Chapter 2
The Betic External Zones

The Betic Cordillera is the major geological domain situated to the S and SE of the Iberian Peninsula. It is bounded by the Iberian Massif and the Iberian Mountain Range to the N and by the Atlantic Ocean and Mediterranean Sea to the SW, S, and SE (Fig. 2.1). It belongs, along with other mountain ranges of North Africa, to the western segment of the Perimediterranean Alpine Orogen. In the Betic Cordillera, three main geological domains of greater rank are differentiated: the Betic External Zones, the Betic Internal Zones and the Campo de Gibraltar Complex. The general knowledge of the geology of the Betic Cordillera has been shown with in previous works (Sanz de Galdeano 1997; Gibbons and Moreno 2002; Vera 2004) and its exhaustive analysis is not the objective of this publication. However, we will present here a synthesis of the External Zones focused in the Subbetic domain.

2.1 The External Zones and the South Iberian Palaeomargin

The outcropping sedimentary rocks of the Betic External Zones were deposited in the South Iberian Palaeomargin (Western Tethys) during the Mesozoic and most of the Cenozoic, and were mainly deformed during the Miocene, between the Burdigalian and the Late Miocene. García-Hernández et al. (1980) proposed a first model of the palaeogeographic evolution of this margin during the Mesozoic, and established a tectonic and palaeogeographic subdivision in geological units that, with some nuances, is still used nowadays (Vera 2004).

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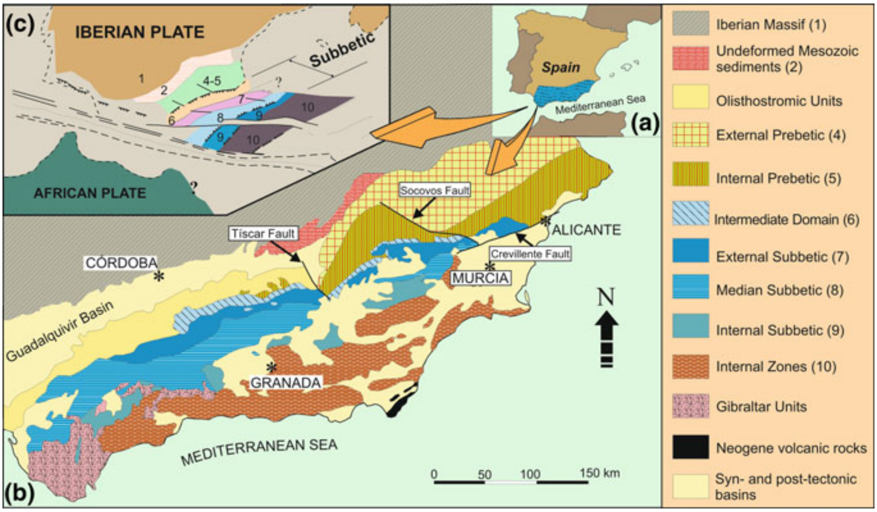


Fig. 2.1 Geological map of the Betic Cordillera

2.1.1 Tectonic Units and Palaeogeographic Domains

In the Betic External Zones units of diverse range have been defined by tectonic and stratigraphic criteria. These units comprise deposits accumulated in the South Iberian Palaeomargin, in palaeogeographic domains individualised throughout the successive stages of its Mesozoic history. The higher rank division of the Betic External Zones is into Prebetic and Subbetic. These terms designate areas clearly differentiated by its regional geographic position as well as by its structural, stratigraphic or palaeogeographic characteristics. This terminology has been used with equivalent meaning since its original definition (Blumenthal 1927; Fallot 1945, 1948; Fontboté 1970). From a tectonic point of view, the Prebetic, located to the north, consists of parauthocthonous or moderately allochthonous sedimentary rocks, whereas the Subbetic allochthony is beyond doubt and the rocks generally more deformed than those of the Prebetic. The Subbetic is relatively well-organised from a structural point of view, but the deformation is locally such intense that large sections of it, predominantly made up of Triassic terrains, have lost their internal coherence and have been transformed into disorganised masses called Subbetic Chaotic Complexes. Part of these chaotic masses was gravitationally slipped and included in the mid-Miocene sediments of the southern edge of the Guadalquivir Basin, forming the Guadalquivir Olisthostromic Complex, or Subbetic Olisthostromic Complex (Pérez-López and Sanz de Galdeano 1994) or Evaporite-bearing Accretionay Complex (Pérez-Valera et al. 2017).

The subdivision in Prebetic and Subbetic is even more necessary from a stratigraphic and palaeogeographic point of view. The Prebetic successions mainly contain shallow marine facies, with important continental episodes, even with intervals of erosion, depending on the sectors. In contrast, in the Subbetic the pelagic facies are dominant from the Upper Pliensbachian (Domerian), when the main phase of intracontinental rifting began and the large shallow marine carbonate platforms disappeared (Vera 2001). This interpretation is evidenced in the palaeogeographic and palinspastic reconstructions for the Jurassic and Cretaceous of Azema et al. (1979) and García-Hernández et al. (1980, 1989).

The Subbetic, the southernmost major unit of the External Zones (Fig. 2.1), is composed of sedimentary rocks from the Triassic to the Middle Miocene and to a minor extent by volcanic and subvolcanic rocks. Within the Subbetic there are different thrusting sheet units structurally organised. The distribution of these units is broadly consistent with the established palaeogeographic subdomains, mainly for the Jurassic. The boundaries between palaeogeographic subdomains, however, do not always coincide with tectonic boundaries (thrust faults). The palaeogeographic nomenclature of the Subbetic was introduced by García-Dueñas (1967) and is constituted by three large subdomains WSW-ENE elongated: External Subbetic, Median Subbetic and Internal Subbetic. This triple division was completed with two modifications (Vera 2004). The first was the assignment to the Subbetic of the Intermediate Domain (Ruiz-Ortiz 1980, 1981). The Intermediate Domain, located to the N of the External Subbetic, was separated from both Prebetic and Subbetic in previous classifications (Azema et al. 1979; Vera 1986), but was ultimately included in the Subbetic because of its similarities in facies and tectonic style, in contrast with the much different Prebetic, to which the Intermediate Domain overthrusts extensively. The second modification is the distinction of the Western Subbetic as a particular subdomain called Penibetic (Martín-Algarra 1987; Martín-Algarra and Vera 1982, 1989, 1994; Vera 2001), for its stratigraphic, palaeogeographic, and tectonic peculiarities.

