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Paleogene tectono-sedimentary evolution of the Alicante Trough (External Betic Zone, SE Spain) and its bearing on the timing of the deformation of the South-Iberian Margin

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Abstract

The Paleogene Alicante Trough of the South-Iberian Margin (External Betic Zone) consists of a narrow sedimentary basin that has active margins located to the north-northwest (active mainly during the Eocene) and to the south-southeast (active during the Oligocene). Both margins, consisting of shallow unstable platforms, were the source areas for the external-platform slope (in the opposite margins) and deep-basin (in the middle) depositional realms. The southern margin, lost under the Mediterranean Sea, is recognized only by the reconstructed Oligocene slope sediments.

The eight successions studied, on opposites external-platform-slope margins and the deep within the central part of the basin, lead us to divide the basin into two depositional realms: the subsident Western Depositional Area (WDA) and the not subsident Eastern Depositional Area (EDA). This study has also enabled us to divide the infilling of the basin into two depositional sequences: Eocene p.p. (EDS) and Oligocene p.p. (ODS) in age, respectively, bound by two sequence boundaries (unconformities) at the Early Eocene (P6 zone) and Early Oligocene (P19 zone). The EDS and ODS are comprised of turbiditic and olisthostromic deposits and frequently slumps, evidencing an active tectonic in the margin-basin system.

The correlation of the Paleogene sedimentary reconstructed in the Alicante Trough with other four synthetic successions throughout the External (three in the Subbetic Domain) and one in the Internal Betic Zone indicate a Paleogene generalised deformational framework. In addition, this evolution is contemporaneous to the Pyrenean, Iberian and the *Nevado-Filabride* Alpine deformation. The Paleogene tectonic recognised in the External Betic Zone is younger since the main orogenic deformation took place in the late Burdigalian to early Tortonian. The origin of these early tectonics is discussed in relation to the *Nevado-Filabride* Alpine deformation.

Keywords: Depositional Sequences, Paleogene Tectonics, Alicante Trough, Subiberian Margin, Palaeogeography, Geodynamic evolution.

1. Introduction and background

The Alicante region (SE Spain) belonging to the South-Iberian Margin (External Betic Zone: Fig. 1) has Mesozoic to Tertiary sedimentary successions from the Internal Prebetic (to the north-northeast) and Intermediate sub-Domains (to the south-southwest) [1]. In the Betic zones, the Mesozoic evolution of the External Zone has been amply studied works [2; 1; 3] but the Paleogene to early Miocene evolution (contemporaneous

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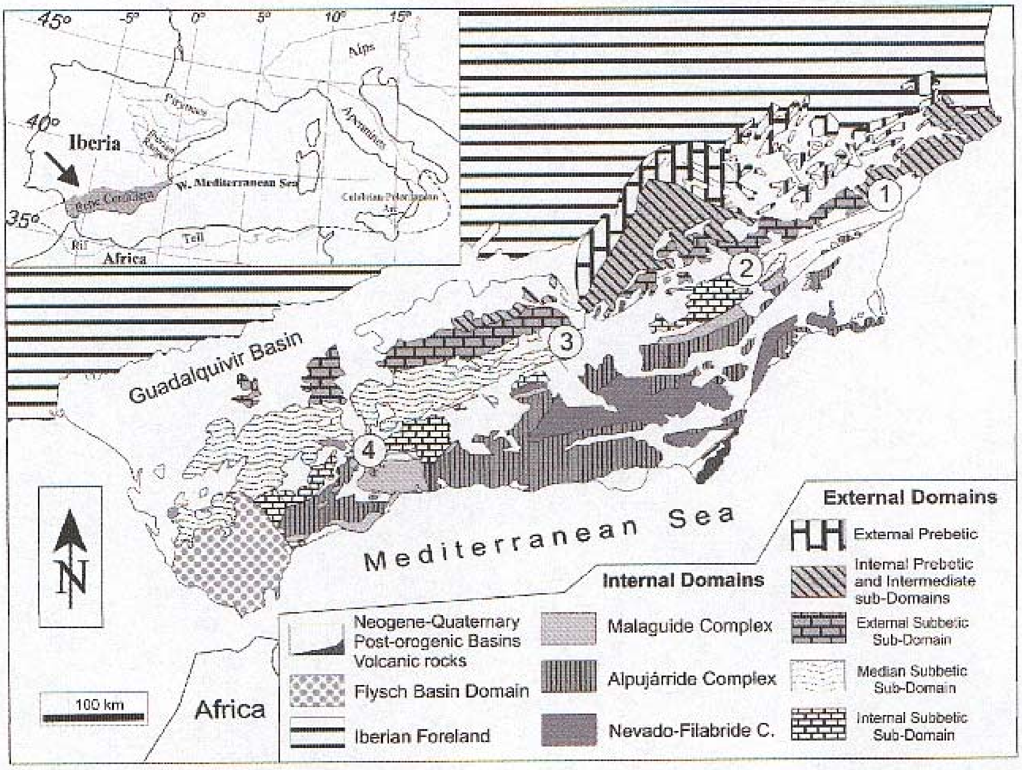

Fig. 1 - Geological sketch map of the Betic Cordillera and the main tectono-sedimentary domains (after Vera [29]). Numbers 1 to 4: main Paleogene sedimentary areas within Prebetic and Subbetic Domains. Key: 1, study area (see stratigraphic sections in Fig. 2); 2 to 4 (stratigraphic sections from the literature and/or unpublished data): 2, 3, Middle Subbetic sub-Domain (from Murcia and Granada provinces respectively); 4, Internal Subbetic sub-Domain (from Malaga province, High Chain).

to a generalised compressive geodynamic evolution in the western Alpine perimediterranean areas) is still poorly known, especially in the eastern sector of the chain.

The Mesozoic evolution is characterized by the rifting of the South-Iberian Margin from the Tethys Ocean [2; 1]. This extensional tectonics allowed the structuring of the South-Iberian Margin into two tectono-palaeogeographic domains (the Prebetic and the Subbetic) separated by another domain having intermediate sedimentary characteristics (the Intermediate sub-Domain). The whole South-Iberian Margin shows an evolution with deeper realms (Middle Subbetic and Intermediate sub-Domains) and shallow realms (Internal and External Subbetic sub-Domains and Prebetic Domain).

The Paleogene basins appear in sedimentary continuity over the previous tectono-palaeogeographic Mesozoic domains, but usually separated by an unconformity close to the K/T boundary in age. Usually, these Tertiary basins show similar conditions to those from the Mesozoic, as pointed out by Comas [4] for the Subbetic Domain in the central Betics. In this sector, nummulitic-platforms developed over the previous shallow realm (External and Internal Subbetic Subdomain). The clear difference during the Paleogene sedimentation is the appearance of turbiditic deposits with olistostrome and slumps over the previous deeper and slopes areas (Intermediate Subdomain and Middle Subbetic Subdomain) which are located between the former shallow domains. These deep basins were previously filled by marly-pelagic sediments (middle Jurassic to Cretaceous) and, afterwards, the first evidence of a clastic supply is evidenced at the Maastrichtian [5], when the tectonic inversion (from distensive to compressive tectonic conditions) must have taken place. The occurrence of Paleogene slumps and olistostromes is a generalised phenomena in the deepest areas along the External Betic Zone [6; 7], but no explanation has yet been provided for these early vertical tectonics, since the paroxysmal deformation took place in these areas during the post-Burdigalian to early Tortonian [8].

In the Alicante area [9; 10], during the Mesozoic (from the Lower Liassic to the Cretaceous) when extensive conditions prevailed, two main sedimentary areas can be recognized:

