realm (Durand-Delga, pers. com., 1991) see also Thurow, 1987] lies on Cenomanian-Turonian sediments made entirely of phtanites similar to those of the Massylian Mellousa unit, which in turn begins with a Ketama-type "Albian-Aptian Flysch" (Didon *et al.*, 1973). It can be concluded, then, that the intra-Rifian Zone graded towards the interior of the basin into the Massylian realm of the North African Flysch Trough. In Spain these domains are represented by the Ubrique, Almarchal and Facinas Units, all of which are constructed with Albian to upper-Senonian materials.

The oldest known Cretaceous rocks in these units are those of the Neocomian in the Ketama Unit (Andrieux, 1971), which is essentially made up of marly limestones. From the upper-Hauterivian onwards the sediments become much more pelitic and begin to contain intercalations of generally thin bedded subarkosic sandstones, which have a sand/pelite ratio and sedimentary structures typical of distal turbidites. During the mid- and upper-Aptian, terrigenous turbidite sedimentation became both more widespread and thicker: the sandstone beds may be more than three metres thick, with Tc-e cycles, which are often cut off at the top and amalgamated. Abundant sole marks indicate palaeocurrents coming from the south and southeast. These facies can be interpreted as belonging to outer fan lobes laid down in the distal areas of a deep turbidite system, fed from the south and southeast. The proximal areas of these fans are to be found in westernmost Algeria, within the Tellian External Zones or even in the Saharian Atlas (Gübeli *et al.*, 1984; Wildi, 1983), where contemporaneous formations with talus-slope, delta-fluviatile and even continental facies appear. Sandy sedimentation ceased in the intra-Rifian Zone during the lower- to mid-Albian and did not recur throughout the whole of the Cretaceous (Kuhnt and Obert, 1989, 1991).

In the others units of this group there are no rocks earlier than the mid-Cretaceous. The oldest are from the Aptian and Albian and are to be found in the Massylian, Facinas and Mellousa Units as well as in the Ubrique Flysch. The Facinas Unit is made up entirely of Aptian(?)-Albian (Didon, 1969) to Cenomanian-Turonian (Thurow, 1987) materials, identical to the coetaneous formations in the Massylian Mellousa Unit of Morocco. The Facinas Unit is composed of grey, greenish and violet clays, totally lacking in carbonates. In the lower part (Aptian), they include decimetric intercalations of fine-grained, quartzite turbiditic sandstones, generally with base-cut-out Bouma sequences, typical of distal turbidites. Within the section there may be occasional intercalations of carbonate turbidites, with bioclasts (particularly orbitolines) deriving from a carbonate platform. The Albian-Aptian turbidite facies of the Facinas-Mellousa Unit are markedly distal, although in the Rifian area somewhat more proximal facies are to be found in the Chouamat Unit (Gübeli *et al.*, 1984).

The Ubrique Flysch sequence begins with an olive-grey, marly-clayey succession, rich in mid- to upper-Albian nannoplankton and planktonic foraminifers, which contains centimetre- to decimetre-thick intercalations of fine- to medium-grained, micaceous sandstones with carbonate cement. The sandstones show base cut-out Bouma sequences, and sole marks indicating palaeocurrents coming from the west and southwest. There are also thicker and coarser beds of carbonate turbidites containing reworked clasts with shallow-platform facies, in which more complete Bouma sequences and amalgamation surfaces can be made out. Farther towards the top, in Vraconian to Cenomanian rocks, the sandstone intercalations become more frequent, the sandstone/pelite ratio increases, the grain size coarsens and the proportion of carbonate clasts, among which there are locally abundant ooids, fragments of limestones containing pithonellas and orbitolines, becomes larger. The Cenomanian and Turonian are represented by a darkish, clayey-siliceous member, some few metres thick, upon which lies a suite of rocks of similar age and facies to the Senonian of the Almarchal Unit.

Despite its present situation in a tectonically complex position in the middle part of the Subbetic, the facies, stratigraphy and composition of the Ubrique Flysch clearly distinguish it from the other coetaneous materials in the Betic External Zones and relate it more with Noth Africa (Martín-Algarra, 1987; López-Galindo and Martín-Algarra, 1990). The mineralogical characteristics of its clays are, in fact, rather comparable to those of the Internal Tangier Unit and the Facinas Unit, the main important difference residing in the relatively carbonate-rich Albian of the Ubrique Flysch (López-Galindo and Martín-Algarra, *in litt.*). This can be explained by the fact that the Ubrique Flysch was laid down above the CCD, in a shallower part of the basin than the other comparable units.

The Facinas clays seem to constitute the original stratigraphic substrate of the Almarchal Unit, although somewhat individualised tectonically. No materials older than the Cenomanian have been described in the Internal Tangier Unit, which, as mentioned before, is the exact counterpart of the Almarchal Unit in the Campo de Gibraltar complex (Didon *et al.*, 1973). The lowest terms in the Internal Tangier Unit form a greenish and, to a somewhat lesser extent, violet pelitic and siliceous suite crowned by a phtanite (radiolarite) member. These materials are covered by a lower Senonian thick, greenish, clayey-marly suite, with intercalations of fine, detrital, marly limestones, in which frequent sedimentary structures of turbidite origin can be made out. During the upper-Senonian (Kuhnt, 1987; Kuhnt and Obert, 1989, 1991) intercalations of microbreccias and breccias become fairly common, although it must be stressed that they always occur in isolated beds, some centimetres to decimetres thick, in which no kind of clear sequential order can be detected. Many of these carbonate turbidite beds are made up of a veritable purée of planktonic foraminifers, which is in complete contrast to the almost total lack of such microfossils in the surrounding clays. The Senonian in the Massylian and Ubrique Flysch is similar in characteristics to the External Tangier Unit. In brief, the Senonian throughout these units is represented almost entirely by pelagic deposits, in which the incidence of turbidite sedimentation appears to have been of minor consequence (*Flysch à microbrèches*). The carbonate contribution to the turbidites bears witness to the partial destruction of earlier deposits, some of them hemipelagic and fairly coetaneous (turbidites bearing planktonic foraminifers) and others deriving from a shallow, carbonate platform, possibly lying farther to the south.

