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PALEOGENE-AQUITANIAN TECTONIC BREAKUP IN THE EASTERN EXTERNAL BETIC ZONE (ALICANTE, SE SPAIN)

Colapso tectónico en las Zonas Externas Béticas Orientales durante el Paleogeno-Aquitaniense (Alicante, SE España)

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Abstract: *Six Paleogene-Aquitanian successions have been reconstructed in the Alicante area (eastern External Betic Zone). The lithofacies association evidences "catastrophic" syn-sedimentary tectonic processes consisting of slumps, mega-olisthostromes, "pillow-beds" and turbiditic deposits. This kind of sedimentation is related to unconformity surfaces delimiting sequence and para-sequence cycles in the stratigraphic record. The data compiled have enabled the reconstruction of the Paleogene-Aquitanian paleogeographic and geodynamic evolution of this sector of the External Betics. During the Eocene the sedimentary basin is interpreted as a narrow trough affected by (growth) folding related to blind thrust faulting with a source area from the north-western margin, while the southeastern margin remained inactive. During the Oligocene-Aquitanian, the sourcing margin becames the southeastern margin of the basin affected by a catastrophic tectonic. The activity of the margins is identified from specific sediment source areas for the platform-slope-trough system and from tectofacies analysis. The southeastern South Iberian Margin is thought to be closer to the Internal Betic Zone, which was tectonically pushing towards the South Iberian Margin. This pushing could generate a lateral progressive elimination of subbetic paleogeographic domains in the eastern Betics. This geodynamic frame could explain the development of such "catastrophic" tectono-sedimentary processes during the Late Oligocene-Early Miocene.*

Key Words: *Depositional sequences, sequence boundary, Paleogene-Aquitanian, slope, deep basin, tectofacies.*

Resumen: *El presente artículo muestra los resultados obtenidos en el estudio y reconstrucción de seis sucesiones de edad Paleogeno-Aquitaniense localizadas en el área de Alicante (Zonas Externas Béticas orientales). Seis asociaciones de litofacies reconocidas evidencian procesos tectónicos sinsedimentarios catastróficos consistentes en la aparición de slumps, mega-olistostromas, incluso con bloques métricos de elementos deslizados de la plataforma, niveles almohadillados y depósitos turbidíticos. Este tipo de depósitos va acompañado de superficies de discontinuidad que delimitan secuencias y para-secuencias deposicionales en el registro estratigráfico. La interpretación de los datos obtenidos ha permitido proponer un modelo de la evolución geodinámica y paleogeográfica de este sector de las Zonas Externas Béticas orientales durante el Paleógeno-Aquitaniense. La cuenca sedimentaria se interpreta como un corredor afectado por una deformación incipiente que produciría pliegues de crecimiento relacionados con cabalgamientos ciegos profundos. Dicha cuenca presentaría durante el Eoceno un margen que se deformaba situado al noroeste, que suministraría el material terrígeno y otro tranquilo al sureste. En el Oligoceno debió producirse una reorganización paleogeográfica que ocasionó que el margen productivo pasara a ser el sureste. La actividad tectónica de ese margen sureste se reconoce por depósitos característicos del borde del corredor-talud-plataforma, que evidencian la destrucción y redepósito en masa de sedimentos procedentes de dicha plataforma. Para explicar la geodinámica responsable de dicha actividad tectónica sinsedimentaria tan catastrófica se propone que las Zonas Internas Béticas debían ocupar una posición muy cercana a la terminación oriental del Mar-*

gen Sudibérico durante el periodo compresivo del Oligoceno Superior-Mioceno Inferior. Esto implicaría un acuñamiento lateral de dominios paleogeográficos subbéticos en la parte oriental de la Cordillera Bética ya en este periodo, de manera que podría faltar el Subbético Interno y Medio.

Palabras-clave: *Secuencias deposicionales, límite de secuencia, Paleogeno-Aquitaniense, talud, cuenca profunda, tectofacies.*

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The Alicante region (SE Spain) belongs to the External Betic Zone of the Western Mediterranean Alpine belt (Fig. 1, inset). This zone is characterized by Mesozoic to Tertiary sedimentary rocks related to two tectono-sedimentary domains: (1) the proximal and mainly shallow marine Prebetic Domain to the N and to NW, and (2) the distal and subsident Subbetic Domain to the S and SE (García-Hernández, et al., 1980). The Mesozoic evolution of the External Betic Zone was characterized by the opening of the South Iberian Margin, which was associated with the Pangaea breakoff and related spreading of the Central Atlantic and Western Tethys Oceans (García-Hernández, et al., 1980; Vera, 2001). The Jurassic extensional tectonics allowed the development of a complex submarine topography with narrow subsident troughs and pelagic highs (swells), which attenuated but did not completely disappear during the Cretaceous post-rift thermal subsidence period. The Paleogene basins were placed on the previous Mesozoic domains, but started to develop under compressive conditions related to the early stages of the Alpine Orogeny (Vera, 2004).

In the central Betics, the Paleogene basin morphology followed, in general, after the cretaceous homogenization, the Jurassic (post-Liassic) previous basin pattern, appearing swells and troughs. So, nummulite-rich platforms were installed over the previous shallow areas, while pelagic turbidite deposits over the former pelagic-hemipelagic ones (sometimes associated with olisthostrome and slumps were deposited in slope and basinal areas: Comas, 1978). A synthetic paper of Vera (2000) and several contributions as Alegret *et al.* (2008), Alcalá *et al.* (2013), Vera (2004), Vera *et al.* (2004) provide a general framework of the Tertiary of the External Betic Zone. These contributions are very useful to divide the Paleogene record into several sedimentary cycles. Nevertheless, the Paleogene basins are still poorly known, especially in the eastern part of the chain, where the real influence of the compressional tectonics in sedimentation is not fully understood. In the Alicante region, previous studies on Paleogene successions have been made in the northern Eocene platform (Everts, 1991; Geel, 1995, 2000; Geel *et al*., 1998; Höntzsch *et al*., 2013) and in the deep Paleogene near the Alicante coast (Roep and Everts, 1992). Guerrera *et al.* (2006) provided new litho- and biostratigraphic data with implications for the timing of deformation, leading to propose tentatively a young Paleogene tectonics connected with the Internal Betic Zone deformation. In addition, the same authors performed a preliminary sedimentologic study on the tectofacies outcropping in the so-called "Alicante Trough" to better define the influence of tectonics in the basin evolution. The aim of the present paper is to provide new evidence for syn-sedimentary tectonics registered in the sedimentation of the Alicante area in order to clarify the geodynamic evolution of the Eastern External Betics during the Paleogene-Aquitanian.

This paper is meant to pay tribute to Juan Antonio Vera Torres, Professor at the University of Granada (Spain) and member of the Royal Spanish Academy of Sciences, colleague of the first author (F. Guerrera) and teacher of the second (M. Martín-Martín), in the year of his retirement, as part of a special issue dedicated to him. F. Guerrera, of Italy, deeply appreciates Professor Vera for the warm reception at the University of Granada with kindness and friendship during the many collaborative studies in Andalusia. M. Martín-Martín expresses his gratitude for the encouragement received from Professor Vera at all times as well as the scientific and economic support, without which his scientific-academic career would not have been possible.

Geological setting

The studied sections (Villafranqueza, Busot, Pantanet, Relleu, Torre del Charco, and Playa Nudista localities) are located in the north of Alicante province between the city of Alicante and Busot, Relleu, and Benidorm (Fig. 1). This area, belonging to the External Betic Zone, today shows several fault systems (Fig. 1). The most representative is the N70E system (coincident with the Cadiz-Alicante lineation). Others less representative fault systems are the N150E and N120 E. These fault systems functioned from the Middle Miocene on, as discussed in Tent-Manclús (2003).

The studied successions nowadays appear in blocks delimited by faults as follow (Figure 1: cadre of study area): Villafranqueza section located in the San Vicente-San Juan block, delimited by the San Vicente and Jijona-SE faults (near to N150 E oriented); Busot, Pantanet, Torre del Charco and Playa Nudista sections located in the Villajoyosa-Benidorm block, delimited by the Busot-Benidorm fault (near to N70E oriented); Relleu section in the Jijona-Sella block delimited by the Relleu and Jijona-NE faults (near to N70E oriented).