In conclusion, in the Subbetic, and especially in the central sector of the cordillera, four sets of tectonic units, of structural guideline WSW-ENE are distinguished. They come from four pre-existing palaeogeographic subdomains (Fig. 2.2). The northernmost unit (Intermediate Domain) was the most subsident and in displays the maximum sediment thickness of the Jurassic and Cretaceous in the whole basin. In the second unit (External Subbetic), located immediately to the S and SE of the previous one, the subsidence was minimal during the Middle and Late Jurassic, which determined the development of condensed facies. The third unit, more southernly (Median Subbetic), was again more subsident and characterised by a predominance of marly facies in the Middle-Upper Jurassic and Cretaceous with intercalations of submarine volcanic rocks in its central part, especially abundant in the Jurassic. Finally towards the S appears the last palaeogeographic subdomain (Internal Subbetic-Penibetic) that during the Middle-Late Jurassic constituted a pelagic swell with slight subsidence (Internal Subbetic in the oriental and central sectors of the mountain range), and that in the western sector has own entity (Penibetic) for its peculiar Jurassic facies and for the frequent stratigraphic hiatuses occurred in the Lower Cretaceous.

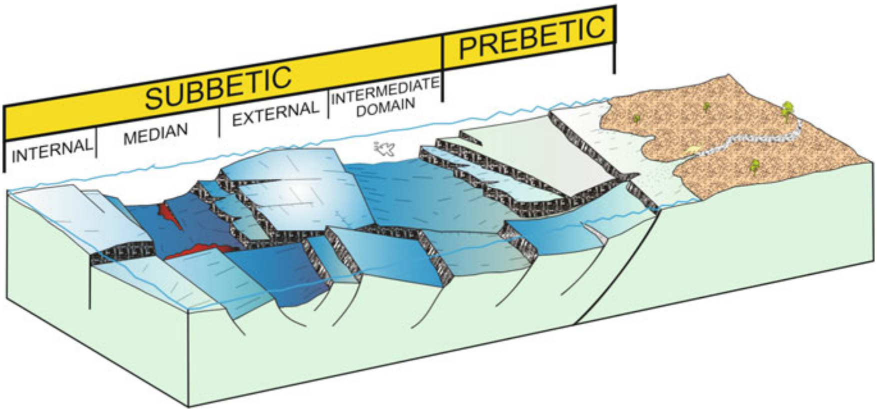


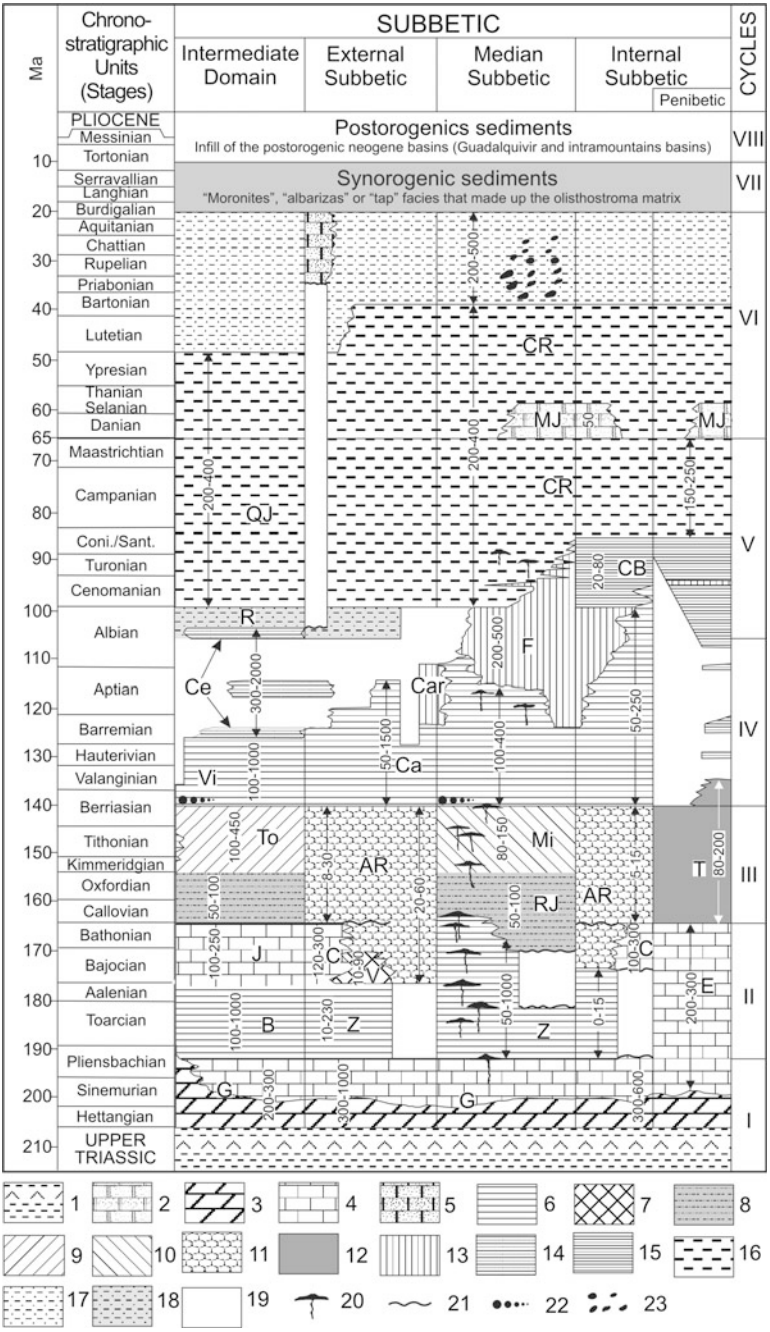
Fig. 2.2 Configuration of the sea floor topography of the South Iberian Palaeomargin during the Jurassic