3.2.3. *Turbidites in the Mauritanian Domain of the Flysch Trough.*

In contrast to the situation in Algeria, the stratigraphic column of the Mauritanian Flysch, on either side of the Straits of Gibraltar, appears to be differentiated by a detachment at level of mid-Cretaceous clayey materials into two independent tectonic units, one composed of lower-Cretaceous and the other of upper-Cretaceous/Tertiary rocks. On the Iberian side these are the Nogales and Algeciras Units and their African counterparts are the Tisiren and Beni Ider Units respectively. The Corredor del Boyar Flysch Unit might also be included in this group were it not for some stratigraphic and tectonic peculiarities, which make its assignation dubious.

The Nogales Unit is composed of Neocomian to Barremian terms (Didon, 1969; Puglisi and Coccioni, 1987), whereas the section of its moroccan counterpart, the Tisiren Unit, is much more complete, including as it does levels corresponding to the upper-Albian (Gübeli *et al.*, 1984; Thurow, 1987). The Neocomian is represented by a marly-clayey suite, containing intercalations of calcareous microbreccias, often rich in aptychus fragments, of similar characteristics to the Neocomian in the Corredor del Boyar Flysch (Fig. 7). These microbreccias contain variable quantities of terrigenous quartz and the beds have a clearly erosional base. They are mainly composed of fragments of Jurassic rocks of diverse ages and lithologies, the product of the erosion of the steep talus slopes separating the Mesomediterranean subplate from the North African Flysch Trough during a period in which tectonic activity at the edges of this trough must have been quite strong, due to the fact that the basin was widening under the influence of the relative transtensional movements of the African and Iberian plates.

The lithological unit that best characterizes the Mauritanian domain is that known as the Mauritanian Flysch s.s., which is made up of a thick succession of siliciclastic turbidites, recognisable from Spain to Sicily throughout the length of North Africa (Bouillin *et al.*, 1970; Chiocchini *et al.*, 1980; Puglisi and Coccioni, 1987). Sandstones began to make their appearance in some places during the Berriasian (Didon *et al.*, 1973). In the Jbel Tisiren the first important deposition of sandstones took place between the end of the lower-Valanginian and the beginning of the Hauterivian (Gübeli *et al.*, 1984): during this interval layers of terrigenous turbidites, generally some decimetres thick but which at times may be up to a couple of metres, alternate with centimetre-thick carbonate turbidites and some marly episodes. Nevertheless, the most important deposition of sandstones began, in most mauritanian sections, during the upper Hauterivian (Boyar: Bourgois, 1978; Tisiren: Gübeli *et al.*, 1984; Nogales: Didon, 1969; and, Puglisi and Coccioni, 1987) and continued throughout the Barremian and Aptian: they form a coarsening-upward megasequence from which the carbonate episodes disappear almost completely, showing up henceforth only at the very bottom of some strata. They usually form decimetre- to metre-thick beds of massive appearance, with numerous current marks at the bottom. Only very rarely do they have complete Bouma sequences and, in most of the sections, it is common to find amalgamated beds. The clayey beds are reduced to centimetre- or decimetre-thick levels and, upwards, the banks of sandstone attain enormous thicknesses, sometimes more than forty metres in the Jbel Tisiren section (Gübeli *et al.*, 1984). The sandstones are subarkoses to arkoses, somewhat micaceous in the lowest levels, and medium- to fine- grained. In general the facies correspond to types B, C and, to a lesser extent, D, of Mutti and Ricci-Lucchi (1975). The Barremian of the Nogales Unit, just as the Albian of the Tisiren Unit on the southern shore of the Straits, show normally negative sequences, although positive sequences are locally present, sometimes beginning with very wide erosion channels at the bottom. The most distal facies have been identified in the Aptian-Albian of the Corredor del Boyar Flysch. The Aptian consists of a thin-bedded succession of pelitic-sandstone turbidites (facies D3 according to Mutti and Ricci-Lucchi, 1975), while from the Albian onwards these facies include decimetre- to metre-thick layers of Mauritanian-facies sandstone.

Broadly speaking, the Mauritanian siliciclastic turbidite sedimentation in the neighbourhood of the Straits of Gibraltar is related to the central and distal areas of a deep submarine fan, which was fed from the north-east (Durand-Delga, 1969; Chioccini *et al.*, 1980; Raoult *et al.*, 1982) by the emerged pre-Mesozoic rocks of the Kabylian sector of the Mesomediterranean subplate. The sedimentary structures in the outcrops around the Straits, which have probably undergone clockwise twisting during the formation of the Gibraltar arc, indicate palaeocurrents coming from the west and northwest. The most proximal facies in this turbidite system have been located by Gübeli *et al.* (1984) in the Jebha sector, where the deposits are typical of a talus slope and there are frequent fining- and thinning-upward sequences with channellized strata.

Siliciclastic turbidite sedimentation ended fairly abruptly at the beginning of the Upper Albian. Thus, the top of the Tisiren Unit in the Punta Cires sector, where the sediments are Middle Albian, is crowned by a pelitic succession with fine turbidite intercalations of mixed siliciclastic-carbonate composition, very different in character from the underlying sandstones. These materials terminate the Tisiren Nappe and the higher terms form normally part of the Beni Ider Unit. This last nappe only exceptionally has been found, in the northern Rif, stratigraphically lying on Lower Cretaceous formations of Tisiren facies (Durand-Delga, pers. comm. 1991). Normally it begins with a Cenomanian Turonian formation, some tens of metres thick, containing thin intercalations of carbonate turbidites and siliceous layers. The Senonian is represented almost entirely by clayey-marly sediments, often reddish in colour, which may contain intercalations of calcareous microbreccias and breccias (*Flysch à microbrèches*). On the Iberian side these materials constitute the bottom of the Algeciras Unit. On its hand and the top of the Corredor del Boyar Flysch, is formed by green marls and marlstones with calcareus microbreccias of Almarchal facies, and a gap in the sedimentary record from the end of the Vraconian to the beginning of the Campanian can be detected. In brief, the upper-Cretaceous formations belonging to the Mauritanian domain are formed by deposits typical of a deep-basin environment alongside a talus slope made up of Jurassic-Cretaceous carbonate rocks from whence turbidite flows arrived from time to time.