The fault traces are usually characterized by the outcropping of strongly brecciated Triassic clays with gypsum due to halokinetic phenomena, while the blocks bound by the fault-bounded blocks are composed mainly of folded Cretaceous to Miocene successions. Younger Neogene deposits related to pull-apart or fault-bend basins (sensu Noda,

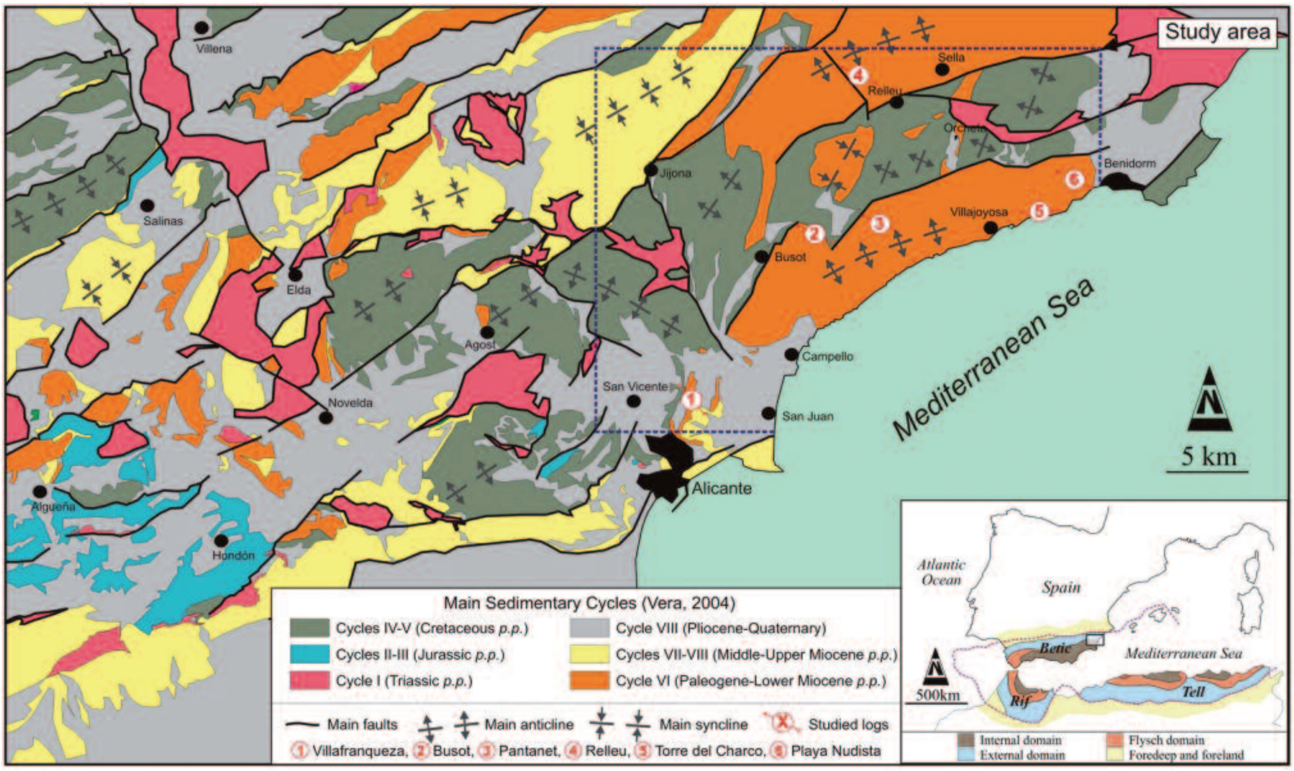

Fig. 1- Geological map of the Alicante sector of the Betic Cordillera with the location of the study area in the framework of the Western Mediterranean Alpine Chain. The stratigraphic units considered refer to the regional sedimentary cycles defined by Vera (2004).

2013) are also present along the fault damage zones (Leret-Verdú and Lendínez-González, 1978; de Ruig, 1992). The blocks among the faults show different internal structure according to the orientation of their fold axis, i.e. N20E or N70E, respectively (Colodrón and Ruiz, 1980; de Ruig, 1992). These folding systems seem to be related to a transpression under a compressional kinematic regional framework established from the Middle Miocene on. First, the N70E fault systems under a kinematic cadre with a nearly E-W oriented σ1, generated the N20E-oriented folding presumably during the Middle Miocene; later, the N120-155E fault systems with a nearly NW-SE oriented σ1, generated the N70E-oriented folding, affecting the Upper Miocene. Thus, the Paleogene-Aquitanian basin now appears fragmented into several blocks bound by main dextral faults that moved after the end of the infilling of the basin.

Litho- and biostratigraphy

The sections studied (Villafranqueza, Busot, Pantanet, Relleu, Torre del Charco and Playa Nudista) were measured adding up about 1500 m thick. At the same time, the successions were analyzed for identifying tectofacies and unconformity surfaces, and sampled for petrographic and biostratigraphic analyses.

Villafranqueza section.

This stratigraphic section (Fig. 2) was previously studied and dated in Guerrera *et al.* (2006). It shows a tectonic contact after Upper Cretaceous (Senonian) basal interval (65 m thick) characterized by whitish marls and marly limestones, and from here starts a monotonous, thicker succession (Late Ypresian-Early Lutetian) subdivided into the following main stratigraphic intervals: (i) reddish and brownish marls and clays (36 m thick) with centimetric beds of marly interbedded limestones; (ii) cream and greenish marls (100 m thick) rich in decimetric nummulites (and other larger foraminifera), blocks and conglomerates olisthostrome-like intercalations, and centimetric nummulite-rich turbiditic sandstones (Tab-Tabc), more abundant upwards in the succession; (iii) brownish and greenish pelites and marls (60 m thick) with several metric slumpings followed by decimetric nummulite-rich olisthostrome-like intercalation; (iv) calcareous and/or marly-calcareous beds (10 m thick); (v) brownish and greenish marls (300 m thick) with several metric slumpings, metric olistholithes, and decimetric nummulite-rich intercalations, nummulite-rich turbiditic sandstones-rudstones (Tab-Tabc), and centimetric marly limestones. Usually, beds are organized in elementary facies sequences consisting of a centimetric marly bed (Fig. 3A), at the bottom, followed by a centimetric bed of pelagic marly limestones ending with centimetric nummulite-rich turbiditic sandstones (Tab-Tabc, Fig. 3B). The paleogene succession is in contact by mean of a regional unconformity with a thick bioclastic-rich calcarenite, sandstone, and conglomerate beds (Upper Miocene). The paleocurrents measured in some turbidite sandstones indicate flows towards N230E and N90-100E. Slump folds indicate depositional slopes facings towards N190E.

Busot section.

This section (Fig. 2), unique in the whole area, shows the stratigraphically most complete (with some gaps) section in the study area, from the Cretaceous to the Upper Oligocene and probably the Aquitanian. Nevertheless it also bears several unconformity related stratigraphic gaps (Guerrera *et al*., 2006). Therefore, it is the reference section for correlation. Over the unconformity located at the top of marly limestones (Upper Cretaceous) the Paleogene succession starts with Ypresian reddish and yellowish marls (25 m thick) with centimetric marly limestone intercalations. After a new but smaller unconformity, the following Eocene succession (at about 60 m thick), affected by several minor fault surfaces (Fig. 2), is composed of whitish and yellowish marls with calcarenitic and marly limestone intercalations. After a new unconformity, the succession continues with a 60 m-thick Oligocene interval composed of whitish marls and lepidocycline-rich limestones (sometimes channelized: Fig. 3C) with olisthostrome conglome-