2.1.2 Higher Range Sedimentary Cycles

Sedimentary cycles of great order have been differentiated in the stratigraphic record of the South Iberian Palaeomargin (Vera 2004; Fig. 2.3). The criteria that can be used for the differentiation of these large cycles are diverse, but the ones that will be distinguished below are based on the recognition of stratigraphic discontinuities in wide sectors of the basin, which are an expression of tectonic, climatic, oceanographic and/or eustatic events that affected the South Iberian Palaeomargin as a whole. The defined cycles have very different durations, from more than 45 My (Cycle I) to about 8 My (Cycle VII), all within the range of second order cycles of the most usual classifications. Within these larger cycles, lower-range cycles are differentiated based on the recognition of other stratigraphic discontinuities and various stratigraphic features, associated to events of similar significance but with less intensity or more local character than those of the larger cycles.

Seven major sedimentary cycles (Cycles I to VII) were differentiated between the beginning of the Triassic and the Upper Miocene (Fig. 2.3). An additional cycle (Cycle VIII) includes sedimentary rocks that have usually been considered as postorogenic (Upper Tortonian to Holocene), that fill the postorogenic sedimentary basins. These basins are not part of the Betic External Zones in the strictest sense of the term. It should be noted that the age of the boundaries between cycles is not always exactly the same in all sectors of the basin, since the phenomena that caused them were often heterochronous.

Cycle I comprises the Triassic and early Jurassic rocks (Fig. 2.3). The earliest are those of Buntsandstein facies which appear in the Tabular Cover and Prebetic, very rarely in the Subbetic. The Muschelkalk facies appear broadly in the Betic External Zones, although the most extensive Triassic outcrops correspond to the Keuper facies. The Jurassic rocks included in this cycle are those of


Ma
Chrono-stratigraphic Units (Stages)
SUBBETIC
Intermediate Domain
External Subbetic
Median Subbetic
Internal Subbetic
Penibetic
CYCLES
PLIOCENE
Messinian
Tortonian
Serravallian
Langhian
Burdigalian
Aquitanian
Chattian
Rupelian
Priabonian
Bartonian
Lutetian
Ypresian
Thanian
Selanian
Danian
Maastrichtian
Campanian
Coni./Sant.
Turonian
Cenomanian
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
Tithonian
Kimmeridgian
Oxfordian
Callovian
Bathonian
Bajocian
Aalenian
Toarcian
Pliensbachian
Sinemurian
Hettangian
UPPER TRIASSIC
Postorogenics sediments
Infill of the postorogenic neogene basins (Guadalquivir and intramountains basins)
Synorogenic sediments
"Moronites", "albarizas" or "tap" facies that made up the olisthostroma matrix
VIII
VII
VI
V
IV
III
II
I
CR
MJ
QJ
CB
R
F
Ce
Car
Ca
Vi
To
AR
Mi
RJ
J
C
X
V
E
B
Z
G
T

◂**Fig. 2.3** Chronostratigraphic chart for the Subbetic (modified of Vera 2004). *1* Keuper Facies. *2* *Microcodium* calcarenites (Majalcorón Fm). *3* Dolostones. *4* Shallow carbonate platform limestones and oolithic limestones. *5* Shallow carbonate platform limestones and calcarenites. *6* Pelagic limestones/marls alternance with ammonites. *7* Cherty limestones (Veleta Fm). *8* Radiolarite facies. *9* Pelagic limestones/marls alternance with calcareous tempestites (Milanos Fm). *11* Condensed pelagic limestones, mainly ammonitico rosso facies. *12* Pelagic oolithic limestones and ammonitico rosso facies (Torcal Fm). *13* Black lutittes and marls, with radiolarites and calcareous turbidites (Carbonero Fm and Fardes Fm). *14* Marls and marly-limestones with terrigenous turbidites (Cerrajón Fm). *15* White marls and marly-limestones with planktic foraminifera (Capas Blancas Fm). *16* Pink marly-limestones with planktic foraminifera and coccolites (Capas Rojas Fm and Quípar-Jorquera Fm). *17* White marls and marly-limestones with calcareous turbidite beds. *18* Calcilimolites (Represa Fm). *19* Hiatus. *20* Submarine volcanic rocks. *21* Mainly unconformities. *22* Turbidites, mainly calcareous. *23* Evaporite-bearing accretionary complex. *AR* Ammonitico Rosso Superior Fm. *B* Baños Fm. *C* Camarena Fm. *Ca* Carretero Fm. *Car* Carbonero Fm. *CB* Capas Blancas Fm. *Ce* Cerrajón Fm. *CR* Capas Rojas Fm. *E* Endrinal Fm. *F* Fardes Fm. *G* Gavilán Fm. *J* Jabalcuz Fm. *Mi* Milanos Fm. *MJ* Majalcorón Fm. *QJ* Quípar-Jorquera Fm. *R* Represa Fm. *RJ* Radiolarítica Jarropa Fm. *T* Torcal Fm. *To* Toril Fm. *V* Veleta Fm. *Vi* Los Villares Fm. *Z* Zegrí Fm

Hettangian-Carixian age. In the Subbetic they are represented by carbonates deposited in shallow marine platforms (Gavilán Fm), within which have been differentiated two cycles of minor order (García-Hernández et al. 1989; Andreo et al. 1991). The events associated with the discontinuity at the top of Gavilán Fm (limit between cycles I and II) were initiated during the Late Carixian (Early Pliensbachian), since its fossilisation occurred between the terminal Carixian and the basal Domerian, according to the sectors. The Domerian (Upper Pliensbachian) is clearly included in Cycle II and consists of pelagic sediments.