4. FACTORS CONTROLLING THE TURBIDITE SEDIMENTATION

Having analysed the evolution of turbidite deposition throughout the Betic Cordillera basin it is now worthwhile comparing the chronology of the beginning and end of the siliciclastic turbiditic sedimentation in palaeogeographical domains originally so far away from one another as were the Intermediate Domain and the North African Flysch Trough. In various zones of the Southern Iberian Margin, such as the Prebetic platform (García-Hernández *et al.*, 1982b; Martín *et al.*, 1982) and various different pelagic swells (Company *et al.*, 1982b; González-Donoso *et al.*, 1983; Martín-Algarra, 1987) brusque changes in the sedimentation and stratigraphic unconformity surfaces have been observed, coinciding chronologically with the most substantial changes in turbidite sedimentation in the troughs. This coincidence leads us to believe that the turbidite sedimentation may well have been controlled by events which affected the basin as a whole. It is difficult to judge whether these events took place on a local or regional scale as we do not yet have a sufficiently exhaustive biostratigraphical scheme to detail the relative positions of all of the events involved. Nevertheless, with the data available it is possible to deduce that turbidite sedimentation in the Betic Cordillera and surrounding areas took place in six principal episodes, which we shall describe more fully below.

4.1. *Chronology and correlation of events.*

During the Neocomian turbidites were deposited in various basinal areas of the Southern Iberian Margin and in the Mauritanian domain of the North African Flysch Trough, in relation to diverse events. In many zones of the Southern Iberian Margin (Intermediate Domain and Subbetic) it has been possible to date these events with certain precision to the Late Berriasian and the Valanginian. During both these periods siliciclastic turbidite deposits were laid down, although they were confined to certain localities and were relatively small in quantity. These events can be correlated with those that caused the unconformities identifiable in the Prebetic (García-Hernández *et al.*, 1982b; Wilke, 1988) and in the Penibetic (González-Donoso *et al.*, 1983; Martín-Algarra, 1987). The Valanginian event was of considerable importance in the North African Flysch Trough as during this period aboundant siliciclastic turbidites reached the Mauritanian domain in the area of Tisirén (Gübeli *et al.*, 1984). Other local tectonic events, such as faulting, tilting and halokynetic processes, prompted the deposition of turbidites and other talus-slope sediments during the Neocomian. Thus, calcareous turbidites (aptychus microbreccias) appear both in the Subbetic and the Flysch Trough (Nogales Unit and Mauritanian Flysch), while intraformational rudites, calcareous breccias and slumps are to be found in the Subbetic and more internal areas of the Prebetic.

During the Late Hauterivian an important event affected the entire basin; the first turbidite system (stages I and/or II, according to Mutti, 1985) was deposited in the Intermediate Domain and adjacent areas as well as in the Flysch Trough. This event is also evident in the Prebetic, in the unconformity which marks the end of the Wealdian. In some of the pelagic swells, such as in the Penibetic (García-Hernández *et al.*, 1982) it is reflected in an unconformity surface with evident signs of emersion.

No event of any importance has been detected in the Barremian and the sedimentation continued with very similar characteristics to the underlying materials.

Around the boundary between the lower and upper Aptian another significant event occurred in the Prebetic: it was reflected in an unconformity followed by a terrigenous episode that separes the Urgonian cycles (García-Hernández, 1978, 1979). In the Intermediate Domain this event determined the onset of the deposition of the second turbidite system, which is volumetrically the most important. In the Flysch Trough (Mauritanian and Massylian) and in the intra-Rifian Ketama unit it also marked the renewal of turbidite sedimentation, initiating the deposition of the so named ''Albo-Aptian Flysch'', that could have been synchronous with this event, although we have no precise chronostratigraphic data of these sequences (see, however, Gübel *et al.*, 1984).

During the Lower-Middle Albian up to the beginning of the Late Albian a new main event affected the whole of the basin. At the Southern Iberian Margin this event is evident in another unconformity, followed by another important terrigenous onlapping episode in the Prebetic (Fig. 4), and in the beginning of the deposition of the third turbidite system in the Intermediate Domain. In the Flysch Trough the same event is reflected in a renewed increase in siliciclastic turbidite sedimentation.

The effects of these two latter events (intra-Aptian and intra-Albian) can also be seen in some parts of the interior of the Subbetic basin, where some pelagic swells show unconformities and are surrounded by breccias, calcarenites and other such turbidites.

Towards the boundary between the Albian and the Cenomanian one of the most significant events of the period took place, although it was of a completely different type from those before it; there began one of the most spectacular rises in sea level to have occurred during the whole of the Mesozoic. As a consequence siliciclastic turbidite sedimentation ceased, anaerobic sedimentation began in some parts of the basin and the sedimentation in general became more homogeneous. During the Cenomanian and the Turonian turbidite sedimentation was very local, confined to areas adjacent to active faults on the seabed. This situation continued until the beginning of the Coniacian, when an event of palaeo-oceanographic significance put an end to the anaerobic sedimentation and initiated a period of pelagic sedimentation of pink marls rich in planktonic foraminifers (Capas Rojas Fm., Vera *et al.*, 1982).

During the Senonian turbidite deposition was reduced to calcareous turbidites (limestone breccias and microbreccias, calcarenites etc.), which crop out mainly as intercalations within upper Senonian rocks in various different palaeogeographical domains, such as the External Prebetic, the Intermediate Domain, the Subbetic, the Mauritanian Domain and the Flysch Trough. These deposits can be attributed to channelized turbidites related directly to simultaneous shallow-platform or pelagic-swell deposits and are probably type III systems, according to the definition of Mutti (1985).

4.2. *Siliciclastic and carbonate turbidites.*

Recents papers on relation between turbidite sedimentation and sea-level changes (Mitchum, 1985; Mutti, 1985; Mutti and Normark, 1987; Mutti and Sgavetti, 1987; Kolla and Macurda, 1988; Posamentier and Vail, 1988; among others) suggest that siliciclastic turbidites of passive margins have been deposited in relation with sea level falls and lowstands. The shelf is drastically eroded causing a type 1 unconformity (Vail *et al.*, 1984, 1987) which correlates with the main turbidite body (Mutti, 1985); during lowstand the terrigenous sedimentation can reach the base of slope and the basin (Posamentier and Vail, 1988). Nevertheless, other authors (Alonso *et al.*, 1989) have described turbidites in relation with type 2 unconformities (Vail *et al.*, 1984, 1987). Turbidites can also be generated in relation with synsedimentary tectonics affecting the basin and its margins (cf. Mutti and Sgavetti, 1987).