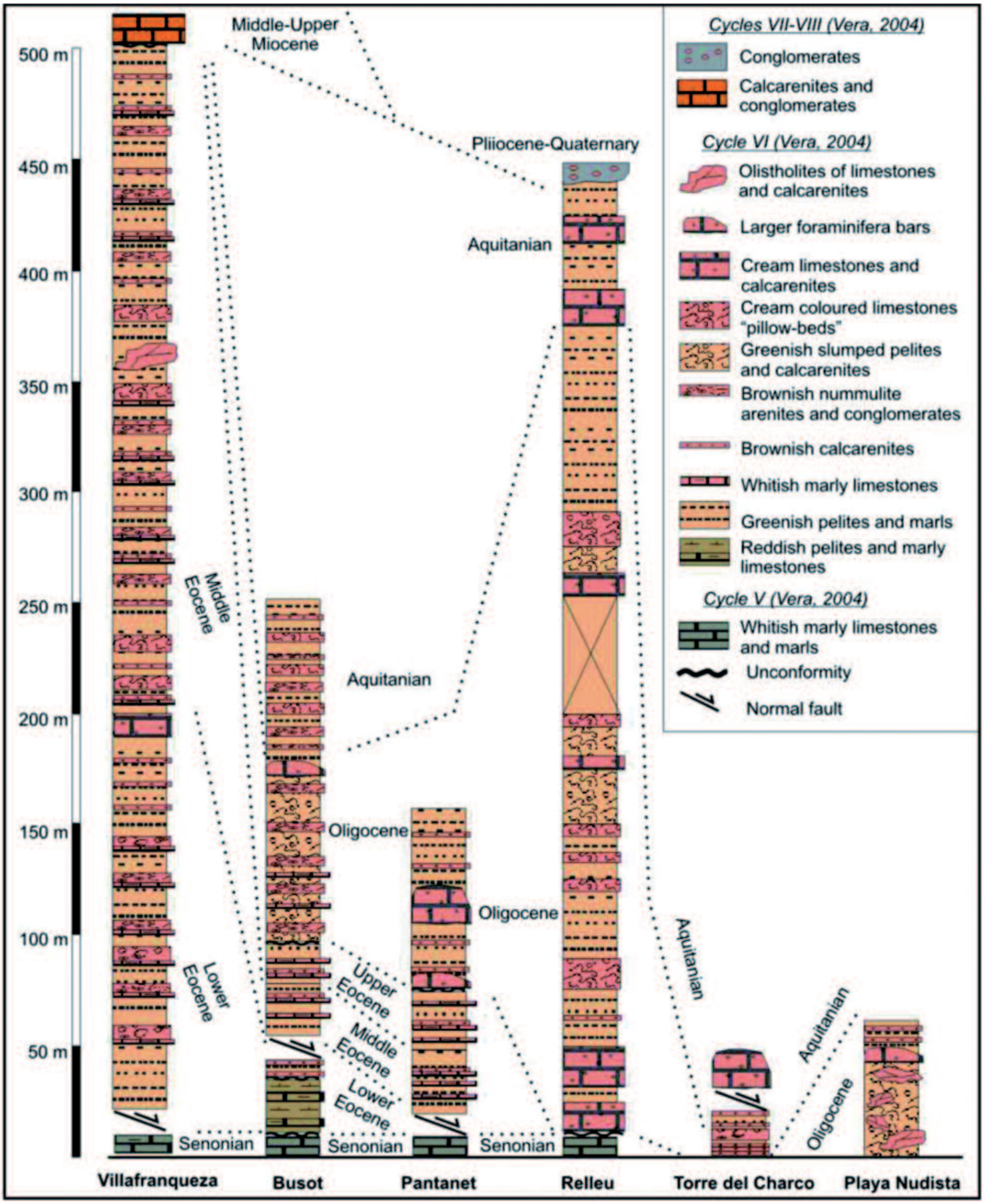

Fig. 2- Measured stratigraphic sections. Sedimentary cycles after Vera (2000).

ratic intercalations having erosional base (Fig. 3D) affected also by numerous metric slumps and pillow-beds (Fig. 3E) as defined by Roep and Everts (1992). A 10-meter-thick interval composed by limestone lens-shaped bodies made mainly of larger foraminifera shows upwardly a northwestward progradation. A 10-meter-thick interval with an internal arrangement in pillow-beds separated the previous succession from a yellowish marly one (70 m thick) with decimetric turbidite sandstone (Tab-Tabc) intercalations affected by decimetric slumping and pillow-beds. The channelized level flows are towards N40-50E. The stratigraphic section ends with several lens-shaped carbonate bodies intercalated among marly levels probably Aquitanian in age.

Pantanet section.

Cremades-Campos (1982) and Guerrera *et al.* (2006) studied the biostratigraphy of this section (Fig. 2), which constitutes the underlying Eocene to Early Oligocene interval to the Torre del Charco section (see below). Its lower part is made up of yellowish marls and marly limestones (at about 50 m thick), affected by several minor faults. A 10-meter-thick, north-westerly prograding lens-shaped larger foraminifera rich calcareous bed with erosional base separates the previous beds from a 70-m-thick yellowish marly succession with northward or north-west prograding of intercalated metric lens-shaped bodies and interbedded decimetric marls, breccias and sandy limestones.

Relleu section.

This Oligocene-Early Aquitanian section, dated here for the first time, lies, after an unconformity on Upper Cretaceous whitish marly limestones (Fig. 2). The section begins with two limestone intervals (at around 20 m thick each) made of bioclastic calcarenites with lepidocyclines and separated by 10 m of marls and minor limestone intercalations and abundant Rupelian planktonic foraminifera, among them, *Globigerina* forms of the groups *G. eocaena-corpulenta*, *G. venezuelana-tripartita*, and *G. ampliapertura-increbescens*. The first calcareous interval shows mega-flute casts at the base, indicating westwards- and northwestward-directed paleocurrents (Fig. 3, F). The section continues with a 150 m thick Late Oligocene interval (Chattian with *Globigerina angulisuturalis*), composed by whitish-cream marls with some beds of lepidocycline-rich limestones, affected by numerous metric slumps, pillow-beds and olisthostromes (pebbly mudstones) with erosional base. An unexposed interval about 55 m thick gives way to calcareous metric beds (20 m thick) followed by thinner calcareous beds and slumped marls (50 m-thick), and by a 15 m-thick calcareous interval at the top, with a pillow-beds arrangement (Fig. 3G). This is followed by 80 m of cream marls with some minor decimetric calcareous bed intercalations. The section ends with two bioclastic calcarenite or limestone levels (c. 15 m thick each) separated by 20 m of marls with thin limestone intercalations, and with 25 m of Early Aquitanian cream marls (with *Globoquadrina dehiscens*, *Globigerina kugleri*, and *Globigerinoides primordius*). Pliocene-Quaternary conglomerates rest unconformably above these levels.

Torre del Charco section.

The section (Fig. 2) is composed, from bottom to top, of bioclastic calcarenites rich in rodolites (5 m), followed by a 2 m thick level of intra-formational breccias and pillow-beds, and by yellowish marls (at about 10 m thick and Late Oligocene in age according to Guerrera *et al.,* 2006) with centimetric turbidite sandstone (Tab-Tabc) intercalations. After a fault surface, a 30-m-thick calcarenitic bed probably Aquitanian in age ends the succession.

Playa Nudista section.

This section at about 70 m thick is composed of two members (Fig. 2). Chaotic olisthostrome deposits with metric olistholites and slumps (Fig. 3 H and I), eroded from a mixed siliciclastic-calcareous platform, form the lower member (50 m thick). Northward- or northwestward-prograding metric lens-shaped bodies, intercalated with yellowish marls and decimetric sandy limestones beds, form the upper member (at about 20 m thick). Guerrera *et al*. (2006) dated this section as Oligocene.

Sedimentologic analysis

A detailed sedimentologic study was performed in all stratigraphic sections based on macro- and microfacies in order to identify tectofacies, source areas, paleocurrents, sedimentary realm, trends, and minor sequences. From the whole area, more than 50 thin sections were studied and each section was analyzed in detail in the field. Table 1 presents the classification of microfacies, Fig. 3 the photos of the macro-tectofacies and Fig. 4 the photos of microfacies, both described in this section of the paper.

Villafranqueza section.

This section shows a rhythmic vertical stacking of lithofacies formed, from bottom to top, by:

– Greenish hemipelagic marls and pelites with Early to Middle Eocene planktonic foraminifera.
– Thin- to medium-bedded, whitish massive micritic limestones with microfacies “a” (Fig. 3A and 3B, Fig. 4A, Table 1) and sharp, normally erosional upper contact with the overlying clastic beds. Locally, some beds contain thin basal horizons (1-2 cm) of rounded calcareous clasts or thin lenses of sandy sediment (similar to microfacies d and e). This facies is interpreted as hemipelagite.
– Thin or very thin-bedded and fine-grained, mixed siliciclastic-calcareous sandstones with Tb-e Bouma sequences and microfacies “b” (Figs. 3A and 3B, Fig. 4B, Table 1), interpreted as low-density distal turbidites or as traction bottom current deposits.
– Rare centimetric to decimetric beds of massive, ungraded, coarse-grained bioclastic calcarenites and cal-