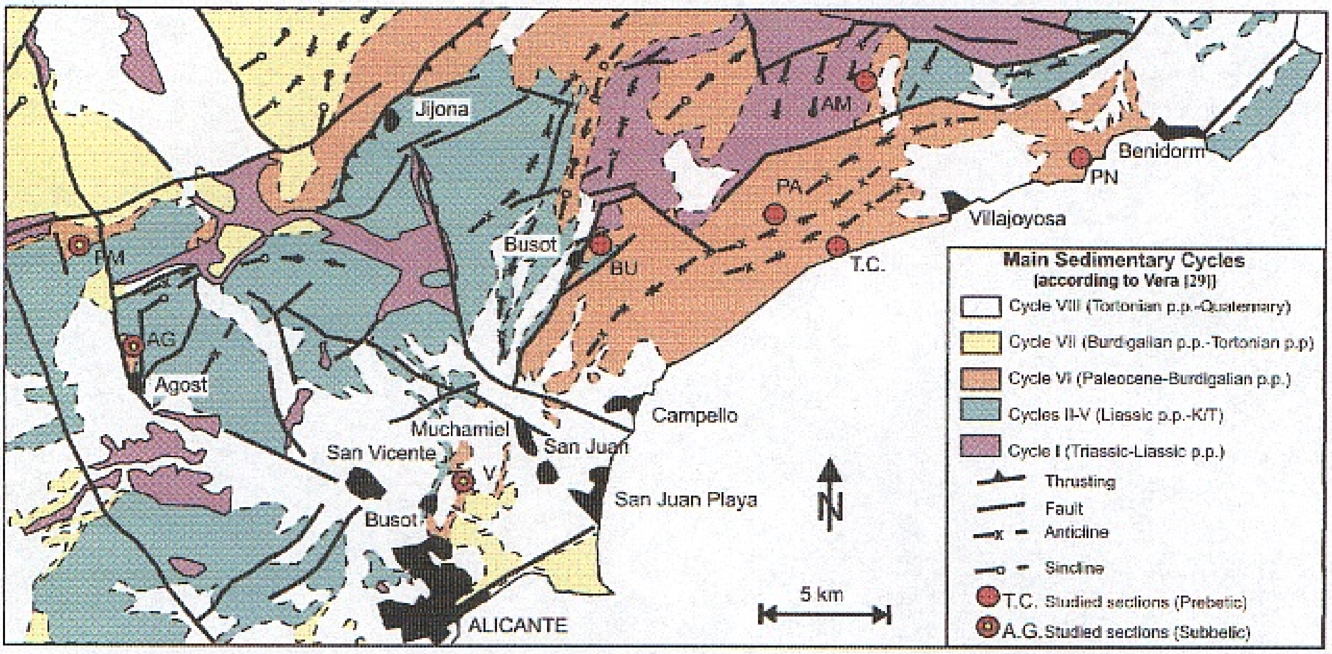

Fig. 2 - Geological sketch map of the Alicante region of the study area (External Betic Zone) within the Internal Prebetic (North-Northeast sector) and Intermediate sub-Domains (south-southwest sector) (number 1 in Fig. 1). Mesozoic to Tertiary Sedimentary Cycles, separated by main unconformities, are recorded according to Vera [29].

(1) to the north, the Prebetic Domain has been divided into an External Prebetic sub-Domain that evolved into a carbonate platform, and Internal Prebetic sub-Domain that evolved into an external carbonate platform with southward transition into a basin;

(2) to the south, the Subbetic Domain is represented, in the Alicante area, by the Intermediate sub-Domain, showing a deep basinal evolution in this period.

During the Cretaceous, the entire area underwent a drowning, represented by scaglia-like deposits. In the latest Cretaceous, when the tectonic inversion occurred, this area underwent compressive conditions, passing the previous tectono-palaeogeographic boundaries (usually normal and strip-slike faults), to move as inverse or transpressive faults, with a slight folding in the basin also beginning. The geodynamic evolution defined in the literature indicates a prior folding phase, later a thrusting phase, and finally diverse system-fault activity related to the changing compressive conditions [11], but no timing is yet proposed for the deformational phases.

Overlying the previous Mesozoic Prebetic area in the Alicante region a "nummulitic platform" was developed, while over the deeper Intermediate sub-Domain a turbiditic basin formed, fed mainly from the platform in the same way to the one that developed during the Late Cretaceous [5]. The birth and evolution of this Palaeogenic basin must have been tectonically controlled by an active margin determined by vertical movements related to folding and/or faulting. In this area, previous research has been performed in the northern Eocene platform area [12; 13; 14], the only margin visible at present, since the southern margin is lost under the Mediterranean Sea and recognized only by the Oligocene slope sediments related to this margin. Sedimentation in the slopes and deep areas has never before been studied in order to clarify the geodynamic evolution. These basin areas were studied by Cremades-Campos [15] only from a biostratigraphic perspective.

Therefore, the aim of this paper is to clarify the lithostratigraphic and biostratigraphic features of eight successions related to the external- plateform, slope and deep central areas of the Paleogene Alicante Basin, paying special attention to the tectonic/sedimentation relationships. On the basis of this study, the sedimentary record has been divided into depositional sequences, to recognize the sedimentary events related to tectonic processes and establish the timing of deformation of the basin from the *K/T* boundary to the Aquitanian. A correlation with other subsident areas from the central and western Subbetic Domain of the Betic Cordillera has also been performed, providing a general geodynamic framework for understanding its possible origin.

2. Geological setting

The studied area is located near the city of Alicante, between the towns of Agost and Benidorm (Fig. 2). This area, belonging to the External Betic Zone, shows two kind of Mesozoic basements from the South-Iberian Margin: the Prebetic to the north-northest, and the Subbetic (Intermediate sub-Domain) to the south-southwest. Today, the area shows (Fig. 2) several dextral-fault systems [11]: Cadiz-Alicante Accident system

(N70E oriented), Vinalopó Fault system (N155E oriented) and Socovos Fault system (N120E oriented). The fault traces are usually characterized by outcropping of Triassic clays with gypsum due to hallocinetic phenomena, while the blocks bound by the faults are composed mainly by folded Cretaceous to Miocene successions. The fault traces also reveal Neogene deposits related to pull-apart or blend-faults basins [10; 16], allowing the dating of the faults' activity to at least the Neogene. The blocks among the faults can be divided according to the orientation of their fold axis in N20E oriented fold axis and N70E oriented fold axis [17; 16]. These folding systems seem to be related to transpressive conditions under a compressive cinematic regional cadre. First, the N70E fault systems (Cadiz-Alicante) under a cinematic cadre with a near E-W oriented $\sigma 1$, generated the N20E oriented folding probably during the Middle Miocene; later, the N120-155E fault systems (Vinalopó and Socovos) with a near NW-SE oriented $\sigma 1$, generated the N70E oriented folding affecting the upper Miocene. Therefore the studied Paleogene to Aquitanian basin is currently fragmented into several blocks bound by main dextral faults that moved after the end of the infilling of the basin.

The outcropping of Jurassic sediments are scarce and composed mainly of Liassic limestones, enabling us in a classic way (sedimentary evolution of the Liassic successions) to differentiate Prebetic (shallow) from Subbetic (deep) areas [10]. According to its possible substratum the stratigraphic sections studied can be grouped as follows: (a) Peñas Montesas, Agost and Villafranqueza sections with a Subbetic-like Mesozoic serie; (b) Busot, Amadorio, Pantanet, Torre del Charco and Playa Nudista with a Prebetic-like Mesozoic serie.

3. Lithostratigraphy

In the Alicante Trough, eight stratigraphic sections were measured, sampled and correlated in the Western (WDA) and Eastern (EDA) Depositional Areas (Fig. 3) within the main Latest Cretaceous-Paleogene successions for studying the most important stratigraphic and tectonic events.

Peñas Montesas Section. The area (Figs. 2, 3), as pointed out by Leclerc [18], consists of a vertical dipping and N70E oriented Cretaceous to Middle Miocene succession. An unconformity level separated the Senonian whitish marl and marly limestones (90 m thick) from a Paleogene succession (140 m thick) comprised of two main members. First, cream- and greenish-coloured marls (70 m thick) with centimetric turbidite sandstones intercalated (Ta, Tab) with larger Eocene foraminifera, followed by decimetric limestone intercalations with intraformational breccias at the top. After greenish marls with metric biostrome-like calcarenite intercalation (70 m), the succession ends with a 35-m thick calcarenitic level and a 20-m thick yellowish marly member, at the top, from the Middle Miocene.

Agost Section. Located to the north of Agost (Figs. 2, 3), noted by Leclerc [18], was biostratigraphicaly studied by Cremades-Campos [15] providing an exhaustive biostratigraphic study including the K/T boundary. The succession rewiewed here is characterized by a continuous sub-horizontal succession beginning by whitish marly limestones (10 m) from the Cretaceous followed by a millimetric to centimetric blackish level related to the *K/T* boundary (studied exhaustively by Alegret *et al.*, [19] and recently by Molina et al. [20]. The following Paleogene succession is made up of cream-coloured and reddish marly limestones (20 m) from the Palaeocene [20] and of several Eocene facies ([15]: cream limestones (30 m), cream marls and marly limestones (20 m), limestones and marly limestones (70 m), cream clays and marls with marly limestones and turbidite sandstones intercalated with decimetric to metrics slumps developing (50 m), limestones and sandy limestones (15 m), and, towards the top, marls and marly limestones (50 m). The sedimentary facies showing a slight terrigene supply and Bouma sequences in the sandstones, and the calcareous/marls rapport indicate an external platform or an upper slope realm. These data are confirmed by Molina *et al.* [20; 21] according to the foraminifera assemblage.