The relation between carbonate turbidite sedimentation and sea-level changes is, on the other hand, mo-

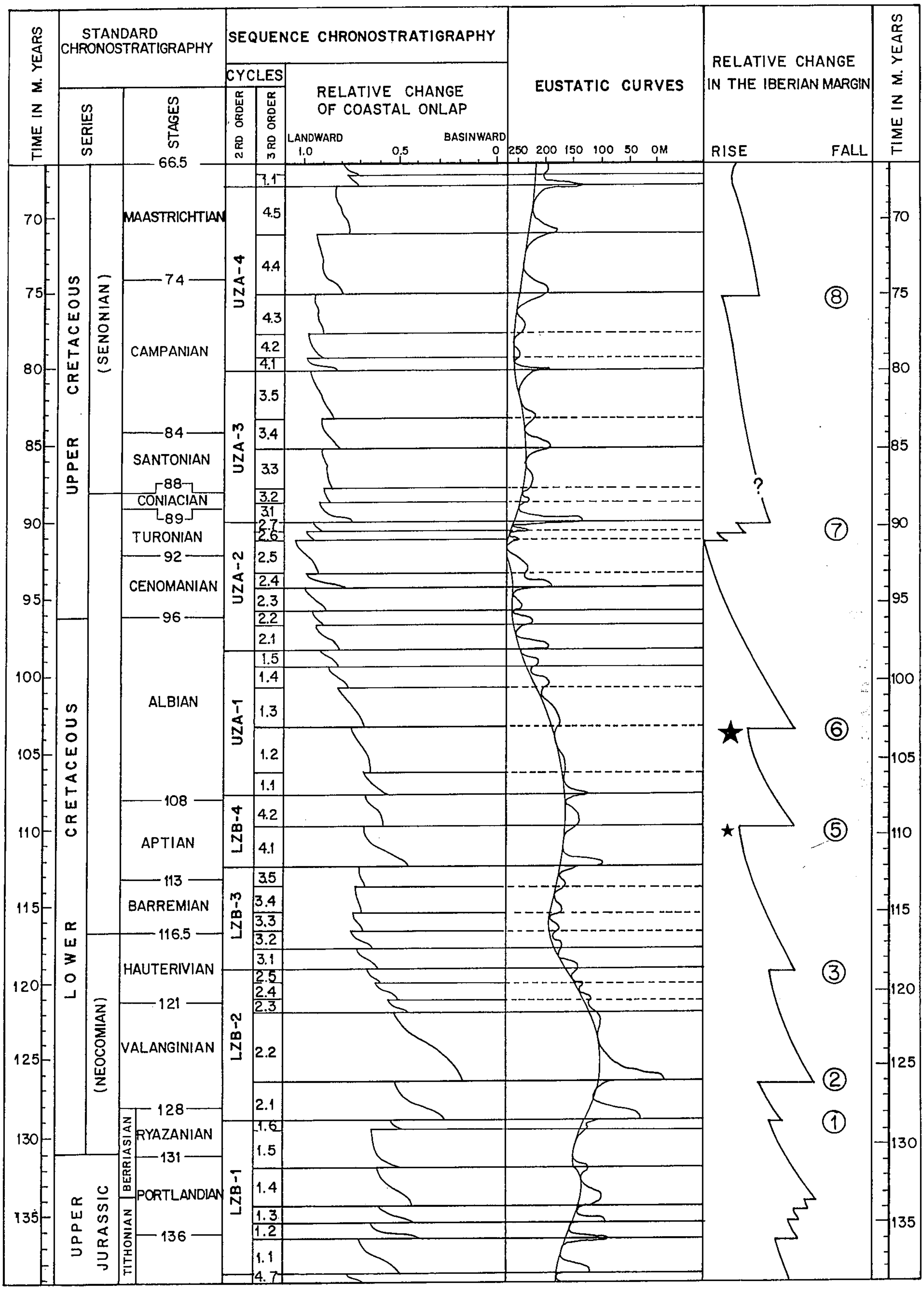

Fig. 8.- Fluctuations in sea-level during the Cretaceous. Sequence stratigraphy and eustatic curves after Haq *et al.* (1987, 1988). Relative changes in the Iberian Margin after Vera (1988). Numbers 1 to 8: mainly discontinuities. Big asterisk: very complex correlation with eustatic events. Small asterisk: probable correlation with eustatic events.

Fig. 8.-Fluctuaciones del nivel del mar durante el Cretácico. Estratigrafía secuencial y curvas eustáticas según Haq *et al.* (1987, 1988). Cambios relativos del nivel del mar en el Margen Sudibérico según Vera (1988). Números 1 a 8: discontinuidades principales. Asteriscos grandes: correlación muy compleja con los eventos eustáticos. Asteriscos pequeños: correlación probable con los eventos eustáticos.

re controversial. Some authors apply to carbonate turbidites the same model as to the terrigenous ones (Vail *et al.*, 1977; Shanmugan and Moiola, 1983; Thiede, 1981; among others). Shanmugan and Moiola (1984) suggets that maximum erosion of the shelf margin and the upper slope together with redeposition from marginal and isolated platforms and, consequently, the frequency of sediment gravity flows, are all related with the downturn from a highstand, when the shallow sea dynamics affects these regions. A study of modern carbonate turbidite sedimentation in the Bahamas carried out by Droxler and Schlager (1985), however has shown, that such carbonate turbidite sedimentation during the Quaternary has taken place during highstands. Others authors, studying principaly modern carbonate basins, also relate carbonate turbidites to sea-level highstand (Mullins *et al.*, 1980; Hine *et al.*, 1981; Mullins, 1983; Boardman and Neuman, 1984; among others).

According to our present understanding of the problem and from the studies carried out on the various carbonate turbidite systems in the Betic Cordillera (Ruiz-Ortiz, 1980; Comas and Ruiz-Ortiz, 1982; Ruiz-Ortiz, 1983 and in preparation) we believe that as a general norm a relationship exists between the true processes of resedimentation of indurated or semindurated carbonate sediments of shelf margin-upper slope regions and sea-level falls and lowstands, and, on the other hand, "resedimentation" of coeval shallow shelf carbonate grains in basin realms and sea-level highstands. This model is consistent with that proposed by Mutti (1985) for siliciclastic turbidites, and with the ideas about modern carbonate turbidite sedimentation (cf. Shanmughan and Moiola, 1984; Droxler and Schlager, 1985).