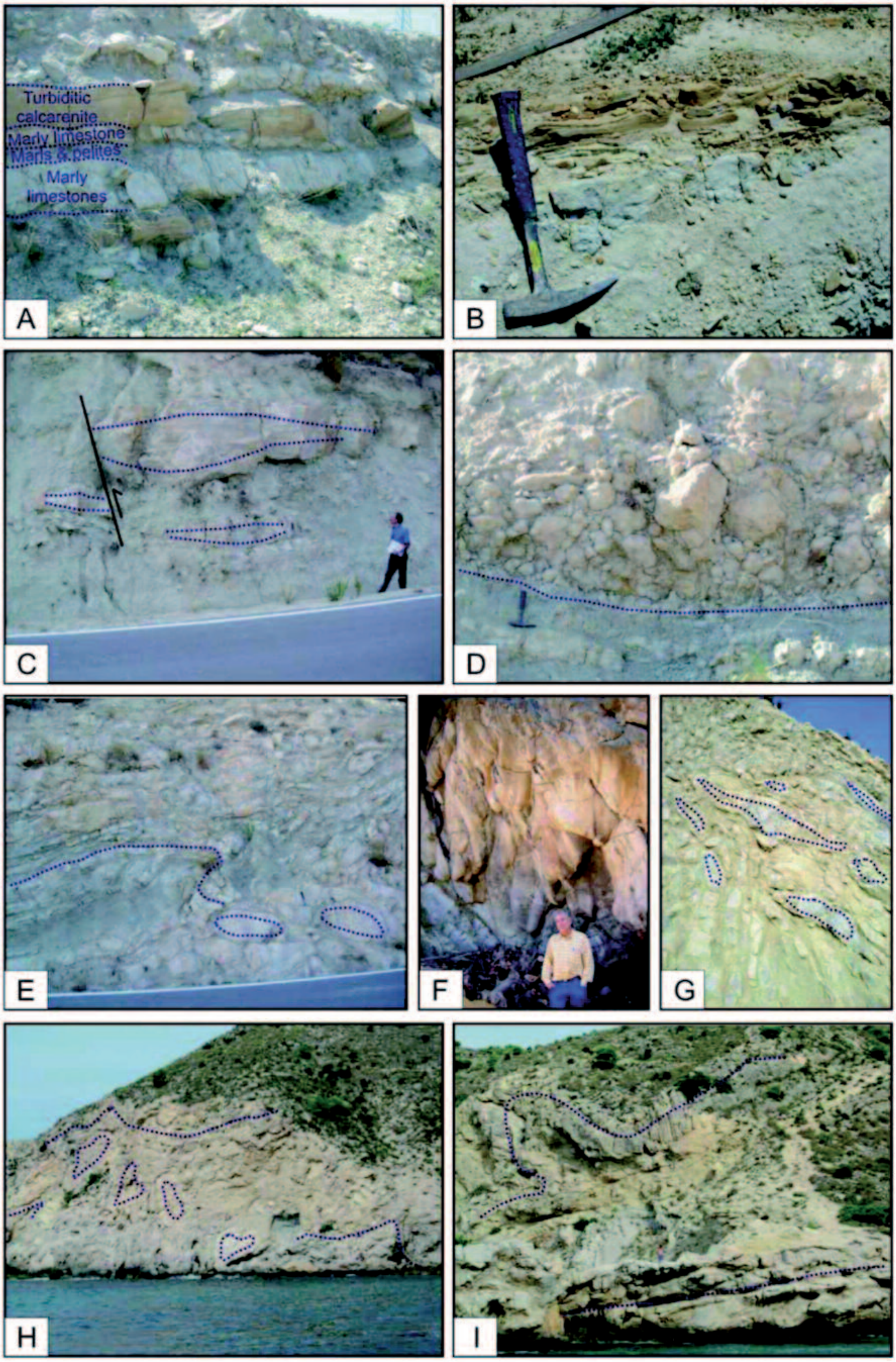

Fig. 3- Field photos of the main macro-tectofacies found in the study area (see text for details). (A) A typical Lower Eocene sequence of the Villafranqueza section. (B) Calcarenite turbidite with convolute bedding (Lower Eocene, Villafranqueza). (C) Two Oligocene carbonate turbiditic channelized bodies (Busot). (D) Oligocene conglomeratic bed with erosional base and reverse grading of clasts, typical of debris flow deposits (Busot). (E) Oligocene slumped level and pillow-beds (Busot). (F) Oligocene mega-flute casts indicating a northwestwards-directed paleocurrents (Relleu). (G) Oligocene pillow-beds (Relleu). (H) Oligocene mega-olisthostrome with huge blocks (Playa Nudista). (I) Slumped megabed (Playa Nudista).

cirrudites (rudstones) with larger foraminifera, red algae and bivalves (microfacies “c”; Table 1). These beds refer to mass flows or hyper-concentrated flows.

– Well-graded calcarenites with Tab or Ta-c sequences, coarse- or very coarse-grained in the Ta interval (rudstones), with well developed Tb interval and a thin or lacking ripple interval or rapid contact to the upper facies (Fig. 3B). This facies (microfacies “c”; Figs. 4C and 4D, Table 1) is interpreted as a classic turbidite. Thickness of the beds: 20-50 cm.

Busot section.

Three members have been distinguished in this section, each characterized by the main following facies:

– A Lower Eocene basal member made of reddish marls and marly limestones with microfacies “a”; Table 1) and fine-grained sandstones (microfacies “b”; Table 1), which are followed by thin- to medium-bedded calcareous (microfacies “i”) and mixed turbidites (microfacies “d, e, and f” in Fig 4E, Table 1) with complete Bouma sequences (Ta-e) and that gradually thicken upwards.

– A Middle to Upper Eocene chaotic member follows, characterized by channelized bodies (Fig. 3C) of intraformational coarse calcareous conglomerates (Fig. 3D), with slumps, and pillow-beds (Fig. 3E), which are interbedded in the middle-upper portion of the stratigraphic section. The slumps and pillow-beds are made of thin- to medium –bedded whitish limestones with microfacies “e and f” (Fig 4F, 4G and 4H, Table 1) that alternate with thin beds of green marls, locally bioturbated by *Zoophycos* isp. The clasts of the channelized carbonate beds show microfacies “e, f, and h” (Table 1).

– The succession ends with Oligocene-Aquitanian lens-shaped bodies made of accumulations of larger foraminifera (microfacies “e, f, and h”; Fig 4I, Table 1)

Pantanet section.

In this section, marly facies predominate in the lower part, followed by calcareous lens-shaped bodies at the top. Two members have been identified:

– A thick Middle to Upper Eocene marly member giving way upwards to marls with minor calcareous and calcarenite intercalations (microfacies “e and f”; Table 1), evidencing a shallowing upward trend.

– An Oligocene lens-shaped member, well cemented and stratified, up to 10 m thick, characterized by massive fine- or medium-grained laminated calcarenites (microfacies “h and i”; Table 1).

Relleu section.

This section, Oligocene in age, is characterized by the following levels:

– A lower calcareous member constituted by a lower, well cemented medium- to coarse-grained calcarenite interval showing microfacies “f and h (Table 1) planar to cross bedding and mega-flute casts indicating north-westward-directed paleocurrents (Fig. 3F); with marly intercalations thickening upwards. This member is interpreted as a deepening upward sequence of carbonate turbidites deposited in an external platform transitioning to the slope.

– A middle marly member with intercalated limestones and sandstones and with chaotic, internal structure, characterized by slumped intervals, intra-formational conglomerates, and pillow-beds (Fig. 3G). The carbonate clasts of the conglomerates and the pillow beds show microfacies “e and f” (Table 1). This member evidences the collapse of an upper slope laterally connected with a distal carbonate shelf or ramp.

– An upper calcareous member (up to 10 m thick), well cemented and stratified, , composed of three coarsening upwards sequences characterized by massive fine-grained calcarenites in their lower part and by thin- or medium- bedded and laminated coarser calcarenite or conglomerate beds in their upper part, locally covered by thin rippled laminae with microfacies “h and i” (Table 1). A sharp, bio-eroded and reddish colored upper surface separates this member from transgressive marls.

Torre del Charco section.

This section shows mudstone facies, made of Upper Oligocene whitish marls and/or calcilutites, sharply interrupted by coarse-grained facies with microfacies “b and c” (Table 1), up to several meters thick, characterized by a lower coarse-grained and clast-supported conglomerate (5-10 cm thick) with reverse to normal grading, composed of well-rounded clasts of limestone pebbles and rodolites. This level changes upwards to a mudstone interval with scattered clasts (pebbly mudstone, 10-20 cm thick) and to a thick upper (10 m) intraformational conglomerate bed composed by well-rounded coarse cobbles or boulders, mainly of biocalcarenites (pillow-beds), coming from a shallow-water environment.

Playa Nudista section.

This section, about 70 m thick, is composed by the following members, outcropping along the coastal cliff:

– A lower member constituted by irregularly cemented, unstratified fine-grained calcarenites (5 m thick) with microfacies “h and i” (Table 1), followed by well cemented, planar to cross stratified, medium- to coarse-grained calcarenite beds, (2 m thick). This member is interpreted as a shallowing-upwards sequence related to a prograding platform bar (Fig. 3I).

– A middle member, mainly chaotic, characterized by slumped intervals (Fig. 3I), up to 40 m thick, including a 3 m thick calcareous bed visible in the middle part of the cliff (Fig. 3H). This member represents the collapse of the carbonate shelf or ramp.