Villafranqueza Section. Comprised of three partially stratigraphic successions (Los Porrones, El Collao and La Vaqueria) easily correlated and N-S to N20E/30-60E orientation (Figs. 2, 3). After a member 65 m thick, with whitish marls and marly limestones from the Senonian and separated by a tectonic contact, a monotonous and thicker Eocene succession can be recognized with the following main member: first, a 36-m thick member composed of reddish and brownish marls and clays with centimetric beds of marly limestones interbeded, followed by cream and greenish marls (100 m thick) with a decimetric nummulite-rich olistostrome-like intercalation and centimetric nummulite-rich turbiditic sandstones (Tab, Tabc) more frequent with height, and finally brownish and greenish marls (60 m thick) with several metric slumpings and decimetric nummulite-rich olistostrome-like intercalation. Usually, parasequences consist of a centimetric marly level at the bottom, followed by a centimetric bed from pelagic marly limestones and ending by centimetric nummulite-rich turbiditic sandstones (*Tab*, Tabc). The succession follows with a 10-m-thick calcareous or marly-calcareous member. After this, appear brownish and greenish marls (300 m thick) with several metric slumpings, metric olistolithes, and decimetric nummulite-rich olistostrome-like intercalation, nummulite-rich turbiditic sandstones (*Tab*, *Tabc*) and centimetric marly limestones arranged in a similar way to that described above in the parasequences. The succession is crowned by a thick bioclastic-rich calcarenitic and conglomeratic member from the Upper Miocene. In the turbiditic sandstones the measured palaeocurrent indicates flows towards N230E and N90-100E. The slumps seems to indicate facings towards N190E.

Amadorio Section. This succession, N110E/25E oriented and at about 50 m thick (Figs. 2, 3), shows overlying by an unconformity with a Fe-oxided palaeokarst surface over the Cretaceous to Eocene mainly marly succession with two members separated by a covered zone. The first member (10 m thick) is composed of whitish to cream-coloured marls with centimetric marly limestones intercalated. After being covered 20 m, the succession continues

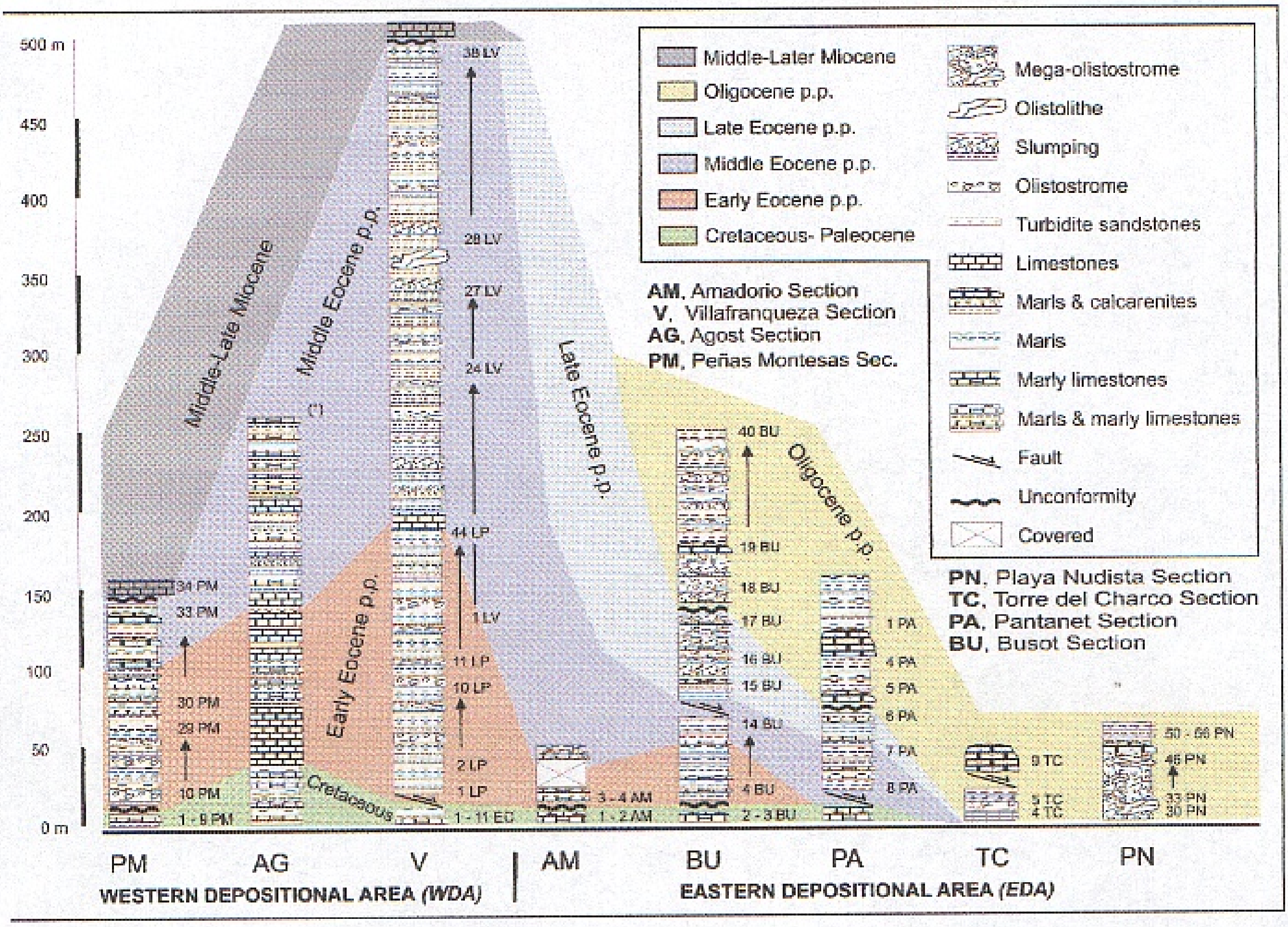

Fig. 3 – Stratigraphy, correlation, sampling localization and main sedimentary cycles recognized (Eocene p.p. and Oligocene p.p.) of the studied successions in the Western (WDA) and Eastern EDA) Depositional Areas.

with greenish marls (10 m thick) containing centimetric turbidite nummulite-rich sandstone intercalations.

Busot Section. This succession (Figs. 2, 3) is unique in the whole area, showing a complete succession from the Cretaceous to late Oligocene, being therefore, the reference succession for the correlations. Over the marly limestones from the Senonian in apparent continuity but with an important biostratigraphic gap, the succession (N100E/25N oriented), from bottom to top, is comprised of a 25-m-thick member with reddish marls with centimetric yellowish marly limestones intercalation from the late early Eocene. A change in the facies separated the following Eocene succession (at about 60 m thick), affected by several minor fault surfaces and composed of whitish and yellowish marls with calcarenitic and marly limestone intercalations. Another unconformity related to the beginning of the erosive channel from the olistostromes, the succession follows with a 50-m-thick member from the Oligocene, composed by whitish marls and lepidocycline-rich limestones, affected by numerous metric slumps and with olistostrome conglomeratic intercalation with erosive surfaces at their bases. A 10-m-thick, north-westerly prograding biostrome-like calcareous level separated the previous succession from a yellowish marly one (70 m thick) with a decimetric turbidite sandstone (*Tab*, *Tabc*) intercalation affected by decimetric slumpings. In the canalised beds, flows are towards N 40-50 E. The successions end below the continental Quaternary cover.

Pantanet Section. This succession (Figs. 2, 3), constituting the continuation of the Amadorio Section to the Torre del Charco Section, was previously studied biostratigraphically [15]. The succession is made of yellowish marls and marly limestones (N120E/45S oriented) to the bottom (at about 50 m thick), affected by several minor fault surfaces. A 10-meter- thick, north-westerly prograding biostrome-like calcareous bed with an erosive surface at the base separated the previous succession from a 70- m-thick yellowish marly succession with northward or north-westerly prograding of intercalated metric biostrome-like bodies and interbedded decimetric sandy limestones.

Torre del Charco Section. The succession oriented N120E/45N, (Figs. 2, 3) is composed, from bottom to top, of 5 m with bioclastic rodolite-rich calcarenites, a level 2 m thick with intraformational breccias and "watermelon structures". This Oligocene succession continues, at about 10 m, with yellowish marls having centimetric turbidite sandstone (*Tab*, *Tabc*) intercalations. After a fault surface, a 30-m-thick calcarenitic member ends the succession.

Playa Nudista Section. This succession, at about 70 m thick, is composed of two Oligocene members N100E/35N oriented (Figs. 2, 3). At the bottom, 50 m of chaotic olistostrome deposits contain metric olistholites deriving from a mixed siliciclastic-calcareous platform. The succession ends with at about 20 m of northward or north-westward prograding metric biostrome-like bodies intercalated with yellowish marls and decimetric sandy limestones, below the continental Quaternary cover.

4. Biostratigraphy and chronostratigraphy

The whole succession has been sampled and dated in this research with the only exception of the Agost succession, for which the data were taken from literature [19; 20; 21], the chronostratigraphic distribution of the successions being synthesised in Fig. 4.