The upper boundary of Cycle II is located near the Bathonian-Callovian transition. In the subbetic pelagic swells (External and Internal Subbetics) this boundary coincides with a very clear stratigraphic discontinuity (Fig. 2.3), a paraconformity whose surface is covered by crusts of iron and manganese oxides (hardground), locally with stromatolithic and microbial structures (Martín-Algarra and Sánchez-Navas 2000; Reolid and Molina 2010; Nieto et al. 2012). When the discontinuities in different sections are analyzed in detail, it is observed that this is a complex discontinuity, composed of three minor discontinuities very close in time (O'Dogherty et al. 2000) developed during the Late Bathonian.

The Cycle III begins after the Upper Bathonian discontinuity, but the Callovian sediments are absent in large sectors of the External Betic Zones (Fig. 2.3). In the pelagic swells of the External and Internal Subbetic its upper limit (top of the Upper Ammonitic Rosso Fm) is located from the Middle Berriasian (Nieto 1997) to the end of the Berriasian (Molina 1987) depending on the sector. In the Intermediate Domain this upper boundary coincides with the limit between the Toril Fm and the Los Villares Fm dated as Upper Berriasian and, therefore, with the first input of sand size terrigenous into the pelagic basin throughout mesozoic history, although this input was initially very moderate.

The Cycle IV has the lower limit in the intra-Berriasian discontinuity described above and ends near the boundary between the Lower Cretaceous and the Upper

Cretaceous (Fig. 2.3). In the Intermediate Domain the upper limit of the cycle coincides with the end of the turbiditic sedimentation of the Cerrajón Fm, that has been dated as the transit between Middle Albian and Upper Albian (de Gea et al. 2001), whereas in other sectors of the Subbetic coincides with the end of a sedimentary hiatus (Fig. 2.3) of wide space-time extension.

The Cycle V begins with the above mentioned intra-Albian discontinuity and reaches the boundary between the Cretaceous and Paleocene (Fig. 2.3). In the Subbetic the sedimentary characteristics are quite uniform and in the majority of this palaeogeographic domain the Quípar-Jorquera Fm (Vera et al. 1982) and Capas Rojas Fm (Vera et al. 1982; Vera and Molina 1999) were deposited, both consisting of pelagic marine sediments (not necessarily deep). The presence in some sectors of the Median and Internal Subbetic of *Microcodium* calcarenites (Majalcorón Fm; Molina et al. 2003, 2006) whose bottom almost coincides with the boundary between the Cretaceous and Paleocene supports the argument of setting the upper limit of this cycle coinciding with this chronostratigraphic boundary.

The Cycle VI starts at the end of the previous cycle, while the upper boundary is located within the Burdigalian (Fig. 2.3). In the central sector of the Subbetic, a stage of "Burdigalian Paroxysm" (Hermes 1985), coincident with the boundary between the Lower and Upper Burdigalian (Soria 1994a, 1998), marks the end of the sedimentation of the Almidar Fm among whose sediments are intercalated acid pyroclastic rocks (Soria 1994b). In the Subbetic, this cycle mostly consists of pelagic marls with turbidite intercalations, although in some localised sectors limestones and calcarenites were deposited on shallow platforms (Molina and Nieto 2003).

The Cycle VII has as its lower limit the intra-Burdigalian discontinuity mentioned above and as upper limit the intra-Tortonian discontinuity detected in different sectors of the Subbetic (Estévez et al. 1982). It comprises rocks that have been considered "synorogenic" (Vera 2000) and are mostly white marls with abundant foraminifera, coccoliths and diatoms.

The Cycle VIII has as its lower limit the intra-Tortonian discontinuity, while the upper one is the end of the sedimentary fill in each postorogenic basin, which originates from a continental elevation and the consequent nesting of fluvial networks and massive erosion of subhorizontal materials of this cycle in the different postorogenic basins.

2.1.3 Geodynamic Evolution of the South Iberian Paleomargin

The following evolutionary episodes are differentiated according to Vera (2004) (see Fig. 2.4):

A. *Initial episode of intracontinental rifting* (*Cycle I*). Corresponds to the initial phase of the distension that developed during the Triassic-Carixian and which