– An upper well cemented calcareous member, up to 10 m thick, composed of three coarsening upwards se-

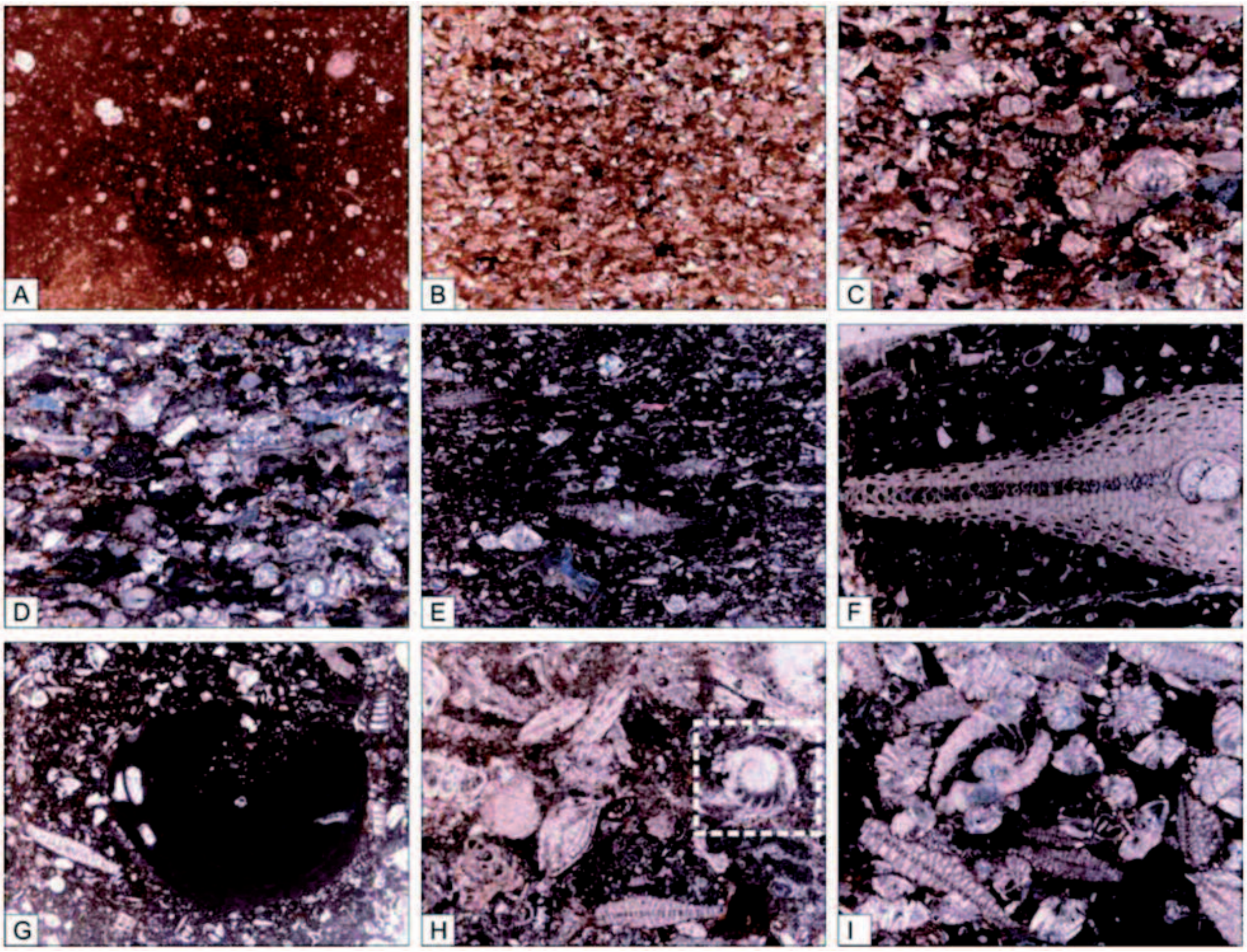

Fig. 4- Some selected Eocene-Oligocene microfacies. A to E and H-I, cross-polarized light (2,5x); F-G, parallel light (5x). (A) Wackestone with planktonic foraminifera (microfacies "a"), Lower Eocene from Villafranqueza stratigraphic section. (B) Fine-grained slightly terrigenous calcarenite (peloidal-bioclastic packstone with fine sand- to silt-sized quartz grains: microfacies "b"), Lower Eocene from Villafranqueza stratigraphic section. (C) Bioclastic packstone with benthic foraminifera (nummulitids, microfacies "c"), Lower Eocene from Villafranqueza stratigraphic section. (D) Lower Eocene microfacies "c" with alveolines from Villafranqueza stratigraphic section. (E) Middle Eocene microfacies "d" from Busot stratigraphic section. (F) Microfacies "e" from Busot stratigraphic section (detail of Nephrolepidina). (G) Microfacies "e" from Busot Section (detail of red alga. (H) Microfacies "f" from Busot stratigraphic section (operculine-like marked in the right hand and others larger foraminifera). (I) Microfacies "h" from Busot stratigraphic section.

quences with massive fine-grained calcarenites in their lower part and thin-bedded or medium- to thick-bedded and coarser laminated beds of calcarenites or conglomerate, locally covered by thin blankets with ripples (microfacies "h and i"; Table 1). A sharp, bio-eroded and reddish colored, surface separates this member from overlying hemipelagic marls (indicating a transgression).

Discussion

Sequence stratigraphy and depocentres.

Two main unconformities of early Ypresian and Early Oligocene age, have been recognized in the studied sections by Guerrera et al. (2006). They allow differentiating two depositional sequences of late Ypresian to Priabonian age and of early Rupelian to early Aquitanian age, respectively. The Eocene sequence is registered in the Villafranqueza, Busot, and Pantanet stratigraphic sections, but a direct stratigraphic (unconformable) contact with the Cretaceous beds is visible only in the Busot section; there, Guerrera et al. (2006) detected a gap affecting the Paleocene-earliest Ypresian. The Early Oligocene unconformity is visible in the Busot and Relleu sections. In the Busot succession, the stratigraphic gap associated with this unconformity affects only the latest Priabonian-earliest Rupelian, while Oligocene deposits rest unconformably over the Upper Cretaceous marly limestones in the Relleu section. The early Rupelian-early Aquitanian depositional sequence is preserved in the Busot, Relleu, Torre del Charco, and Playa Nudista sections.

The observed lateral changes in thickness of the Late Ypresian to Priabonian depositional sequence evidence a main depocenter in the western (Villafranqueza) sector and a secondary depocenter in the eastern (Pantanet) sector (Fig. 5). The Busot and probably the Relleu sectors were raised areas with less accommodation space located in the central part of the basin (Fig. 5). As regards the early Rupelian-early Aquitanian depositional sequence (Fig. 5), the thinnest to thickest variation from the Playa Nudista, to the Torre del Charco, Busot, and Relleu successions evidences

Microfacies type (logs where recognized)	Microfacies	Other components	Micropalaeontologic assemblages	Sedimentary, taphonomic and diagenetic features	Source area	Age
a (Villafranqueza; Busot)	Biomicritic mudstones/wackestone	Thin basal horizons (1-2 cm) of rounded micritic lithoclasts or thin lens of sand (quartz and feldspars)	Planktonic foraminifera, bioclasts of red and green algae, bryozoans, mollusc shells. Rare small-sized larger foraminifera	Massive structure	hemipelagic	Early-Middle Eocene
b (Villfranqueza; Busot)	Mixed siliciclastic/calcareous sandstone	Quartz, feldspars, glaucony grains, with some micritic lithoclasts	Broken tests of small-sized benthic and planktonic foraminifera	Poorly sorted and rounded grains; grain-supported; rare reverse grading	Mixed clastic distal shelf	Early-Middle Eocene
c (Villafranqueza; Busot)	Bioclastic, foraminiferal packstone/wackestone/ grainstone	Micritic lithoclasts	Larger foraminifera (*Nummulites, Operculina* and *Assilina*, unidentified alveolinids and microgranular specimens like nodosarids), bioclasts of red algae, bryozoans, mollusc shells and planktonic foraminifera	Normal or reverse grading; grain orientation; breaking and slight abrasion of benthic foraminifera	Open marine shelf (carbonate platform or ramp)-upper slope	Early-Middle Eocene
d (Busot, Relleu; Pantanet,Torre del Charco; Playa Nudista)	Biomicritic mudstone/ wackestone	——-	Larger foraminifera (*Nummulites-like and discocyclina-like*), echinoid spines, bioclasts of red algae, hydrozoans, mollusc shells and bryozoans	Breaking, abrasion and slight oxidation of larger foraminifera tests; poor sorting	Open marine shelf, lower photic zone	Oligocene-Aquitanian
e (Busot, Relleu; Pantanet,Torre del Charco; Playa Nudista)	Bioclastic packstone/wackestone	Glaucony grains and lithoclasts of micritic mudstone	Benthic foraminifera (*Nummulites-like, discocyclina-like*), echinoid spines, small-sized planktonic foraminifera, bioclasts of red algae, bryozoans and mollusc shells	Normal grading; micrite cements on *Lepidocyclina* tests; abrasion and microbioerosion of benthic foraminifera	Open marine shelf, lower photic zone (carbonate platform)	Oligocene-Aquitanian
f (Busot, Relleu; Pantanet,Torre del Charco; Playa Nudista)	Packstones	Clasts of *Operculina*-rich wackestone	*Operculina-like* and bioclasts of red algae and other larger foraminifera	Poor sorting; grain supported; bioclasts	Open marine shelf, lower photic zone	Oligocene-Aquitanian
g (Busot, Relleu; Pantanet,Torre del Charco; Playa Nudista	Pel-biomicritic wackestone/packstone	Micritic peloids, bioclasts	Bioclasts of benthic and planktonic foraminifera, rare fragments of red algae	Good sorting; mainly matrix supported; well rounded peloids	Open marine shelf boundary with the aphotic zone	Oligocene-Aquitanian
h (Busot, Relleu; Pantanet,Torre del Charco; playa nudista)	Bioclastic packstone	Clasts of: (i) biosparitic grainstone with abundant miliolids, textularids and alveolinids; (ii) bio-pelsparitic packstone/wackestone with miliolids, hydrozoans and bryozoans often encrusted by red algae; (iii) rhodolite bafflestone with bryozoans and mollusc shell fragments	Larger foraminifera (*Nummulites-like, Lepidocyclina -Nephrolepidina-, Miogypsinoides*-like), red algae (*Lithophyllum*-like), echinoid spines, abundant bioclasts of mollusc shells, bryozoans, hydrozoans and green algae	Microbioerosion, abrasion and micrite cements on *Ledpicyclina*; grain supported	Marine shelf	Oligocene-Aquitanian
i (Busot, Relleu; Pantanet,Torre del Charco; playa nudista)	Bio-pelmicritic mudstone	bioclasts and lithoclasts of micritic mudstone	Larger foraminifera (*Nummulites-like*), rare planktonic foraminifera and fragments of hydrozoans	———-	Protected shelf	Oligocene-Aquitanian

Table 1- Microfacies classification, main components, fossil assemblages, sedimentary-diagenetic features, and source-area interpretation.

an eastward drift of the main depocenter, which is also related to a broader range of the gap associated with the Early Oligocene unconformity (Fig. 5).