Peñas Montesas Section. Dated by means of planktonic foraminifera and calcareous nannoflora the Paleogene succession shows the following fossil assemblages. At the bottom of the succession (samples PM-10 to PM-26) the foraminifera are *M. aragonensis*, *M. spinulosa*, *A. bullbrooki*, *A. broedermanni*, *A. cuneicamerata*, *S. inaequispira* (see taxonomic Appendix) indicating a latest early Eocene dating (Zone P9, by Blow [21], emended by Berggren *et al.* [23]). The nannoflora consists of *D. lodoensis*, *D. sublodoensis* and *T. orthostylus* (see taxonomic Appendix) from the Zone CP12 (Subzone CP12a) by Okada & Bukry [24]. The following member, made of cream and greenish coloured marls (samples PM-27 to PM-29), is composed by the foraminifera *P. micra*, *G. lozanoi* (including *G. higginsi*) and *M. caucasica* (with the absence of *Hantkenina* and *Globigerinatheka*), still from the uppermost lower Eocene. It is remarkable that in the sample PM-29, forms close to *M. lehneri* have been found; however, this species seems to be restricted to the middle Eocene (since Zone P11). In the upper interval made of greenish marls with biostrome-like calcarenite intercalation (PM-30 to PM-33), forms from the middle Eocene can clearly be found, such as *Globigerinatheka* (*G. subconglobata*, *G. mexicana*, *G. kugleri*) and *Truncarotaloides* (*T. topilensis*, *T. rohri*) being frequent forms from the *G. eocaena* group. The sample PM-33 shows in the foraminifera the absence of *M. aragonensis* and the presence of *H. dumblei*, indicating at least the Zone P12 (middle part of the middle Eocene). Above the Paleogene sequence appear middle Miocene sediments (PM-34) dated by means of planktonic foraminifera as Zone N8 (early Langhian).

Agost Section. Cremades-Campos [15] studied a set of partial sections in Lomas de las Beatas, near Agost, over the well-known levels of the K/T transit. In the oldest levels, this author mentioned the presence of *M. velascoensis*, *M. acuta* and *A. soldadoensis* (Zone P5), corresponding to the uppermost part of upper Palaeocene; in successive levels of the different sections *M. subbotinae*, *M. formosa*, *M. aragonensis*, *M. caucasica*, *S. frontosa*, *P. micra*, etc., were noted. This would show a sedimentation mainly during the early Eocene (zones P6 to P9). Only in the highest levels of the Agost sections was the presence of *Hantkenina* and *Globigerinatheka* mentioned, jointly with *M. aragonensis* and *M. lehneri*, indicating that the sedimentation would continue during the first part of the Middle Eocene (zones P10 and P11).

Villafranqueza Section. The Collao partial section belongs completely to the Maastrichtian (samples EC-1 to EC-11). Above, by means of a tectonic contact, the Paleogene sediments of Los Porrones section (sample LP-1) contain planktonic foraminifera assemblages with *M. subbotinae*, *M. formosa* and *M. aragonensis*, indicating the middle part of the early Eocene (Zone P7). Higher levels show *M. caucasica*, *A. broedermanni*, *A. bullbrooki*, *S. inaequispira* whereas *M. formosa* and *M. subbotinae* are not detected (samples LP-2 to LP-10). This suggests sedimentation during the final part of the early Eocene (zones P8 and P9). In the upper levels of the Los Porrones section, *A. cuneicamerata* and *M. spinulosa* are noted but no forms characterizing the middle Eocene are found (samples LP-11 to LP-44). Therefore, the uppermost sediments of the Los Porrones section are dated to the latest part of the early Eocene (Zone P9). The upper part of Los Porrones section correlates partially with the La Vaqueria section. The first levels of this section contain assemblages similar to the above-mentioned ones (samples LV-1 to LV-12). Higher levels (samples LV-13 to LV-24) contain *P. micra* and only towards the middle part of the section (LV-25) *G. subconglobata* and *T. topilensis* appear, indicating middle Eocene sedimentation. As occurs in the Peñas Montesas Section, *Hantkenina* is not observed in levels corresponding to the first part of the middle Eocene.

Amadorio Section. In this section, the basal levels (AM3 and 4) over Fe-oxided palaeokarst surface developed in the top of the Senonian, contain *A. soldadoensis*, *A. angulosa*, *M. aequa*, *M. subbotinae* and *P. chapmani*. The absence of both homomorphic *M. velascoensis* and *M. aragonensis* in these assemblages suggests that these levels belong to the Zone P6, earliest Eocene in age. The sample AM3 also studied by nannoflora analysis shows *D. diastypus* and *T. orthostylus*, indicating the Zone CP 9 (Subzone CP 9a) from the early Eocene; this age is also supported by the absence of *D. lodoensis*. Upper levels (AM5 and AM6) show the presence of *M. aragonensis* and *M. lensiformis*, at the same time as *P. chapmani* disappears, indicating that they must belong to the Zone P7, still early Eocene in age. Over a covered portion, the succession is made up of greenish marls containing larger foraminifera probably from the middle Eocene.

Busot Section. In this section, the Cretaceous-Paleogene boundary occurs in a poorly stratified 2-m-thick interval (samples Bu-2 and Bu-3) where components of the Senonian, Palaeocene and lower Eocene are mixed. The first level that shows a synchronous association (Bu-4) contains the

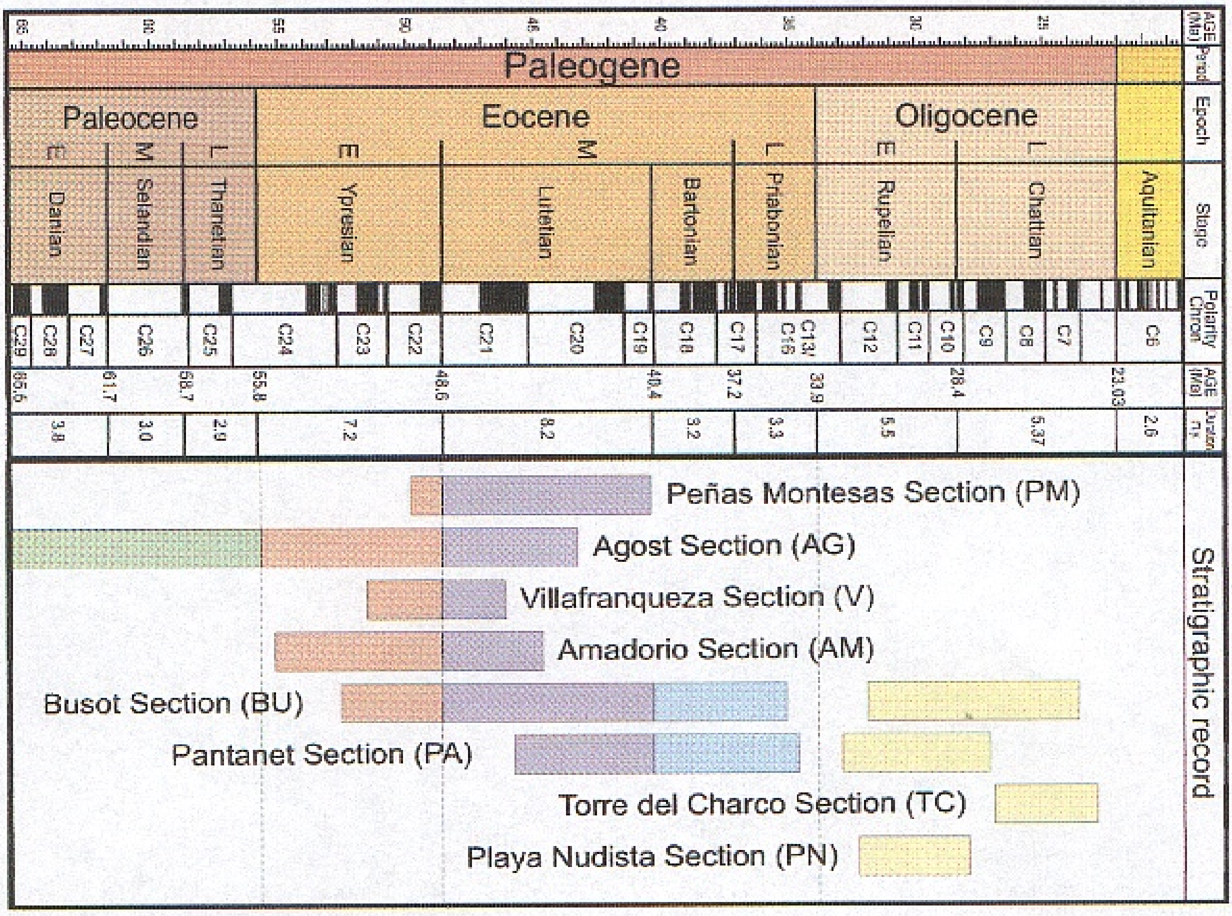

Fig. 4 - Chronostragraphy of the studied successions.