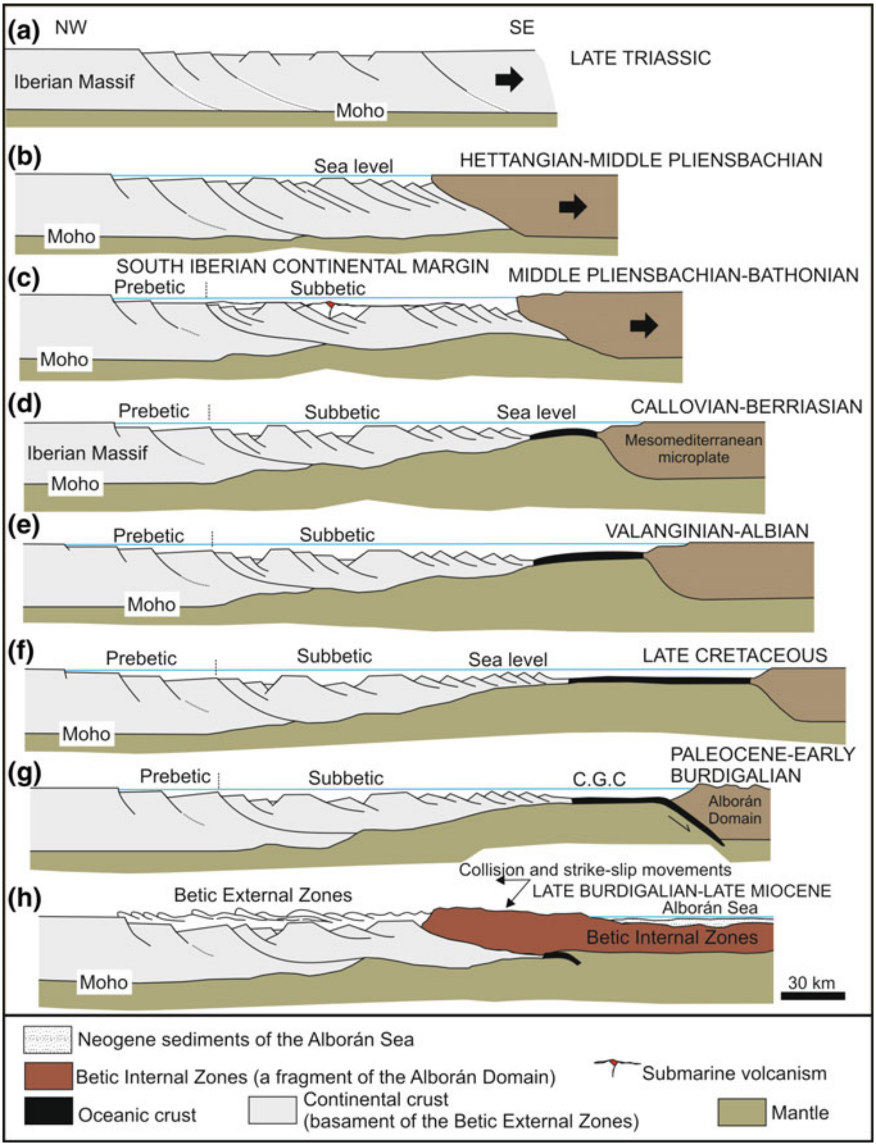


Fig. 2.4 Evolution of the South Iberian Continental margin from the first extensional stages until main deformation phases. C.G.C.: Campo de Gibraltar Complex (Actualized from Vera 2004)

is expressed by Cycle I comprising the rocks of the Triassic and the Liassic infra-Domerian (Fig. 2.4a, b).

B. *Main episode of intracontinental rifting* (*Cycle II*). It was developed during the Domerian-Bathonian period. In the Subbetic, it shows remarkable variations of facies and thicknesses from one palaeogeographic subdomain to other, but in all cases at the beginning of the cycle pelagic sedimentation began (Fig. 2.4c). During the cycle in some sectors were developed large-scale shallowing sequences that ended again with shallow platform limestones.

C. *Expansive episode* (*Cycle III*). It began when the first oceanic crust (or oceanic affinity) was formed between the Iberian Plate and the Meso-Mediterranean Plate. It started towards the boundary between Bathonian-Callovian (Vera 1988, 2001) and ended in the Upper Berriasian. During this episode it can be properly said that there is a relatively diversified and evolved South Iberian continental margin (Fig. 2.4d). In the greater part of the Prebetic there was a clear differentiation with respect to other areas adjacent to the Iberian Massif, reaching higher values of subsidence. In the Subbetic, there was a clear differentiation between subsident troughs and less subsident swells.

D. *Rifting episode of the margin edge* (*Cycle IV*). The Cycle IV was deposited from the upper Berriasian to the Upper Albian and is equivalent to the "tectosedimentary period without-extension" of Vilas et al. (2001) recognised in the Prebetic. It was a rifting phase that simultaneously affected the South Iberian Palaeomargin and other continental margins that surrounded the Iberian Massif. In the Subbetic, the upper part of this cycle (Barremian-Albian) is particularly well recognised in the Intermediate Domain (Fig. 2.4e) for the maximum development of turbidites (Ruiz-Ortiz 1980, 1981; de Gea et al. 2001).

E. *Post-rift episode* (*Cycle V*). It is characterised by the progressive disappearance of tectonic subsidence and the existence of a slow but persistent thermal subsidence (Vera 2001; Vilas et al. 2001). This episode began in the Late Albian and ended near the Cretaceous-Tertiary boundary (Figs. 2.3 and 2.4f) and during this period a homogenisation of the facies took place in wide sectors of the South Iberian Palaeomargin.

F. *Convergent episode* (*Cycle VI*). The transition from a passive margin to a convergent one occurred near the Cretaceous-Tertiary boundary (Vera 2001), although probably it began somewhat earlier, during the Campanian, as proposed Martín-Chivelet et al. (1997). During this period, the cycle VI comprising the sediments of the Lower Paleocene-Burdigalian was deposited (Fig. 2.4g). The end of this episode coincides with the beginning of the continental collision, during the Burdigalian, between the Alborán Domain and the South Iberian Palaeomargin.

G. *Collision episode* (*Cycle VII*). Between the Burdigalian and the beginning of the Upper Miocene, the displacement of the Alboran Domain towards the W was completed and the collision with the South Iberian Palaeomargin was blocked. The "Burdigalian Paroxysm" of Hermes (1985) coincided with the main deformation of the palaeomargin, which marked a true palaeogeographic revolution by raising the areas of its southernmost part and determining the individualisation of a subsident basin located at the deformation front. Also during this time interval (from Late Burdigalian to Early Tortonian) a remarkable extension occurred in the AlboránSea, simultaneous to a remarkable shortening of the sedimentary cover of the South Iberian Palaeomargin with the consequent structuration of the External Betic Zones (Sanz de Galdeano 1983, 1990, 1997; Vera 1988, 2000; Maldonado et al. 1992; Comas et al. 1992). Cycle VII corresponds to the sediments deposited in the South Iberian Palaeomargin from the beginning of the collision to the phase of intra-Tortonian tectonic deformation (Estévez et al. 1982). Since the structure of the Betic External Zones took place during this episode, the sedimentary rocks deposited therein can be considered as synorogenic. The area of greater depth and greater subsidence, in the western half, was located in the northen deformation-front of the Betic External Zones that progressed little by little towards the north. During this episode also occurred the deformation of a notable part of the Subbetic that produced the lost of internal coherence and the consequent formation of the Subbetic Chaotic Complexes.