The lateral evolution of the unconformities and associated gaps, together with the vertical variation in thicknesses of the two depositional sequences is interpreted as follows (Fig. 5):

a- The early Ypresian unconformity was probably the response to the tectonic inversion registered in the western Tethys domains (Williams et al., 1989), changing from extension to compression.

b- The rapid variation in duration of the stratigraphic gaps and thickness of the late Ypresian to Priabonian depositional sequence in adjacent sectors of the same basin can be adequately explained if they are interpreted as a local response to incipient folding related to starting blind thrust faulting following decollement horizons deeper in the succesion (e.g., Triassic evaporites) and/or tectonic inversion of (formerly) extensional faults in the basement. This would have lead to the starting development of the anticlinal presently found in the Relleu-Busot sector (central part of the basin) and of two lateral synclines in the Villafranqueza and Pantanet sectors, where the two Eocene depocenters were located. Guerrera et al. (2006) conceived the whole depositional area as a narrow basin or a trough (the so-called Alicante Trough of the Intermediate sub-Domain) between two raised areas corresponding to the Prebetic platform and the External Subbetic sub-Domain, respectively located to the NW and SE. This interpretation also fits adequately within the frame of the pre-Cenozoic stratigraphy and palaeogeographic evolution (Vera, 2004).

c- The variations in the stratigraphic gap associated with the early Rupelian unconformity and the lateral variation in thicknesses of the early Rupelian-early Aquitanian depositional sequence is thought to be the response to the normal evolution of the blind thrust below the *Jijona-Relleu growing Anticline*. The foreward- (northwestward-) propagating blind fault would have determined the elevation of the sea bottom areas located in the hanging wall during thrusting onto the footwall succession. According to Guerrera *et al.* (2006), these areas would correspond, respectively, to the External Subbetic (hanging wall, currently under the sea) and to the Prebetic (footwall, currently outcropping to the N) typical Mesozoic successions.

Paleoenvironmental interpretation.

The *Villafranqueza section* is interpreted as an Eocene sedimentation in a deep basin and/or slope environment of greenish pelites and marls affected by periodical high-density flows or diluted tractive currents coming from a mixed carbonatic-siliciclastic platform, ramp or upper slope (microfacies "a and b"; Table 1) and by hemipelagic micritic marly-limy sedimentation (microfacies "a"; Table 1) when clastic supply to the basin stopped. The measures of paleocurrents from bedding surface (scour and tool marks) and from internal bedding sedimentary structures, or of paleoslopes from slumps facing, indicate, during the Eocene, flows and slopes toward E and SE, evidencing a main supply from NW (corresponding to the Prebetic Platform or to the Iberian Continent). Some depositional rhythmicity is evidenced by the intercalations of hemi-pelagic marly-calcareous beds in the succession.

The *Busot section* evolved from a basin plain environment during the Eocene, indicated by reddish marls and fine-grained limestones (microfacies "a"; Table 1) to a less deep basin and/or slope environment of greenish pelites and marls affected by periodical high-density flows or diluted traction currents coming from a mixed carbonate-siliciclastic platform, ramp or upper slope (microfacies "b and c"; Table 1). This is followed by a toe-of-slope Early Oligocene system characterized by thin- to medium-bedded carbonate (and mixed) turbidites (microfacies "d, e, f, g, h, and i"; Table 1). The paleocurrents from Oligocene sediments indicate NE-directed flows. The regressive trend ends during the late Oligocene-early Aquitanian with the superposition of deposits assigned to an external platform characterized by marls with lens-shaped intercalations with internal geometries indicating a northwestward progradation.

The *Pantanet section,* Eocene to Early Oligocene in age, it shows a similar regressive trend as described above for the Busot succession. Nevertheless, deposition in the Pantanet sector accounted in deeper settings as basinal marls are thicker than in the Busot area. The upper lens-shaped bodies intercalated (microfacies "d, e, f, g, h, and i"; Table 1), Oligocene in age, prograded to the west or northwest.

The *Relleu section* shows a similar evolution as in Busot area, even if some differences are possible because the Paleocene-Eocene stratigraphic record is lacking here. The evolution during Oligocene to early Aquitanian times also indicates a regressive trend from a slope environment (characterized by westward- or northwestward-directed turbiditic flows in the lower part), followed by external platform deposits with features of turbulent or hyper-concentrated flows. Also collapse or gravity flow of semi-consolidated mudstone or calcilutite and associated calciclastic deposits (microfacies "d, e, f, g, h, and i"; Table 1) sliding on a slope realm to deeper areas is sometimes visible. The sedimentation ends with the installation a cyclic evolution from slope or ramp system to platform carbonate environments.

The *Torre del Charco section*, represents the Late Oligocene continuation of the former stratigraphic section, testifying a catastrophic event that caused the sliding of part of the platform, followed by a turbulent or hyper-concentrated flow and finally by a collapse or gravity mass flow) of a sector of the external platform consisting of semi-consolidated mudstone or calcilutite, into a slope realm (microfacies "d, e, f, g, h, and i"; Table 1).

The *Playa Nudista section* is interpreted as an Oligocene shallow marine sequence characterized by a cliff-platform system at the base with wave exposure differences between headlands and bays —gravel beach, embayment beach, sub-wave chutes, horizontal platform at different levels— may indicate various sinks (microfacies "d, e, f, g, h, and i"; Table 1). Aggregate conglomerates and accumulations of wave-eroded clasts are also present on a surf-dominated platform or at the cliff foot under the wave base level. This situation is followed by the collapse or gravity flow of semi-consolidated mudstone or calcilutite of a platform sliding into a slope realm. To the top, the facies sequences indicate a cyclic shallowing evolution from a slope to platform environments. At this upper level, lens-shaped bodies prograding north- northwestward.

Throughout the study area, two main senses of flows have been evidenced: (a) towards the ENE and SE during the Eocene; and (b) towards the W, NW or N during the Oligocene-Early Aquitanian. These observations indicate a change in the main source area: from proximal areas of the Southern Iberian Margin (Iberian Continent and/or Prebetic Platform) during the Eocene, and from distal Subbetic areas of the same margin. However, the Subbetic was a pelagic area since the Early Jurassic, which became more subsident during the Cretaceous-Palaeogene. So, it is necessary to invoke a paleogeographic reorganization of this sector of the Southern Iberian Margin during the Oligocene-Aquitanian. This reorganization provoked the tectonic raising of some parts of the basin located, presumably, on the most external Subbetic realms. These raised areas evolved to Palaeogene carbonate platforms or ramps with abundant carbonate production essentially by macroforaminifera, red algae and other shallow water organisms, and most of these sediments were redeposited in