planktonic foraminifera *S. inaequispira, A. broedermanni* and *M. aragonensis* (Zone P8), and the nannoflora *D. kuepperi, D. lodoensis and T. orthostylus* (Zone CP 10). This microfauna suggests sedimentation during the late early Eocene. Overlying levels (Bu-5 and Bu-6) contain, in addition to the above foraminifers, *M. senni, A. cuneicamerata, A. bullbrooki, M. caucasica, M. spinulosa* and *P. palmerae*. This assemblage is very characteristic of the Zone P9, corresponding to the upper part of the lower Eocene. In agreement, sample Bu-6 shows the absence of *D. sublodoensis* and the registry of *D. lodoensis*, characterizing the Zone CP 11. The upper part of the reddish marls with yellowish marly limestones (Bu-7 to Bu-11 levels) reveals the presence of *T. topilensis, G. subconglobata and S. frontosa*, implying that sedimentation also took place during the beginning of the middle Eocene (zones P10 –P11). As in the Peñas Montesas and Villafranqueza sections, the beginning of the middle Eocene sedimentation is not accompanied by the appearance of *Hantkenina*. Throughout the middle Eocene whitish and yellowish marls (samples Bu-12 to Bu-14), some new biostratigraphic features are observed, such as the presence of abundant large *Globigerina* of the group of *G. eocaena-corpulenta*. In relation to the nannoflora, samples BU-8, BU-11 and BU-12 contain *D. lodoensis* and *D. sublodoensis*, indicating the Zone CP12 (Subzone CP12a). Levels affected by several minor fault surfaces (Bu-15 to Bu-17) undergo a drastic change in the planktonic assemblages, involving the sudden irruption of relatively evolved *Hantkenina* (*H. primitiva* and *H. alabamensis*) by abundant *Globigerinatheka* (*G. mexicana, G. index* and *G. semiinvoluta*), by the presence of evolved forms of *Turborotalia* (*T. cerroazulensis* and *T. cocaensis*) and at the same time by the disappearance of *Morozovella* and *Acarinina*. All these features show clearly that the high part of this section belongs, at least, to the upper Eocene (Zone P15). In addition, it is remarkable that the nannoflora en sample Bu-17 shows the presence of *R. umbilica, R. bisecta, H. compacta* and *S. predistentus*, but *D. barbadiensis* is absent; this is a biostratigraphic event that usually occurs close to the Oligocene.

Above, in the first levels of the whitish marls with lepidocycline-rich limestones (Bu-19), the planktonic assemblage is made up mainly of *Globigerina* of the groups *G.eocaena-corpulenta, G. venezuelana-tripartita* and *G. ampliapertura-increbescens* accompanied by *C. dissimilis, G. suteri*

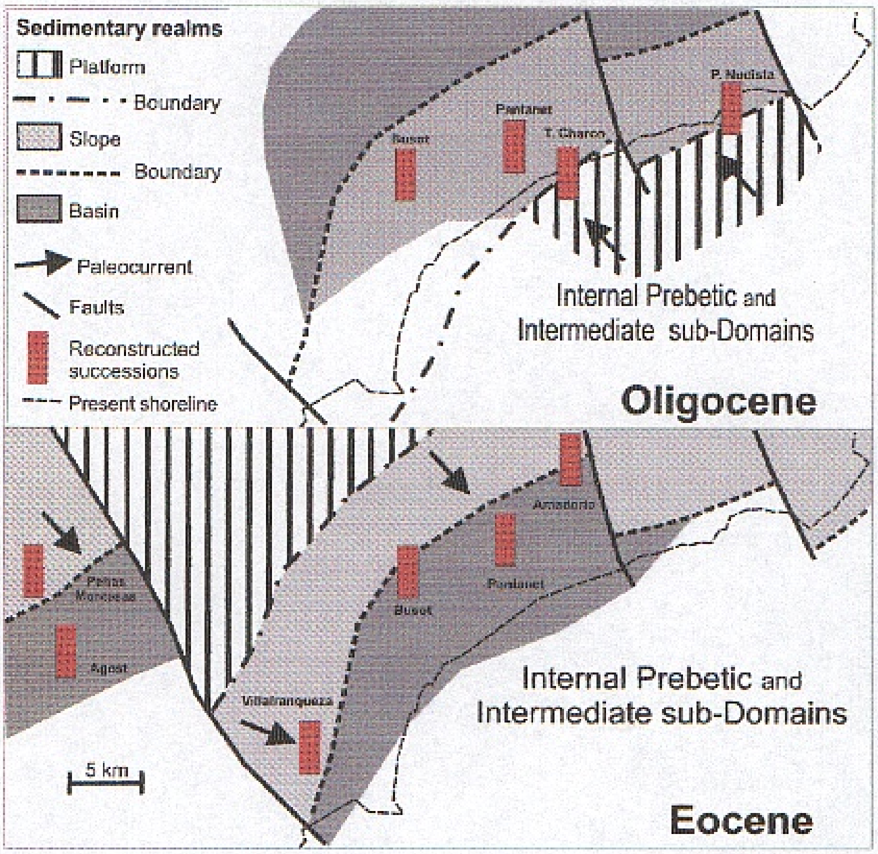

Fig. 5 - Main Eocene and Oligocene sedimentary realms and location of the studied successions in the Internal Prebetic and Intermediate sub-Domains.

and *N. nana*. This assemblage lacks typical components of the Late Eocene, indicating sedimentation during the early Oligocene (Rupelian). The absence of *P. micra* suggests that these levels date from the middle part of the Rupelian (Zone P19). Therefore, based on the planktonic foraminifera, the Busot sequence shows a stratigraphic gap including the last part of the upper Eocene and the first part of the lower Oligocene (complete zones P16 to P18 and probably a part of the zones P15 and P19). Throughout the member of whitish marls occur new biostratigraphic events. We emphasize the appearance of *N. opima* (Zone P19) from the sample Bu-24, the disappearance of the group of *G.ampliapertura-increbescens* (Zone P20/N1) from the sample Bu-31, the appearance of *G. angulisuturalis* matching the base of Zone P21/N2 in the sample Bu-32, the disappearance of the *G. eocaena-corpulenta* (within Zone P21/N2) from the sample Bu-34, and finally the disappearance of *N. opima* (base of Zone P22/N3) in the sample Bu-38. Nannoflora from the sample Bu-29 correspond to the Zone CP18, which is characterized by the registry of *S. distentus* and *S. predistentus*. This succession of bioevents indicates that the sedimentation of the whitish marls extends without interruption until the upper Chattian. In the top of the sequence (Bu-40) appear forms close to Gr. *kugleri*, but we have not found specimens indubitably assignable to this species. The nannoflora in this sample contains *S. distentus* and *S. ciperoensis* (Zone CP19) from the upper Oligocene. The end of the successions occurs below the continental Quaternary cover. This suggests that the section could reach the Aquitanian.

Pantanet Section. Nannoflora from sample Pan-8 registers the presence of *N. fulgens*, *R. dictyoda* and *C. grandis* (Zone CP13), middle Eocene in age. A higher sample (Pan-7) belongs to Zone CP14b, which has been recognized by the registry of *D. nodifer* and the absence of *C. oamaruensis* and *C. solitus*, also middle Eocene in age. In the sample Pan-6, a nannoflora assemblage composed by *D. nodifer*, *H. euphratis*, *C. oamaruensis* in absence of *I. recurvus*, indicates upper Eocene sedimentation (Zone CP15). Lower Rupelian deposits have been recognized in the samples Pan-5 to Pan-2, where the nannoplankton assemblages are made up of *R. umbilica*, *I. recurvus*, *C. altus*, in absence of *S. distentus*, which is determinative of the Zone CP16c. In the top of the section, the sample Pan-1 contains *S. distentus* and *S. ciperoensis* (Zone CP19a) from upper Oligocene. In agreement with the above-mentioned nannoplankton results, the stratigraphic gap of the uppermost Eocene - lowermost Oligocene reported in the Bussot section, is perceived here with minor extension.

Torre del Charco Section. The yellowish marls with centimetric sandy turbidites (samples TC-4 and TC-5) show planktonic foraminifera assemblages characterized by the frequent presence of *G. angulisuturalis* and *N. siakensis*, which are accompanied by abundant *G. venezuelana*, *G. praebulloides*, *C. dissimilis*, and rare forms close to *Gr. kugleri*. These associations, without either *N. opima* or forms of the *G. eocaena* and *G. ampliapertura* groups, indicate that the section was deposited during the late Chattian (zone P22/N3). In fact, the preservation of the microfauna does not rule out that some individuals assigned to *G. praebulloides* have supplementary apertures identifying *G. primordius*. All this suggests that the top of the section, truncated by a fault, was deposited very next to the Chattian-Aquitanian boundary. The calcarenitic member resting on the fault surface (sample TC-9) contains very poorly conserved benthic microfauna, which does not allow assignment of a specific the age within the upper Oligocene–lower Miocene interval. However, the