H. *Post-collision episode* (*Cycle VIII*). During the Late Tortonian-Messinian-Pliocene the sedimentation occurred preferentially inside the Postorogenic Neogene Basins as differentiated subsidence areas, one of them, the most extensive, to the north of the cordillera (Guadalquivir Basin) and the others within the cordillera (intramontane basins) (Fig. 2.4h).

2.2 Sedimentary and Palaeogeographic Evolution of the Lower Jurassic

2.2.1 The Gavilán Formation

The Jurassic begins with the Gavilán Fm whose contact with the Triassic of the underlying Keuper facies. Three members are differentiated:

Lower member of dolomitised algal laminites (*M1*): it is constituted by massive dolomites (around 500 m thick), with remains of algal lamination. These facies, which are very uniform throughout the mountain range, have been interpreted as typical of tidal flat environments (García-Hernández et al. 1978, 1979; Andreo et al. 1991; Nieto 1997). Its top has been interpreted as a discontinuity related to the early stages of development of intracontinental ritfing (Nieto et al. 1992; Vera 2001).

Intermediate member of pseudo-oolitic limestones (*M2*): it presents varying thicknesses (0–150 m) and very diverse facies: limestone of oncoids and ooids, limestone with *Lithiotis* or limestones with chert. This facies variability is probably related to a sudden change in the sedimentary conditions of the platform that divided it into more or less protected sectors and somewhat more open and energetic sectors, as well as into hemipelagic environments (García-Hernández et al. 1986; Andreo et al. 1991). It is a marine platform compartimentalised in small banks or swells, isolated by somewhat deeper sectors.

Top member of crinoidal limestones (*M3*): it is composed by calcarenites with abundant crinoid bioclasts and peloids, usually packstone or grainstone, interpreted as high-energy deposits of an external platform (Dabrio and Polo 1985).

The local differences among the members consist in the greater or lesser development, or in its case the absence of the more modern members. The upper member (M3) is not always present, whereas the massive dolomites of the lower member (M1), can extend vertically to cover almost all the formation in some outcrops due to the unequal extent of the dolomitisation that, according to Martín (1980), reached greater stratigraphic height in the limits between palaeogeographic subdomains.

The top of this cycle coincides with the more evident discontinuity of the Subbetic, record of the rupture of the carbonate platform and the drowning of the shallow environments (Fig. 2.5). Nieto et al. (2002) have described two phases of fracturing from the record of breccia deposits and other features related to the genesis of this discontinuity. The first levels situated on the discontinuity show condensed sedimentation rich in ammonites of the basal Domerian (Braga 1983), while in the Gavilán Fm several biozones of the Carixian (Lower Pliensbachian) have been dated (García-Hernández et al. 1979; Rivas 1979).

2.2.2 *The Zegrí Formation*

The Jurassic of the External Zones of the Betic Cordillera has been interpreted, from the perspective of basin analysis, as the recording of a rifting episode that led to the formation of a continental margin on the southern margin of the Iberian plate (e.g., García-Hernández et al. 1989; Vera 2001). The development of this rifting event meant, in its early stages, the fracturing and dismemberment of the enormous carbonate platform that during the Early Jurassic covered the entire area of the South Iberian Palaeomargin (Fig. 2.6) and extended widely to more northern sectors. In the early stages of rift evolution, the tectonic phase of the Early Pliensbachian had a very significant impact (Vera 2001; Nieto et al. 2002; Ruiz-Ortiz et al. 2004). During this phase the differentiation of the two great domains of the Betic External Zones, the Prebetic and the Subbetic, took place, and from that moment, they underwent different evolutions. In particular, in the Subbetic, the sedimentation in the Domerian is restarted, but with a marked pelagic character. Thus, the Zegrí Fm rocks deposited in a basin compartimentalised block rotated and tilted by faults. This caused important differences in the rate of subsidence that were recorded in the thickness, and more locally in the facies, of this lithostratigraphic unit. This formation is therefore the record of the first stages of the syn-rift stage, so the study of the distribution of thickness and facies is considered critical in order to quantify the process, not only in terms of sedimentation/subsidence rates, but also in relation to the size of the blocks, the lateral extension of the fractures and their spatio-temporal distribution.

The Zegrí Fm was defined by Molina (1987) in the Subbetic. Its age is generally comprised between the Middle Domerian (Upper Pliensbachian) and Lower Bajocian although in some places the bottom of the formation is of Early Domerian age and the top can reach the late Bajocian. This lithostratigraphic unit has two members (Fig. 2.5): (1) The lower member (Middle Domerian-Lower Toarcian) is a