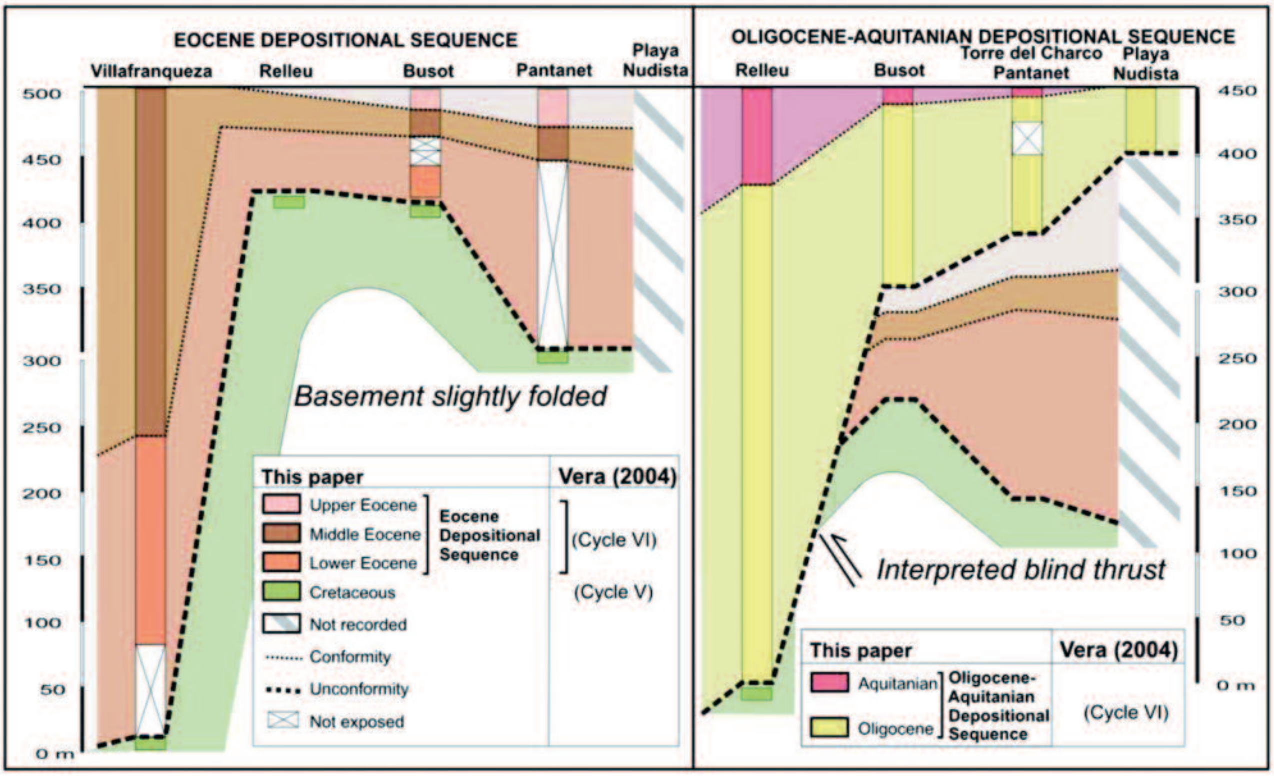

Fig. 5- Unconformities, associated gaps of the Eocene and Oligocene-Miocene depositional sequences compared with the sedimentary cycles of (Vera, 2000). The figure shows a tectonic basement interpreted as folding during the Eocene and blind thrust during the Oligocene-Aquitanian. The different evolutionary trends are discussed in the text.

the adjacent subsiding areas. Moreover, the paleo-flows and tecto-facies evidence increasing tectonic unstability during the Oligocene-Aquitanian. It becomes evident a generalized dismantling of the shallow water realms and even of their Mesozoic substratum due to platform collapse and gravity mass flow of the proper external platform into abrupt slopes to the adjacet deep basin.

Palaeotectonic interpretation.

The whole study successions show a clear regressive trend because the sedimentation evolves from turbiditic calcarenites alternating with hemipelagic deposits and with some slumps, during the Eocene, to deposists of toe of slope to slope-platform, during the Oligocene-Aquitanian. In addition an upward increase in the presence of lithofacies usually interpreted as indicators of tectonic unstability (slumps, mass flows, olisthostromes and/or mega-olisthostromes, which characterize the Oligocene-early Aquitanian sedimentation. More in detail, this general trend shows several tectonic indicators, as follows:

a- In the late Ypresian to Priabonian depositional sequence, no clear general sedimentological trend is detected. Nevertheless, the succession is made of vertically stacked sequences (decimetric to metric in thickness) made up by marls and pelites followed by marly limestones and turbiditic calcarenites, which can be explained as a rhythmic deposition controlled by relative sea-level variations (interferences among eustatism, sediment supply, and local-regional tectonic activity). These sequences appear complete or may lack some terms: the turbiditic bed can be missing in some cases while, in others, the turbidity current erodes and cancels part of bottom (hemipelagic) sediments. Also, the whole sequence is frequently slumped, testifying a slope environments. The marly and pelitic deposition of each sequence is interpreted as the response to deepening, the marly limestones interval is here related to a moderate shallowing tendency and the turbiditic arenites (coming from the western-northwestern area) in response to the erosion in the platform and the emerged lands due to shallowing. The alternation of rhythmic deposits has been widely treated in literature for Mesozoic periods by Vera and Molina (1999, and references therein) as the response to eustatic sea-level variations. In this case, the occurrence of turbidite calcarenites as part of the rhythms and the common presence of slumps appear to indicate tectonic activity and platform instability in the sedimentary environment and its source area (Prebetic Platform and Iberian foreland).

b- The Oligocene-early Aquitanian depositional sequence appears to be arranged in a regressive-transgressive-regressive trend. This sequence ends by slope deposits with slumps, olisthostromes, mega-olisthostromes, and pillow-beds, all coming from the dismantling of a platform (visible throughout the area). Roep and Everts (1992) proposed that the pillow-bed structures constitute a new type of seismites deposited in turbidite lobes of submarine fan systems as the result of earthquakes with a magnitude of 6-7 on the Richter scale.

c- A blind tectonic is interpreted since a tectonic insta-

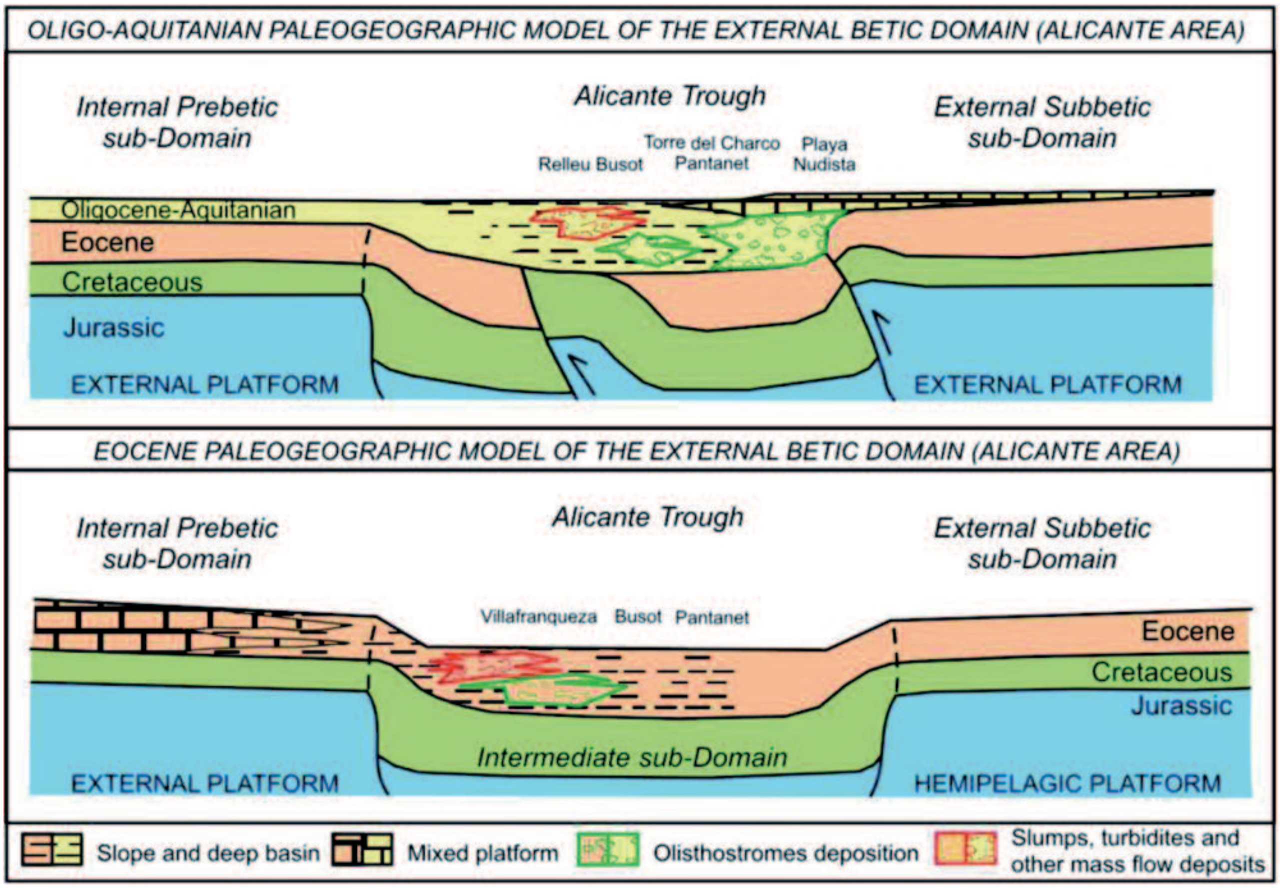

Fig. 6- Paleogeographic-geodynamic model of the Alicante Trough during Eocene and Oligocene-Miocene times.

bility is evidenced but no older (previous to Upper Cretaceous) terrains resedimentation appear. Triassic to Lower Cretaceous was not outcropping during Oligocene to Aquitanian. The first evidences in the area are places mainly at Middle Miocene.