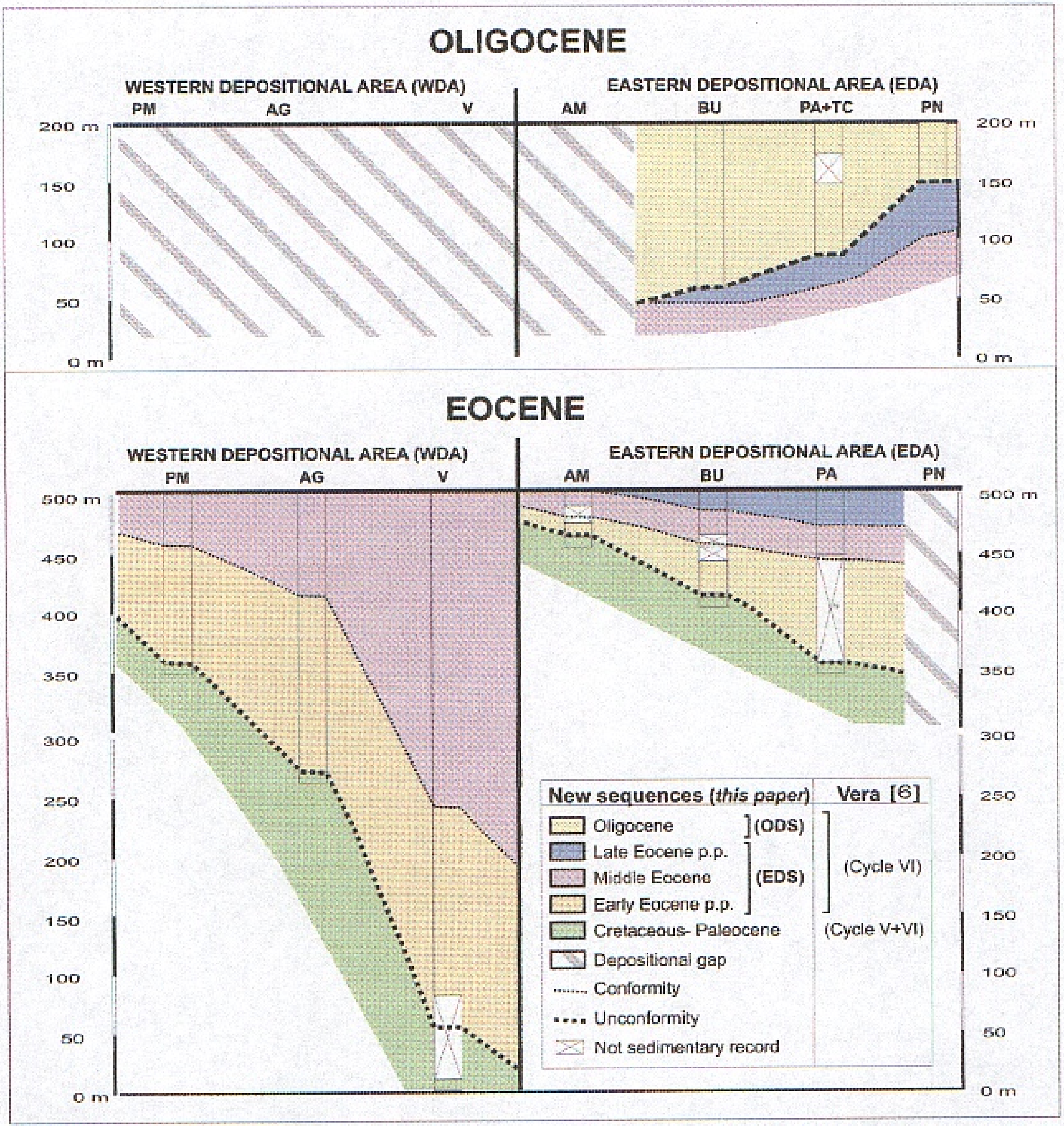

Fig. 6 - Sedimentary record and new sequential stratigraphy in the study area; acronyms correspond to the stratigraphic sections explained in the test and in Fig. 3.

nannoflora include *Sphenolithus distentus* and *Sphenolithus ciperoensis*, indicating late Oligocene in age.

Playa Nudista Section. In general, the nannoflora is poorly preserved and affected by dissolution; for this reason, in some cases a reliable identification has not been possible. In the lower part of the chaotic olistostrome, the pelitic matrix (sample Ben-30) contains rare and poorly preserved nannoflora. *C. abisectus* has been identified unaccompanied of *R. umbilica*. This suggests that the deposit occurred during the middle Oligocene (zones CP17-18), but the characteristic of this interval, *Sphenolithus*, has not been observed. Pelites located throughout the olistostromic layout register *S. distentus* and *S. predistentus* in samples Ben-33, 35, 38 and 46, characterizing Zone CP18, while samples Ben-50 to Ben-56 show *S. ciperoensis* accompanied by *S. distentus*, indicating Zona CP19a from the upper Oligocene. A covered portion of the top of this succession lead us to consider the probably presence of the Aquitanian beds.

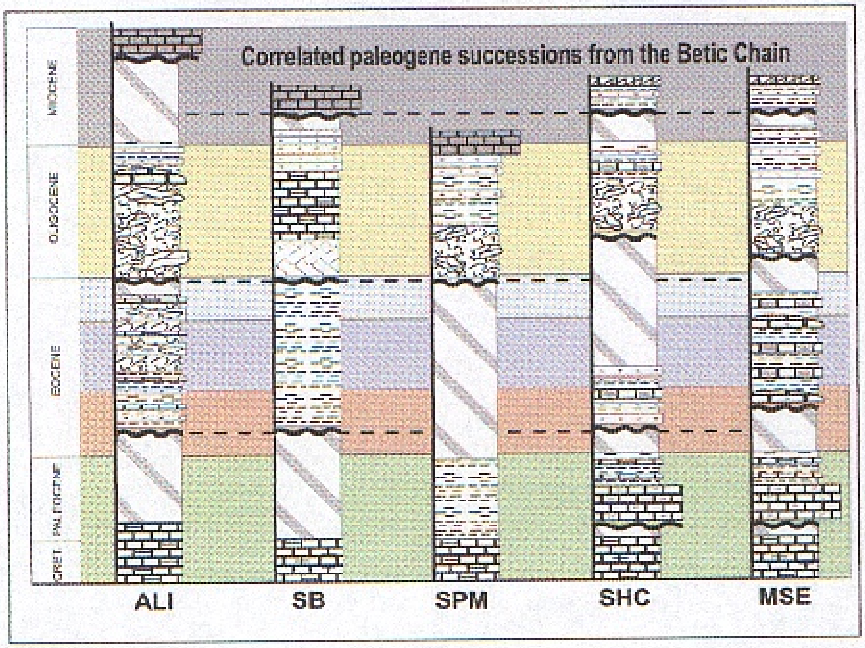

Fig. 7 - Correlation among synthetic Paleogene successions and main unconformities in the Betic Chain. Key: ALI, Alicante succession (Internal Prebetic-Intermediate sub-Domains); SB, Bullas succession, (Murcia province, Middle Subbetic sub-Domain); SPM, Piñar-Moreda succession, (Granada province, Middle Subbetic sub-Domain); SHC, Malaga succession (High Chain, Internal Subbetic sub-Domain); MSE, Sierra Espuña succession (Murcia province, Internal Betic Zones, Malaguide Complex).

5. Sedimentary realms, boundaries and depositional sequences

The study basin has been divided according to the characteristic of the Jurassic substratum, the age of the sedimentary record, the thickness of the successions (subsidence), and the main source area of the sections studied, into two depositional realms: the Western Depositional Area (*WDA*) and the Eastern Depositional Area (*EDA*), its characteristics being presented in Table 1.

The facies studied allow us to propose the following sedimentary realms for the defined depositional domains (Fig. 5). The *WDA* is represented by the Peñas Montesas, Agost and Villafranqueza stratigraphic sections, consisting in an external platform-upper slope (Peñas Montesas and Agost) or lower slope-deep basin (Villafranqueza) subsident realms with a Subbetic substratum. This area shows thick successions that are mainly Eocene in age with major supply, with a northern source area consisting of a bioclastic carbonate platform. The *EDA* is represented by the Busot, Amadorio, Pantanet, Torre del Charco and Playa Nudista stratigraphic sections, comprising an external platform-upper slope (Amadorio, Upper part from Busot, Upper part from Pantanet, Torre del Charco and Playa Nudista Sections) or lower slope-deep basin (lower part of Busot and Pantanet sections), not subsident realms with a Prebetic substratum. The thin successions show a late early Eocene to late Oligocene sedimentary record with two source areas related to bioclastic carbonate platforms located to the north and/or north-east during the Eocene with minor supply, and later, to the south and/or south-east during the Oligocene with an abundant supply.

The relative location in the depositional realm of the studied succession, has been identified taking into account their sedimentary facies, sedimentary record and gaps, proximity to the source area, and thickness. Moreover, the stratigraphic, sedimentologic, and biostratigraphic data presented above lead us to propose that the sedimentary infilling involved two depositional sequences (Fig. 6): The Eocene (*EDS*) is bound by two sequence boundaries (unconformities) at the early Eocene p.p. (PF-6a and NP-9a zones) and the earliest Oligocene (CP-16c zone). The Oligocene p.p. (*ODS*) is bound to the top by the end of the sedimentation (P-22 and CP-19b zones) or by a continental Quaternary cover. Nevertheless, new analysis, still in progress, are found in order to clarify the probably existence of Aquitanian beds in this depositional sequence.