4.3. *Eustatic controls.*

In previous publications (García-Hernández *et al.*, 1982b; Vera, 1988; Vera and Martín-Algara, *in litt.*) the relative sea-level fluctuations curve for the Southern Iberian Margin has been established and compared with the eustatic curve of Haq *et al.* (1987). In fig. 8 the eustatic curve of Haq *et al.* (1988) and that proposed for the Southern Iberian Margin (Vera, 1988) have been reproduced. An analysis of these curves reveals a relationship between the siliciclastic turbidite systems, types I and/or II of Mutti (1985), and the main sea-level falls (intra-Hauterivian, intra-Aptian and intra-Albian).

The lutitic successions in between these sandy turbidite systems should represent lowstand wedge, transgressive and/or highstand deposits. They include some turbidite sandstone intercalations that may correspond to type III turbidite systems of Mutti (1985). The presence of carbonate intercalations, especially these containing benthic foraminifers such as the Aptian-Albian Orbitolinids of the Intermediate Domain and the Flysch Trough, suggest that these deposits must represent highstand carbonate turbidites derived from the washing-off of two originally very distant pericontinental carbonate shelves: the Prebetic of the Southern Iberian Margin and the most external areas of the North African Margin. They were laid down when the terrigenous sediments became trapped in continental, coastal and inner platform environments.

The minor terrigenous and carbonate turbidite intercalations represented in Fig. 4, are also related to specific stands of sea-level. With the exception of those in the Senonian, carbonate turbidites are related to sea-level highstands (Early Berriasian and Early Valanginian, Figs. 4 and 8), and terrigenous turbidite intercalations to sea-level falls pointing the unconformities (Upper Berriasian and Valanginian, Figs. 4 and 8). The carbonate turbidites of the Upper Senonian, which are associated with slumps and other slope deposits, were probably laid down during sea-level falls, causing the turbidite event number 8. The top of this succession, with only some calcarenite intercalations, may well been related to a sea-level highstand (Figs. 4 and 8).

Turbidites at the North African Margin and in the Flysch Trough may also have been deposited in response to changes in sea-level. We do not have enough data to confirm the isochroneity of the African turbidite deposits with their spanish counterparts. Nevertheless the available biostratigraphic data point out that the turbidite deposits of the North African Margin and Flysch Trough are, at least in a great part, coetaneous with those at the Southern Iberian Margin. The Neocomian episodic terrigenous turbidites of the Mauritanian Flysch and of the Ketama Unit could be synchronous with the terrigenous turbidites of the same age of the Intermediate Domain. The terrigenous intercalations in the upper part of the "Aptychus complex" of the Corredor del Boyar and Nogales units were deposited at the same time than the Late Hauterivian terrigenous turbidites of the Intermediate Domain. The "Albo-Aptian flysch" could be the counterpart of the second and third turbidite systems of the Cerrajón Fm. The Senonian (*Flysch à microbréches*) of the Mauritanian, Massylian and intra-Rifian units are clearly related with the Senonian carbonate turbidites of the External Prebetic.

It is interesting to point out that sea-level changes that affected the African margin (Butt, 1982; Von Rad and Sarti, 1986) were probably isochronous with those which took place at the North African margin and the Southern Iberian Margin (García-Hernández *et al.*, 1982b; Vera, 1988) (Fig. 8). Butt (1982) has studies the Cretaceous of the Moroccan atlantic coast and come to the conclusion that the sea-level fell during the Valanginian, the Aptian and the Albian. The more brusque of these falls was intra-Aptian, as witnessed by the continental red beds in the stratigraphic sections close to the present-day coastline and by the turbidite at D.S.D.P. sites 370 and 416. Von Rad and Sarti (1986) have studied the Lower Cretaceous of the Atlantic margins of the Morocco and Cape Hatteras (USA). Seismic profiles of the Moroccan margin (Von Rad and Sarti, 1986, their fig. 7) reveal unconformities of intra-Valanginian, intra-Hauterivian and intra-Aptian ages. They also interpret the Aptian turbidites at the American margin (their fig. 9b) as being related to a sudden sea-level fall during the middle Aptian, which caused the partial denudation of the shelf.

New arguments to support the hypothesis that the Cretaceous turbidites were controlled eustatically are to be found in a close study of the pelagic swells. Materials showing a great variety of facies have been identified in these swells and are similar to those described in Jurassic pelagic swells in the Subbetic by García-Hernández *et al.* (1988). Such a study of the most extensive swell in the basin during the Cretaceous, the Penibetic (Fig. 7), is of particular interest. Several unconformities have been discovered in the Lower Cretaceous (González-Donoso *et al.*, 1983; Martín-Algarra, 1987; Martín-Algarra and Vera, *in litt.*) in which various stratigraphic features have been recognised, such as neptunian dykes (Company *et al.*, 1982b), pelagic stromatolites (Martín-Algarra and Vera, *in litt.*) and hardgrounds and omission surfaces (Vera, 1989), all of which, together with a very precise dating leads to the deduction that we are dealing with intra-Valanginian, intra-Hauterivian, intra-Aptian and intra-Albian unconformities. Some of these unconformities have been correlated with materials in the most external outcrops of the basin, in the Prebetic, which permited García-Hernández *et al.* (1982a) to work out the first eustatic curve for the Cretaceous basin.

In the light of all these data it would seem reasonable to interpret the intra-Valanginian, intra-Hautiverian, intra-Aptian and intra-Albian unconformities as being related to changes in sea level that affected the basin as a whole. In fact, it appears likely that they are related to brusque falls in sea level, which caused siliciclastic turbidite sedimentation in the two marginal troughs, the Intermediate Domain at the Southern Iberian Margin and the Flysch Trough at the North African Margin. The upper-Berriasian, upper-Valanginian and upper-Senonian turbidites might also be related to eustatic falls, although the unconformities which they may have produced are not to be seen in the basin as a whole.