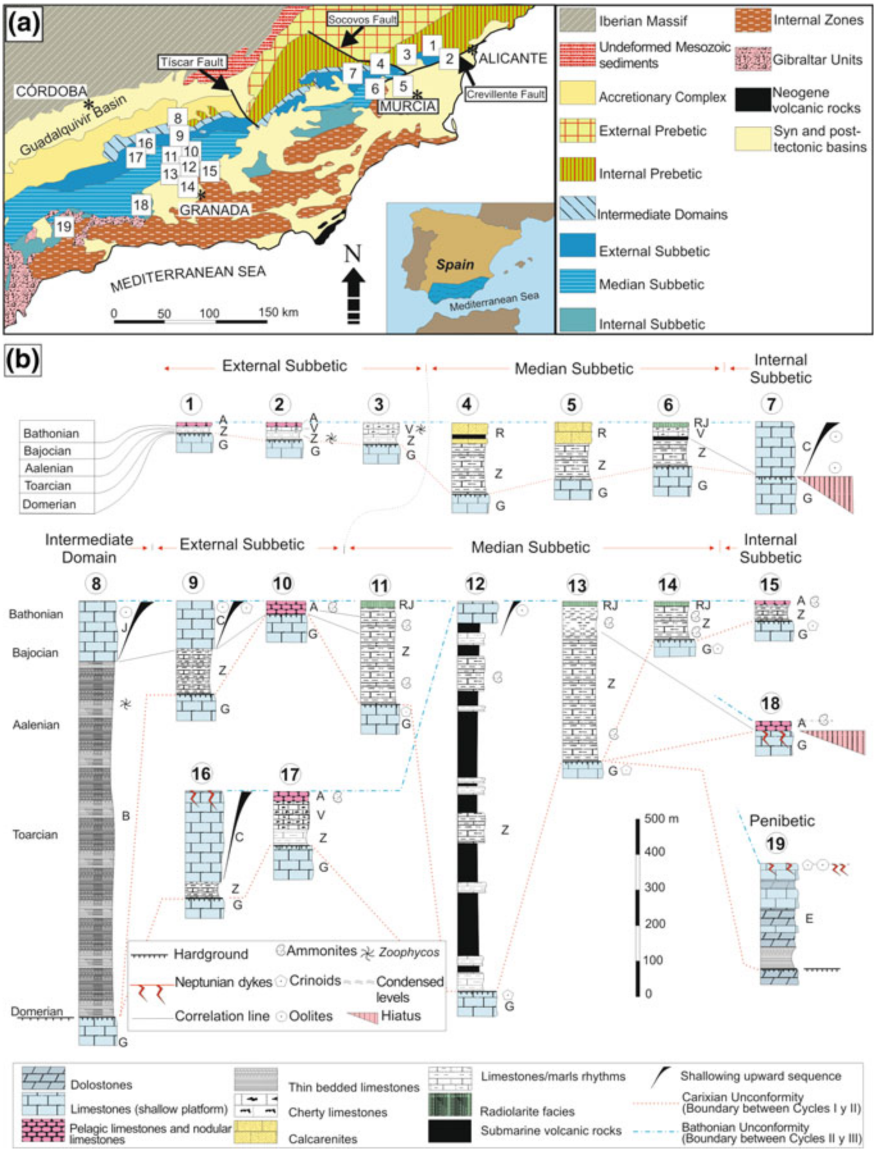


Fig. 2.5 Correlation for the Cycle II (see Fig. 2.1). **a** Geological sketch of the Betic Cordillera with location of the stratigraphic successions. **b** Correlation for the Cycle II Upper Pliensbachian to Bathonian for the Subbetic (modified from Vera et al. 2004). *1* Sierra de Reclot. *2* Sierra de Crevillente. *3* Sierra de Lúgar. *4* Bermeja Unit (Sierra de Ricote). *5* Garita Unit (Sierra de Ricote). *6* Sierra de Ponce. *7* Sierra del Gigante. *8* Jabalcuz. *9* Grajales-Mentidero Unit. *10* Ventisquero Unit. *11* Noalejo. *12* Benalúa de las Villas. *13* Zegrí. *14* Sierra Elvira. *15* Sierra Harana. *16* Camarena-Lanchares Unit. *17* Gaena Unit. *18* Sierra Gorda. *19* Torcal de Antequera

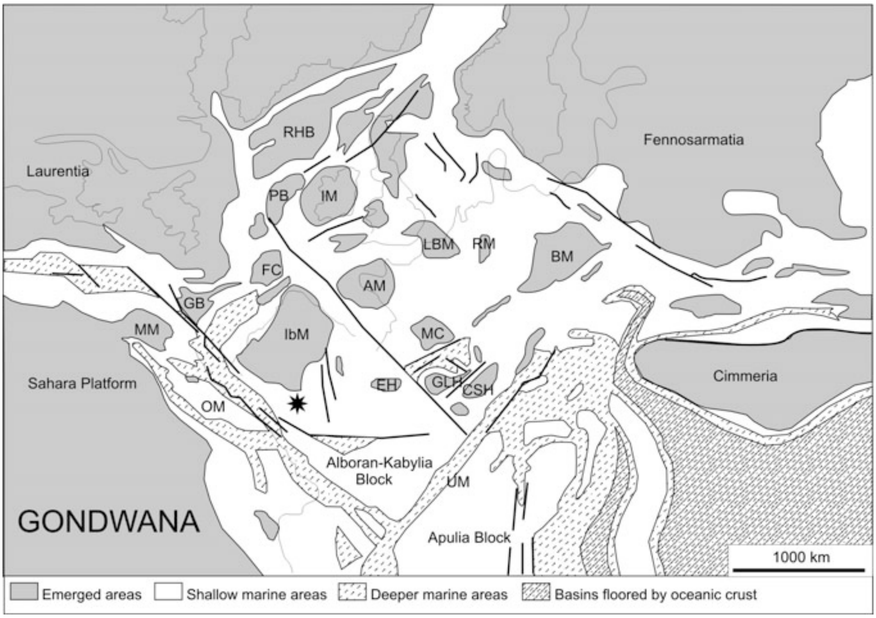


Fig. 2.6 Palaeogeographic reconstruction for the Toarcian in the westernmost Tethys based on Ziegler (1988) with location of the South Iberian Palaeomargin (*star*). *Note AM* Armorican Massif; *BM* Bohemian Massif; *CSH* Corsica-Sardinia High; *EH* Ebro High; *FC* Felmish Cap; *GB* Gran Bank; *GLH* Golf de Lyon High; *IbM* Ibeian Massif; *IM* Irish Massif; *LBM* London Brabant Massif; *MC* Massif Central; *MM* Moroccan Massif; *OM* Oran Massif; *PB* Porcupine Bank; *RHB* Rockall-Hatton Bank

rhythmite of marly limestones and marls, although locally only marls are present; and (2) The upper member, which is less potent, with mainly marly ammonitico rosso facies. The lateral and vertical changes in facies and thickness between both members are frequent. In some sectors this formation has very significant gaps affecting part or even the entire time interval (Domerian-Aalenian). The total thickness varies generally between a few metres and 250 m, although in some parts of the Median Subbetic can reach more than 500 m (Nieto et al. 2004).