Both depositional sequences are recognized in the *EDA*, where both slopes are represented, while in the *WDA*, only showing the north or north-western slope, the *ODS* is absent.

The Palaeocene represents the continuation of the scaglia-like Upper Cretaceous sedimentation, evidencing deep pelagic conditions [25] separated by the *K/T* black level. In this paper, Palaeocene will be considered as belonging to the same cycle as the Cretaceous. This Cretaceous-Palaeocene cycle constitute the basement of the Eocene-Oligocene basin. The *EDS* shows evidences of a regressive evolution with a transition from deeper (bottom) to shallow realms (top). This is the case of the Peñas Montesas Sections (Fig. 3), where an upper slope is registered at bottom of the succession and an external platform, at the top. This depositional sequence evidences, also, an increase in the tectonic activity showing olistostrome and slump deposits more evident upwards in the successions (see Villafranqueza Section, Fig. 3). Finally, this period is characterized by an active margin located to the north. The occurrence of the *ODS* implies a change in the active margin of the basin, the southern one being active during this period. During this period, the sections studied evidence a regression during the early Oligocene and a transgression during the late Oligocene. First, slope

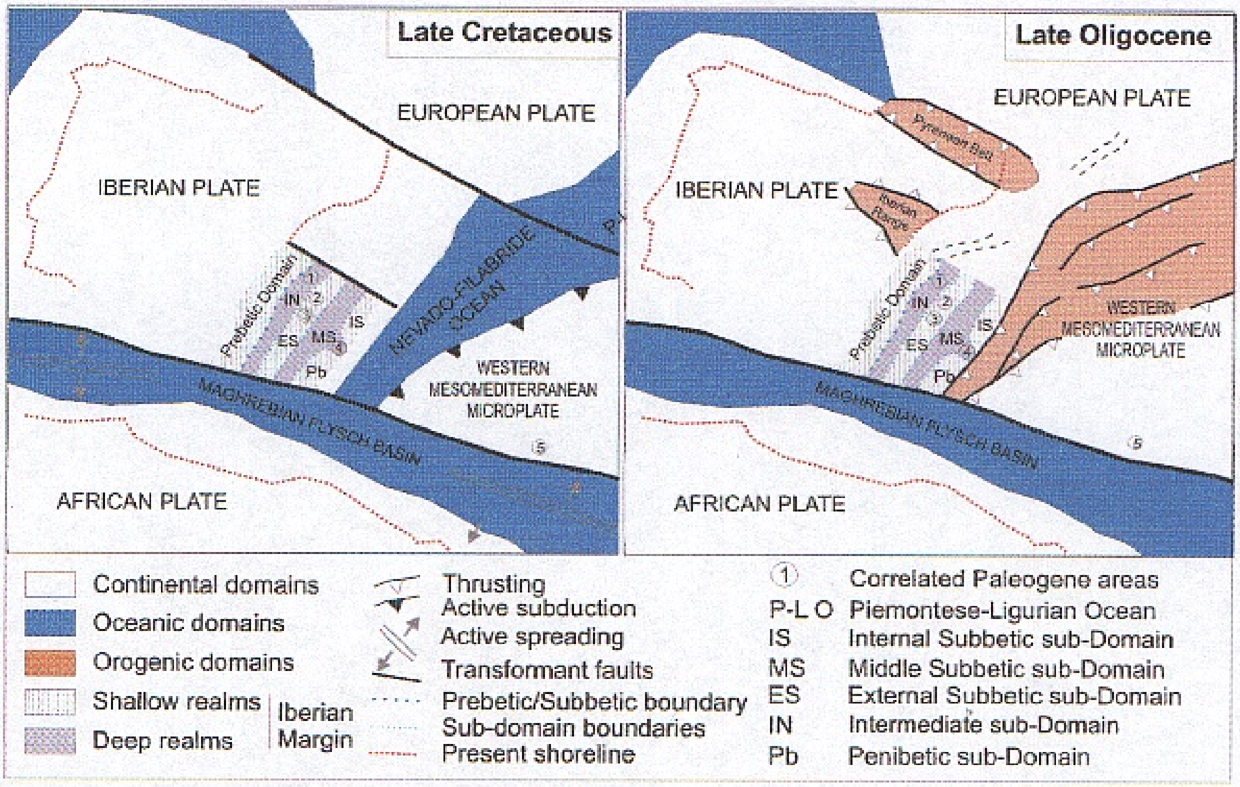

Fig. 8 - Palaeogeography and geodynamic model of the Western Tethys (from [27] and [28] modified) during Late Cretaceous and Late Oligocene. Numbers 1 to 5 indicate the location of the correlated successions.

facies are developed with olistostromes and mega-slumps (see Playa Nudista and Busot sections, Fig. 3) followed by a calcarenite-platform prograding level towards the end of the Oligocene. Sedimentation ends at the latest Oligocene, when deep slope marly facies were developed with slumps and turbiditic deposits, evidencing a drowning of the area. Also, this evolution of the *ODS* appears to be parallel in time with a tectonic decrease upwards.

6. Timing of deformation and geodynamic implications

The Alicante Trough palaeogeography at the beginning of the Paleogene stage (late early Eocene p.p.) was relict to that from the Mesozoic, giving a deep-subsident area in the central part of the basin and two shallow margins. In the *WDA* the wide subsident area should present a Subbetic-like basement (Intermediate sub-Domain), while in the *EDA* the basement for this central less subsident and narrower area, should be the Internal Prebetic sub-Domain (less subsident that from the Intermediate Unit). The southern margin, currently lost under the Mediterranean Sea and recognized only by the Oligocene slope sediments related to this margin, must be the shallow External Subbetic sub-Domain in both depositional domains, while the northern margin must, in the *WDA*, be the Internal Prebetic sub-Domain and, in the *EDA*, the External Prebetic sub-Domain.

At present in these sections, Palaeocene sediments are present only in the central section from Agost in the *WDA*, the late early Eocene (P-6a, CP-9a zones) being unconformable over the Cretaceous, revealing the first tectonic deformational process in the margins of the Alicante Trough, probably due to a slight folding. Nevertheless, in the Villafranqueza succession from the central part of the basin in the *WDA*, the Palaeocene is not recognized, although the geological map from literature [9] indicates a stratigraphic contact between Mesozoic and Palaeocene beds. The presence of a continous succession in the Agost area and the fact of the great thickness of the Villafranqueza succession seem to indicate continuous sedimentation in the Villafranqueza area, but the action of a fault should obliterate such Palaeocene features. The first deformational phase could be related to an incipient folding following the Mesozoic tectonic lineation (a near W-E axis).

After this, the sedimentation appears to be continuous till the upper Eocene, showing a regressive evolution and a tectonic increase reflected in the sedimentation by the presence of turbiditic flows, olistostromic deposits, and slumps intervals. The normal sedimentary pattern when no olistostrome or slumps are presents consists of minor regressive cycles with three stratigraphic intervals: first, marls, followed by pelagic marly-limestones and ended by turbiditic sandstones.

TAXONOMIC INDEX

Plancktonic foraminifera (formal nomenclature)

A. angulosa: Acarinina angulosa (Bolli)
A. broedermanni: Acarinina broedermanni (Cushman & Bermúdez)
A. bullbrooki: Acarinina bullbrooki (Bolli)
A. cuneicamerata: Acarinina cuneicamerata (Blow)
A. soldadoensis: Acarinina soldadoensis (Brönnimann)
C. dissimilis: Catapsydrax dissimilis (Cushman & Bermúdez)
G. ampliapertura: Globigerina ampliapertura Bolli
G. angulisuturalis: Globigerina angulisuturalis Bolli
G. corpulenta: Globigerina corpulenta Subbotina
G. eocaena: Globigerina eocaena Gumbel
G. higginsi: "Globigerinoides" higginsi Bolli
G. increbescens: Globigerina increbescens Bandy
G. index: Globigerinatheka index (Finlay)
G. kugleri: Globigerinatheka kugleri (Bolli, Loeblich & Tappan)
G. lozanoi: Globigerina lozanoi Colom
G. mexicana: Globigerinatheka mexicana (Cushman)
G. praebulloides: Globigerina praebulloides Blow
G. primordius: Globigerinoides primordius *Blow & Banner*
G. semiinvoluta: Globigerinatheka semiinvoluta (Keijzer)
G. subconglobata: Globigerinatheka subconglobata (Shutskaya)
G. suteri: Globorotaloides suteri Bolli
G. tripartita: Globigerina tripartita Koch
G. venezuelana: Globigerina venezuelana Hedberg
Gr. kugleri: Globorotalia kugleri *(Bolli)*
H. alabamensis: Hantkenina alabamensis Cushman
H. dumblei: Hantkenina dumblei Wienzierl & Applin
H. primitiva: Hantkenina primitiva Cushman & Jarvis
M. acuta: Morozovella acuta (Toulmin)
M. aequa: Morozovella aequa (Cushman & Renz)
M. aragonensis: Morozovella aragonensis (Nuttall)
M. caucásica: Morozovella caucasica (Glaessner)
M. formosa: Morozovella formosa (Bolli)
M. lehneri: Morozovella lehneri (Cushman & Jarvis)
M. lensiformis: Morozovella lensiformis (Subbotina)
M. senni: Muricoglobigerina senni (Beckman)
M. spinulosa: Morozovella spinulosa (Cushman)
M. subbotinae: Morozovella subbotinae (Morozova)
M. velascoensis: Morozovella velascoensis (Cushman)
N. nana: Neogloboquadrina nana (Bolli)
N. opima: Neogloboquadrina opima (Bolli)
N. siakensis: Neogloboquadrina siakensis (LeRoy)
P. chapmani: Planorotalites chapmani (Parr)
P. micra: Pseudohastigerina micra (Cole)
P. palmerae: Planorotalites palmerae (Cushman & Bermúdez)
S. frontosa: Subbotina frontosa (Subbotina)
S. inaequispira: Subbotina inaequispira (Subbotina)
T. cerroazulensis: Turborotalia cerroazulensis Cole
T. cocaensis: Turborotalia cocaensis Cushman
T. rohri: Truncorotaloides rohri (Brönnimann & Bermúdez)
T. topilensis: Truncorotaloides topilensis (Cushman)