4.4. *Tectonic controls.*

As has already been pointed out, the deposition of carbonates turbidites in the Subbetic was probably tectonically controlled. In fact, with the exception of the carbonate turbidites of the Argos Fm. in the External Subbetic, which are related genetically to the Cerrajón turbidites, all the other carbonate turbidites were deposited as a response to processes such as faulting or halokynesis. This tectonic activity may have been the cause, at least in part, of local relative sea-level changes, not directly or by force related to the global eustatic fluctuations and may also have triggered mass-flow processes. The main diagnostic features of these tectonically controlled turbidites is their local extent and provenance, their composition closely dependent of their sustratum, the wedge-shaped morphology and other sedimentological features of turbidite bodies, and also their palaeogeographic position close to the transition zones between seamounts and adjacent troughs, which were areas of obvious synsedimentary tectonic unstability and subsidence change. They do not made up continuous apron all along these transition zones (ancient slopes) but they are local deposits. The Neocomian carbonate turbidites of the Median and Internal Subbetic conform precisely to this model.

The Mid-Cretaceous was a period of active tectonism, as it has been shown by studies carried out in different part of the Betic Cordillera (Comas, 1978; Vera *et al.*, 1982; Molina, 1987). A stratigraphic gap embracing all the Lower and Middle Cretaceous locally exists in the External Subbetic (Molina, 1987) and the Penibetic (Martín-Algarra, 1987) with Upper Cretaceous *Globotruncana* limestones filling up karstic cavities excavated within Middle and Upper Jurassic limestones: during the Lower Cretaceous these areas were temporarily emerged as a consequence of fault movements. However, a more detailed biostratigraphic analysis is needed to check the possible isochronism between some of these tectonic events and the eustatic sea-level changes. For instance, two important sea-level falls causing terrigenous turbidite sedimentation in the marginal troughs occurred during the Aptian-Albian, which were also times of important carbonate turbidite sedimentation and of denudation of seamounts and swells in the Subbetic.

4.5. *Relationship between tectonics and eustasy.*

The rise of the continental reliefs adjacent to the Southern Iberian and North African margins was tectonically induced, in a framework of global tectonic, as a consequence of plate movements. The relation of this factor with the deposition of the terrigenous turbidites appears as evident. These latter are specially aboundant after a stage of continental block-faulting and tilting which causes the rising of some continental areas and their erosion, allowing the clastics to reach the outermost edge of continental margins. Tectonic phenomena affecting the basin and the relative sea-level changes must have been, then, closely related. The tectonic movements can be considered as having occurred on two different scales: on a wide scale the relative movements of the three Cretaceous plates present in the area (Iberian, African, and Mesomediterranean); and on a more local scale movements such as faulting, block tilting, changes in the subsidence rate, halokynetic movements, etc., which could be related with deformational phases of larger scale but which had only local effects in the basin.

Our times of more sudden sea-level falls have their equivalent in the curves of Haq *et al.* (1987, 1988) and they might be considered as being eustatic sea-level falls, but they are more likely to have been controlled by the plate movements (Pitman, 1978; Pitman and Golovchenko, 1983; Hallam, 1984). They may well have been