This formation was likely deposited in a pelagic or hemipelagic environment below the base level of the storm surge, but close to it. The Toarcian Oceanic Anoxic Event (T-OAE) has been recognised in the Zegrí Fm (e.g., Jiménez et al. 1996; Reolid 2014) in the Serpentinum ammonite Zone (according to the Submediterranean ammonite biozonation, Fig. 2.7). In the central part of the Median Subbetic, submarine volcanic rocks are intercalated in the Zegrí Fm, in an WSW-ENE alignment, locally reaching accumulated thicknesses of several hundred metres. These volcanic rocks are mainly pillow lavas of a transitional-alkaline composition related to extensional crustal thinning. Based on geochemical data, Vera et al. (1997) indicated that these Jurassic submarine basic volcanic rocks are mainly ultrapotassic, with some showing shoshonitic affinities. Magmas were

		Boreal	Subboreal	Submediterranean	Mediterranean
TOARCIAN	Middle	*compactile*	*variabilis*	*gradata*	
		braunianus	*bifrons*		
		commune			
	Early	*falciferum*	*serpentinum*		*levisoni*
		antiquum	*tenuicostatum*		*polymorphum*
PLI.	Up.	*viligaensis*	*spinatum*	*emaciatum*	

Fig. 2.7 Uppermost Pliensbachian and Toarcian subdivisions and correlation of ammonite zones for Borela, Subboreal, Submediterranean and Mediterranean domains based on Elmi et al. (1997), Zakharov et al. (1997) and Page (2003)

generated in the upper mantle, passed through a thick continental crust, and were extruded at the sea-floor.

The lithostratigraphic equivalent in the Intermediate Domain is the Fm Baños (Ruiz-Ortiz 1980). In the section type has a thickness of 1000 m and is made up of thin-bedded limestones, among which centimetre marly levels are intercalated. Its deposition occurred in a pelagic environment of some tens to hundred metres deep (Ruiz-Ortiz 1980).

In the Penibetic, the Lower and Middle Jurassic is represented by a basal dolomite (Dolomía Jarastepar) on which the Endrinal Fm (Martín-Algarra 1987) is located. This formation is 200–300 m thick and likely misses the Upper Pliensbachian and Toarcian deposits equivalent to the Zegrí Fm in this palaeogeographic domain.

According to available biostratigraphic data (see Rivas 1972; Jiménez 1986; Molina 1987; Nieto 1997; among others), the top of the Zegrí Fm is heterochronous, with a large stratigraphic hiatus in wide sectors of the Subbetic, this hiatus covers at least the entire Aalenian (Ruiz-Ortiz et al. 1997). In some units this hiatus can extend from the Upper Toarcian to the Lower Bajocian.

The sedimentary rocks superimposed on the Zegrí Fm can be included in two large groups. First, those deposited in shallow carbonate platforms, which have been called Jabalcuz Fm (Intermediate Domain), Camarena Fm (Subbetic) and Endrinal Fm (Penibetic); and second, typical sediments of hemipelagic or pelagic environments, included in the Veleta, Ammonitic Rosso Superior, Jarropa and Ricote Fms, all of them of the Subbetic.

The similarity of the Zegrí Fm facies throughout the subbetic domain revealsthat the fracture of the large liassic platform in the middle-upper Carixian and the generalised onset of pelagic sedimentation in the subbetic basin did not involve, on the contrary, substantial variations of the facies that were deposited from some areas to others. A limestone-marl rhythmite sedimentation is generalised and only in the areas closest to the Prebetic platform, in the Intermediate Domain (Baños Fm), the sedimentation is more calcareous. The rate of subsidence and accordingly the accumulated thickness in the Middle Jurassic is the only factor that makes a difference between the incipient Subbetic subdomains that will end up being individualised, from the point of view of the nature of the facies.

The correlation between the sections of the Zegrí Fm analyzed in previous published papers is based mainly on lithostratigraphic criteria, since there is no precise dating that can reveal all the possible gaps within the formation as in the age of its top in each outcrop. On the other hand, the overlapping of overthrust nappes characteristic of the structure of the Betic Cordillera, and the lack of solidly argued palynspastic restitutions, makes difficult the elaboration of palaeogeographic reconstructions that otherwise, with the knowledge of the currently available stratigraphic architecture, could be realised. Even with the difficulties exposed, the few sections in which the Zegrí Fm shows a great contrast of thickness without significant tectonic translations between them, are located at such great distances (between 20 and 30 km).

The boundary faults of blocks and palaeogeographic subdomains would have directions around N 70° E (e.g., Nieto 1997). These faults were responsible of the changes in thickness that are detected in directions perpendicular to them. In addition, there would be other transverse faults (transfer faults) that would have directions close to the N-S. This type of faults would explain the thickness changes in an approximately E-W direction.

Nieto et al. (2002) identified gravitational deposits linked to small-slip and low lateral continuity faults, with approximately N-S directions., corresponding to outcrops with physical continuity belonging to a same subbetic subdomain (Intermediate Domain). In contrast, it is remarkable that uptodate there are not known deposits of breccias or other gravitational deposits in relation to what could be major faults, or margin faults, which would constitute the boundaries of the then incipient subbetic subdomains.

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