Paleogeographic-geodynamic evolution of the study area: implications for the general model for the Betics.

The entire study area during the Paleogene was defined as the Alicante Trough, whose pre-Cenozoic substratum is constituted by successions equivalent to the Intermediate sub-Domain between the distal areas of the Prebetic Platform and the External Subbetic sub-Domains, northwestward and southeastward, respectively (Guerrera *et al*., 2006). The data presented here match this model very well and allow new insight on the paleogeographical and geodynamic evolution (Fig. 6), and on the influence of the internal (southeasterward) border of the trough. During the Eocene (Fig 6) sedimentation in this trough was mainly related to Prebetic and Iberian Continent sources, located to the W or NW and affected, as stated above, by an incipient tectonic activity. On the contrary, during the Oligocene to Early Aquitanian (Fig 6), the main sediment influx was related to turbiditic and mass flow redeposition of sediments coming from the E and SE, as indicated by paleocurrents and slump facings, and that this deposition was related to erosion of penecontemporaneous and/or older deposited sediments that formed in the southern border of the Alicante Trough, then coming from a Subbetic source. This indicates the dismantling of a platform and of a tectonically active raised area located in a region of the Southern Iberian Margin that had made part of deeper pelagic environments since the late Mesozoic up to the end of the Eocene.

When the geological map of the Betics is examined, a progressive elimination of a great part of the Subbetic between the Prebetic and the Internal Domains is today visible from west to east of the chain. This progressive elimination was classically thought to be related to strike-slip faulting associated with the Cadiz-Alicante fault system (Sanz de Galdeano, 1983; Sanz de Galdeano, 2008) or Crevillente fault zone (Nieto and Rey, 2004 and references therein) giving southwestward displacements of paleogeographic subbetic subdomains at about 75-100 km. Ages proposed for those displacements varies according the authors (see discussion in Nieto and Rey, 2004) mainly from Aquitanian to late Middle Miocene. Nevertheless, from the present study it becomes evident that tectonic unstability in the basin started earlier, during Paleogene, and reached a maximun during the earliest Miocene, just before the paroxismal tectonics that deformed the Alicante Trough at the end of the Early Miocene. According to the above exposed a compressive basement folding should began in Eocene times, followed by blind-thusts in Oligocene and a breakup and dismantling of inner Subbetics at Oligocene-Aquitanian times. Thus, we propose the hypothesis that progressive missing of the Subbetic in the Alicante region probably was related in part

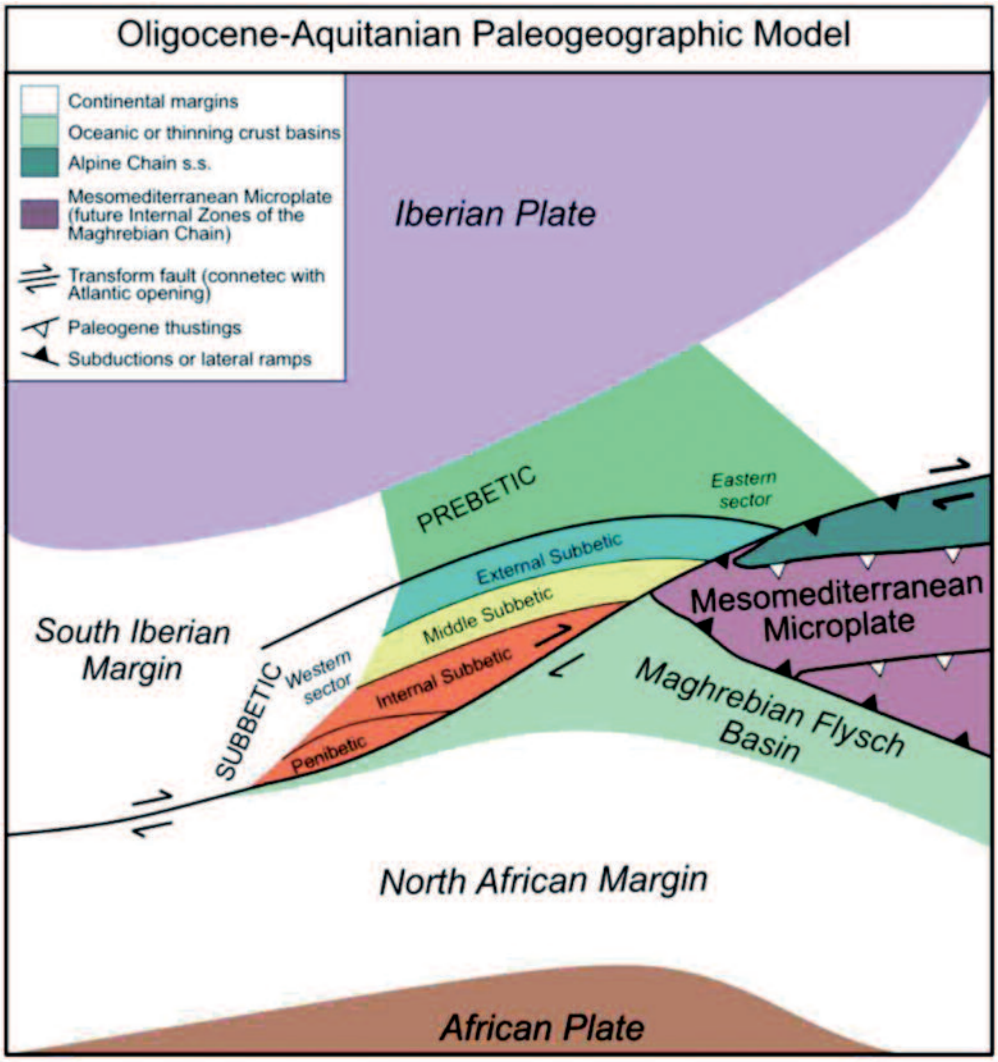

Fig. 7- Synthetic Oligocene-Aquitanian paleogeographic-geodynamic model proposed for the western Tethyan domain.

to an original paleogeographic feature. We suppose that original paleogeography (before the southwestward displacements of Subbetic subdomains during Miocene) was an oblique ending of the Subbetic paleogeographic subdomains against a transcurrent megafault (Fig. 7). That fault should accommodate the westward drift along the Internal-External Zone Boundary after the collision of the Mesomediterranean Microplate (sensu Guerrera et al., 1993; 2005; and references therein) with the External Betic Zone from Early Miocene on.

Conclusions

The main conclusion of this study can be summarized as follows:

(1) Two main unconformities, of Ypresian and Early Oligocene age and associated with stratigraphic gaps of different regional development, allow the differentiation of two depositional sequences in the Paleogene-earliest Neogene record of the Alicante. These sequences are of late Ypresian to Priabonian and of early Rupelian to early Aquitanian ages, respectively.

(2) The late Ypresian to Priabonian depositional sequence shows a main depocenter in the Villafranqueza sector and a secondary depocenter in the Pantanet sector, while the Busot and Relleu sectors constituted raised areas, probably due to starting folding of the Mesozoic substratum of the Cenozoic basin.

(3) During deposition of the early Rupelian to early Aquitanian depositional sequence, the main depocenter was located eastwards, in the Relleu area, while the Busot, Pantanet-Torre del Charco, and Playa Nudista constituted raised areas due to folding related to blind thrust deformation of the bottom of the basin.

(4) During the Eocene, the sediment source was located to the N and NW, in the Prebetic Platform and continental regions of Southern Iberia. The deposition accounted in a deep basin evolving to a distal slope realm under moderately unstable tectonic conditions related to gentle basement folding in large anticlines and synclines. This evidences that the, up to now passive, Southern Iberian Margin started to be transformed in a convergent margin at least since the early Paleogene.

(5) During the Oligocene-Aquitanian, increasingly present (mainly carbonate) turbidites and mass flow sediments derived from Subbetic sources located to the E and SE,

indicate a strong paleogeographic reorganization of the basin and that its southern (Subbetic) border certainly constituted a raising and tectonically very active region related to strong folding associated with blind thrust faulting.

(6) The study area is envisaged as a trough, the Alicante Trough, located between the distal regions of the Prebetic Platform and the External Subbetic sub-Domain. Consequently, it strictly correspond to the Cenozoic equivalent of the Intermediate Subdomain of the Southern Iberian Margin, when the geodynamic stetting started to change from the mature divergent stage to the active convergent stage related to the early Alpine orogenic evolution.

(7) The regional evidence of the eastwads tectonic elimination of the Subbetic units and the tectono-sedimentary evidences obtained from the study of the Paleogene-Aquitanian record of the Alicante Trough suggest that this elimination could start much earlier than previously supposed and could be in part related to an original paleogeographic feature. The observed increasing tectonic ustability can be related to the early stages of the westward drift of the future Betic Internal Domains from the Paleogene to the Aquitanian, before their lateral collision against the External Domains during the Burdigalian.

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