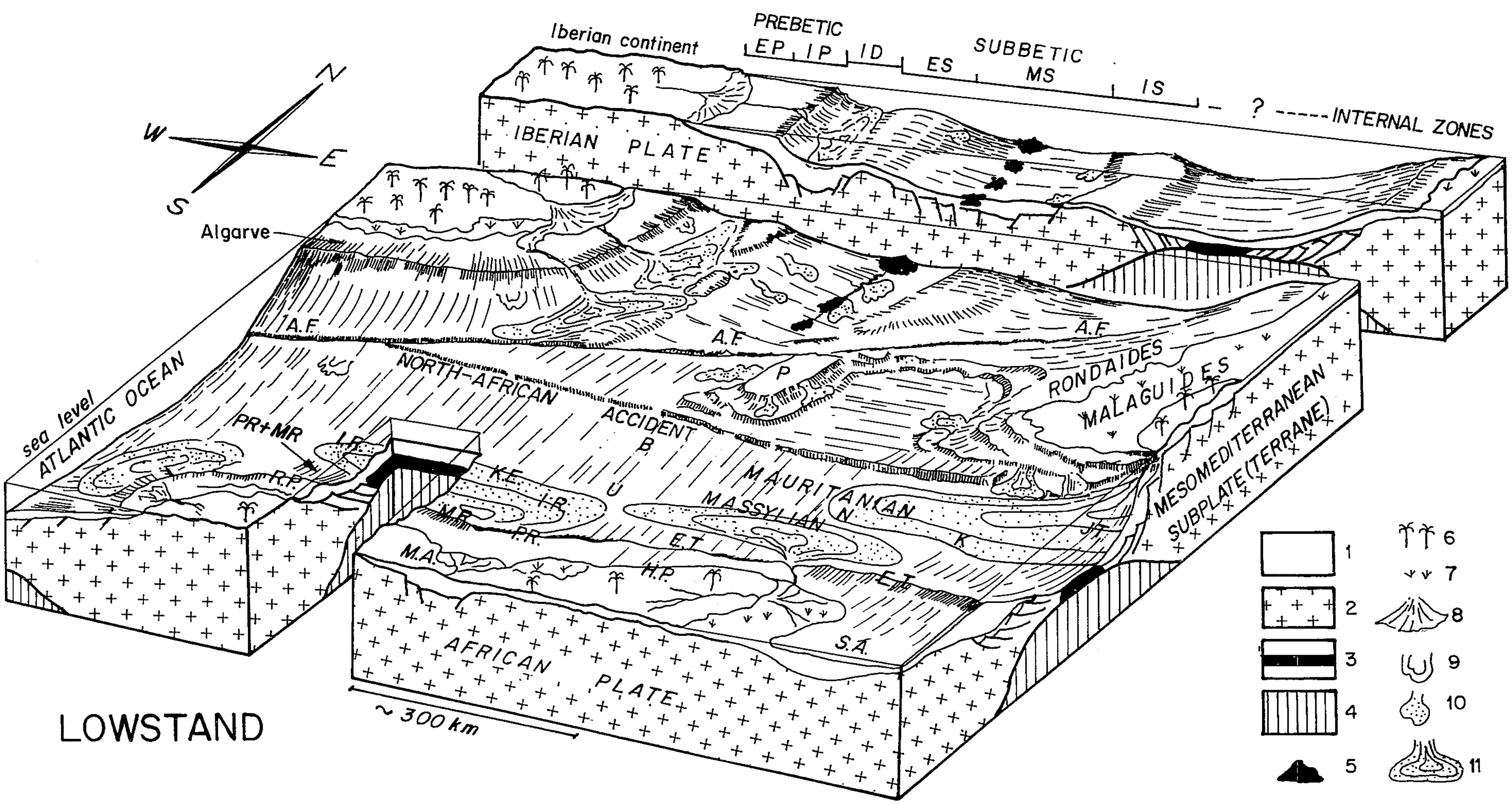

Fig. 9.-Three-dimensional palaeogeographic sketch of the Westernmost Tethys (Southern Iberian Margin, North-African Margin and Mesomediterranean Subplate) during the Aptian times. Key: 1.- Mesozoic sediments. 2.- Continental crust. 3.- Areas with very thinned continental crust and oceanic crust. 4.- Upper mantle. 5.- Inherited Jurassic-Neocomian volcanic reliefs. 6.- Continental environments. 7.- Tidal flat. 8.- Deltaic sediments. 9.- Slumps, slides and rockfalls. 10.- Local calcareous and/or terrigenous turbidites. 11.- Terrigenous turbidites. E.P.- External Prebetic. I.P.- Internal Prebetic. I.D.- Intermediate Domain. E.S.- External Subbetic. M.S.- Median Subbetic. I.S.- Internal Subbetic. P.- Penibetic. A.F.- Transform Antequera Fault. I.R.- Intrarif. P.R.- Prerif. M.R.- Mesorif. P.R.- "Rides prerifaines". M.A.- Middle Atlas. H.P.- High Plateaux. S.A.- Saharan Atlas. E.T.- External Tell. Hypothetical position of the sections in figure 6: KE.- Ketama. U.- Ubrique. B.- Boyar. N.- Nogales. K.- Ksar es Sghir. JT.- Jbel Tisirene.

Fig. 9.-Esquema paleogeográfico tridimensional del extremo occidental del Tethys (Margen Sudibérico, Margen Norte-Africano y Subplaca Mesomediterránea) durante el Aptiense. Leyenda: 1.- Sedimentos mesozoicos. 2.- Corteza continental. 3.- Áreas con corteza continental muy adelgazada y con corteza oceánica. 4.- Manto superior. 5.- Relieves volcánicos heredados del Jurásico-Neocomiense. 6.- Medios continentales. 7.- Llanuras de mareas. 8.- Sedimentos deltaicos. 9.- *Slumps*, *slides* y caidas de rocas. 10.- Turbiditas terrígenas y/o calcáreas de distribución muy local. 11.- Turbiditas terrígenas. E.P.- Prebético Externo. I.P.- Prebético Interno. I.D.- Dominio Intermedio. E.S.- Subbético Externo. M.S.- Subbético Medio. I.S.- Subbético Interno. P.- Penibético. A.F.- Falla transformante de Antequera. I.R.- Intrarif. P.R.- Prerif. M.R.- Mesorif. P.R.- "*Rides prerifaines*". M.A.- Atlas Medio. H.P.- *High Plateaux*. S.A.- Atlas Sahariano. E.T.- Tell Externo. Posición hipotética de las secciones en la figura 6: Unidades KE.- Ketama. U.- Ubrique. B.- Boyar. N.- Nogales. K.- Ksar es Sghir. JT.- Jbel Tisirene.

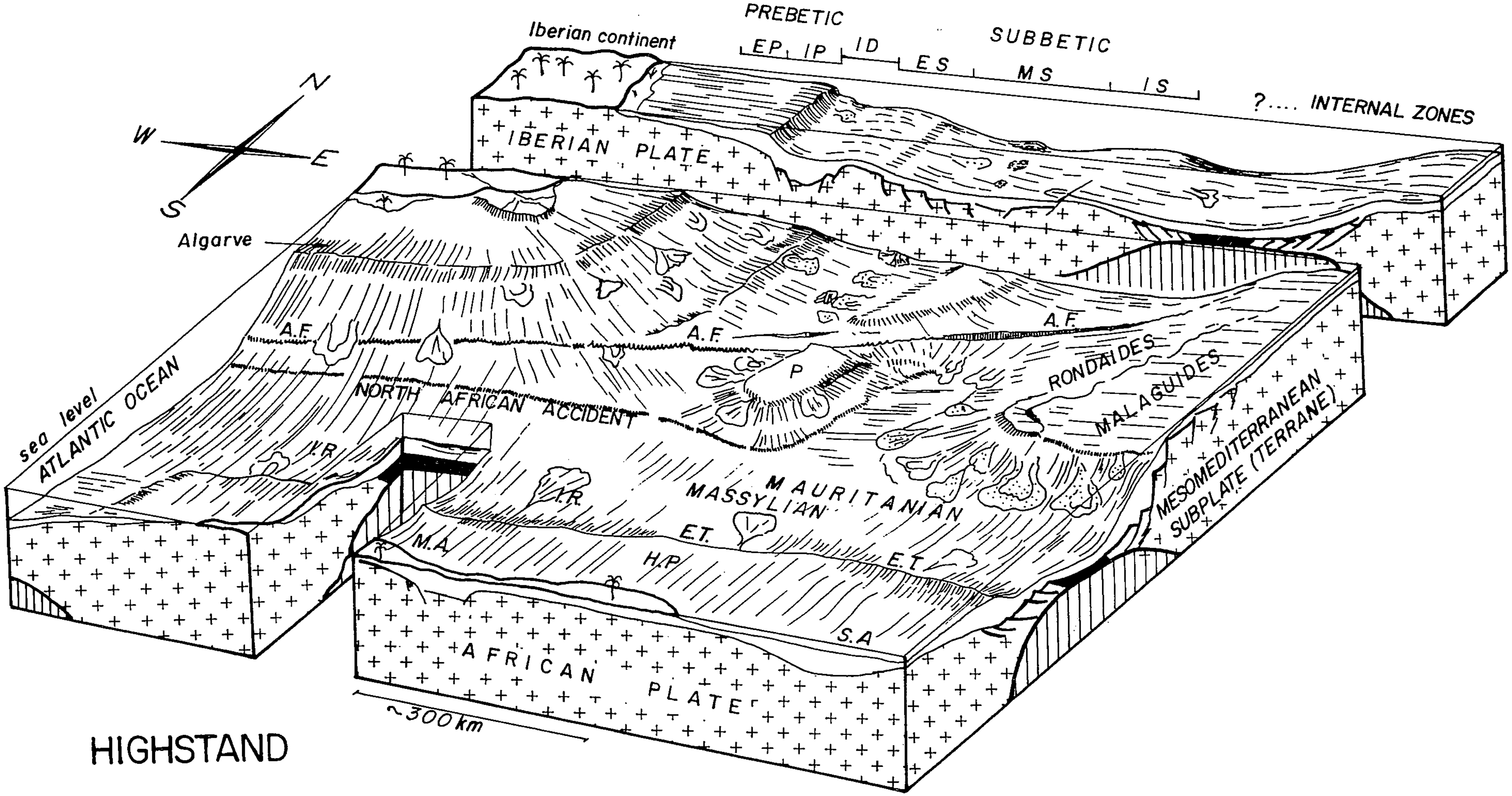

Fig. 10.- Three-dimensional sketch of Southern Iberian continental Paleomargin of the Betic Cordillera, the North-African margin and the Mesomediterranean Subplate (terrane) during the Senonian. Key as in figure 9.

Fig. 10.- Esquema paleogeográfico tridimensional del extremo occidental del Tethys (Margen Sudibérico, Margen Norte-Africano y Subplaca Mesomediterránea) durante el Senoniense. Leyenda como en figura 9.

in fact the consequence of stages of acceleration in the spreading of the Mid-Atlantic ridge which caused the deepennig of the betic and rifian basins, which formed the connection between the Atlantic and the Tethys. Many of these plate movements would have been reflected not only in the sea-level changes but also in intrabasinal synsedimentary tectonics, which in their turn may generate turbidite deposits. In this way, the isochroneity of the onset of the eustatically controlled siliciclastic turbidite sedimentation coming from the continent, and the tectonically controlled carbonate turbidite sedimentation derived from the denudation of subbetic pelagic swells, can be quite logically explained.

We want to remark, then, that the separation between tectonic and eustatic factors is not so distinct as could be thought, as both type of factors may be widely and intimately linked, the eustatic changes resulting from changes in plate motion.

4.6. *Proposed Model.*

The proposed sedimentary model to explain the deposition of Cretaceous turbidites in the Betic Cordillera is shown in Figures 9 and 10. A three- dimensional sketch of the basin during a lowstand phase is represented in Figure 9 , taking the probable palaeogeography during the Aptian as a model. In Figure 10, a highstand period is shown in the context of the probable Senonian palaeogeography of the basin. These two intervals of time have been chosen because, between them, there was relatively little plate movements, as a result of the stop of the transform movements between Africa and Iberia during this that time and, consequently, the general morphology of the basin remained much the same.

The siliciclastic turbidites were concentrated in the subsident areas near the respective continents. In the case of the Southern Iberian margin they came from the Iberian continent and were preferently deposited in the Intermediate Domain. The Prebetic was an area of shallow marine and coastal sedimentation, with erosion, bypassing and washing-off episodes. But the siliciclastic supply never reached the most internal sectors of this margin. The Subbetic basin was an area without siliciclastic sedimentation: only marly-clayey sediments and pelagic carbonate and siliceous oozes, with local carbonate turbidites strongly controlled by the local basin topography, were deposited. The most internal part of the Southern Iberian margin, the Penibetic, was an swell area, with a very thin pelagic cretaceous sedimentation, and the area that separated it from the northern margin of the Mesomediterranean subplate was a very deep starved basin with a scarce oceanic-type sedimentation of varicoloured clays. In the case of the area between the Mesomediterranean subplate and the African plate, two opposed terrigenous source areas existed, and so the North African Flysch Trough formed a well nourished siliciclastic basin: the Mauritanian, which was very close to the Kabylian emerged continent, was the site of the terrigenous turbidites coming from the North which were deposited in a west-east deep sea trench; on their hand, the North African margin, and possibly the Massylian realm of the Flysch Trough, were nourished from the south, the great African continent, where the terrigenous clastics mostly came from.

The deposition of all these siliciclastic turbidites took place in the stages inmediately after sea-level falls (Fig. 9), when wide shelf areas were emerged and eroded. In this way type I and/or II turbidite systems of Mutti (1985) were generated during intra-Hauterivian, intra-Aptian and intra-Albian falls. Other siliciclastic turbidites of lesser volume and minor palaeogeographic significance, and probably corresponding to type III turbidite systems (Mutti, 1985), were deposited during time of rising of the sea-level (fig. 10), with a similar geographic distribution but with a more reduced extent and thickness. A third type of turbidites should correspond to those, mainly of calcareous nature, placed to the interior of the pelagic basin (Subbetic), genetically related to synsedimentary tectonic processes (faulting, tilting and halokynesis), and controlled by the importance, position, geometry, and nature of the event.

5. CONCLUSIONS

1.- The Cretaceous siliciclastic turbidites of the Betic Cordillera, were mainly deposited in the more subsident areas of the Southern Iberian Margin (Intermediate Domain) and in the North African Flysch Trough. Other turbidites, chiefly of calcareous nature, occur irregulary distributed all along the basin.

2.- The Cretaceous turbidites of the Betic cordillera may be grouped in two types: eustatically and tectonically controlled turbidites respectively. The basis for this division is the dominant factor involved in each case, as, in fact, both phenomena were often quite closely related.

3.- The eustatically controlled turbidites are extensive siliciclastic deposits laid down at the same time in the marginal subsident trough of the Southern Iberian margin (Intermediate Domain) and in the North African Flysch Trough. The isochronism of the different turbidite systems laid us to consider the deposition namely as eustatically controlled. The age of these turbidites is, basically, Late Hauterivian-Barremian-Aptian-Albian. They make up the main turbidite bodies of specific turbidite systems, probably equivalents to type I and/or II turbidite systems (or stages) of Mutti (1985), and can be related to periods of sea-level fall.

4.- The second type of turbidites was tectonically controlled. They are mainly carbonate turbidites outcropping in different palaeogeographic realms and ages. Tectonic events determined local sea-level fluctuations and also the accumulation of redeposited materials in areas adjacent to synsedimentary tectonic accidents.

5.- The onset of siliciclastic turbidite sedimentation was controlled by major tectonic events such as the relative movements of the Iberian, European and African plates and the Mesomediterranean subplate during the Neocomian. These major tectonic events result in relative sea-level changes.

6.- The end of siliciclastic turbidite sedimentation throughout the basin, was brought about by a general rise in sea-level at the beginning of the Late Cretaceous.

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