Calcareous nannoplanckton (formal nomenclature)

C.*altus: Chiasmolithus altus Bukry & Percival*
C. *grandis: Chiasmolithus grandis (Bramlette & Riedel) Radomski*
C. *oamaruensis: Chiasmolithus oamaruensis (Deflandre) Hay, Mohler & Wade*
C. *solitus: Chiasmolithus solitus* (Bramlette & Sullivan) Locker
C. *abisectus: Cyclicargolithus abisectus (Müller) Wise*
D. *barbadiensis: Discoaster barbadiensis Tan emend Bramlette & Riedel*
D. *diastypus: Discoaster diastypus Bramlette & Sullivan*
D. *kuepperi: Discoaster kuepperi Stradner*
D. *lodoensis: Discoaster lodoensis* Bramlette & Riedel
D. *nodifer: Discoaster nodifer Bramlette & Riedel*
D. *sublodoensis: Discoaster sublodoensis* Bramlette & Sullivan
H. *compacta: Helicosphaera compacta Bramlette & Wilcoxon*
H. *euphratis: Helicosphaera euphratis Haq*
I. *recurvus: Istmolithus recurvus Deflandre*
N. *fulgens: Nannotetrina fulgens (Stradner) Achuthan & Stradner*
R. *bisecta: Reticulofenestra bisecta* (Hay, Mohler & Wade) Roth
R. *dictyoda: Reticulofenestra dictyoda (Deflandre) Stradner*
R. *umbilica: Reticulofenestra umbilica (Levin) Martin & Ritzkowski*
S. *ciperoensis: Sphenolithus ciperoensis Bramlette & Wilcoxon*
S. *distentus: Sphenolithus distentus (Martini) Bramlette & Wilcoxon*
S. *predistentus: Sphenolithus predistentus Bramlette & Wilcoxon*
T. *orthostylus: Tribrachiatus orthostylus Shamarai*

Those minor cycles can be interpreted also as tectonically controlled when the rhythmic hemipelagic conditions with marl and marly-limestones are altered by the occurrence of turbidites due to a tectonic instability in the upper slope. When this instability is extreme, olistostromes and slumps are found. The tectonic activity in the margins of the basin during this period could be related to the progression of the previous folding and by the beginning of the change in the regime of the relict Mesozoic fault: changing from normal to blind-inverse or transpressive faults.

At the end of the Eocene a new gap is detected in the sedimentation affecting the latest Eocene (P-15 and CP-15 zones) to earliest Oligocene (CP-16c zone). The Oligocene sedimentation begins at the CP-16c zone with mega-olistostrome deposits (see Busot and Playa Nudista sections, Fig. 3) evidencing relief generation during the gap and a new tectonic phase once again in the margins of the basin, represented only in the *EDA*. The tectonic activity during this period may be related to the progression of the previous relict Mesozoic fault changed during the Eocene into inverse or transpressive, generating an unstable slope on the southern margin. After this, the basin evolved to relatively quiet conditions when platform prograded northwards into the basin. The latest period of the basin during the latest Oligocene (and probably during the Aquitanian) consisted of a drowning of the basin with marly and turbiditic deposits, probably due to a new folding since this period predates the thrusting phases in these domains, when the basin was broken and blind-faults became emergent thrusts during the early Miocene.

Studied Successions	**Sub-stratum**	**Eocene Sedimentary Realm**	**Oligocene Sedimentary Realm**	**Sedimentation age**	**Gaps**	**Area**
Peñas Montesas (PM)	Subbetic	Slope-External Platform (feed from N)	Not sedimentary record	Early-Middle Eocene p.p.	Paleocene; Early Eocene	Western Depositional Area (WDA) Subsident
Agost (AG)	Subbetic	Slope-Basin	Not sedimentary record	Paleocene p.p.- Early- Middle Eocene p.p.	Continuity	
Villafranqueza (V)	Subbetic	Slope (feed from N)	Not sedimentary record	Early-Middle Eocene p.p.	Paleocene; Early Eocene	
Amadorio (AM)	Prebetic	Basin and Slope (feed from N)	Not sedimentary record	Early-Middle Eocene p.p.	Paleocene; Early Eocene	Eastern Depositional Area (EDA) Not Subsident
Busot (BU)	Prebetic	Basin (feed from N)	Slope (feed from SE)	Eocene p.p.- Oligocene p.p.	Paleocene; Early and Late Eocene	
Pantanet (PA)	Prebetic	Basin	Slope (feed from SE)	Middle-Late Eocene p.p.- Oligocene p.p.	Late Eocene	
Torre del Charco (TC)	Prebetic	Not sedimentary record	Slope (feed from SE)	Late Oligocene p.p.	Not found	
Playa Nudista (PN)	Prebetic	Not sedimentary record	Slope (feed from SE)	Early Oligocene p.p.	Not found	

Table 1 - Main characteristics of the successions studied in relation to the depositional areas (*WDA* and *EDA*) of the successions studied.

7. Discussion

The sedimentary evolution of the Alicante Trough implies the existence of at least three main unconformities, dating respectively to the: (1) Early Eocene, (2) Eocene/Oligocene boundary, (3) latest Oligocene (or Aquitanian). The sedimentary record is made up by two depositional sequences during the: (a) Eocene p.p. and (b) Oligocene p.p. (and probably Aquitanian p.p.), respectively. Both depositional sequences show a flysch-like sedimentation, with turbidites, slumps and olistostromes, evidencing active tectonics in the margins of the basin, during this period.

When the sedimentary evolution of the Alicante Trough is correlated with other sectors from the External Betic Zone (Fig. 7), such as the Middle Subbetic from Bullas (Murcia province, [7]) and Piñar-Moreda (Granada Province [4; 26]), Middle-Inner Subbetic from the High Chain (Malaga province, [27]), similar characteristics are found. Two main unconformities, with related sedimentary gaps, are present at the early Eocene and the Eocene/Oligocene boundary, the end of the sedimentation being latest Oligocene or early Miocene in the other sectors. The sedimentation trend evidences active tectonics with generalized instability along the margins of the basins of the Betics, as can be recognised also by the presence of turbidites, slumps and olistostromes ([4; 27]) throughout the successions. In the Subbetic Domain from the External Betic Zones the Tertiary succession can be found in subsidence realms (Intermediate and Middle Subbetic sub-Domains) the Tertiary sedimentation usually being eroded in the rising domains. Normally, the evidence of the sedimentation in the rising domains can be found in the clastic supply in the subsident domains.

The existence of these unconformities with related sedimentary gaps and a flysch-like sedimentation at the Eocene and Oligocene, although widespread in the Subbetic Domain, seems to be early since the tectonic impelling in the External Betic Zones is documented from the late Burdigalian to early Tortonian. Moreover, if this evolution is correlated with the succession from the Malaguide Tertiary from Sierra Espuña area (Murcia province, Internal Betic Zone), the same evolution is found with the same unconformities, sedimentary gaps, and flysch-like sedimentation.

Fig. 8 (from [27] and [28] modified) shows the palaeogeography and geodynamic evolution of the Western Tethys sector during late Cretaceous and late Oligocene; the correlated successions are also located (1 to 5). At the end of the Cretaceous the oceanic spreading was complete in two oceanic Tethysian branches: Nevado-Filabride Ocean, to the north (in prosecution of the Piemontese-Ligurian Ocean) and Maghrebian (Ocean) Flysch Basin, to the south (Fig. 8). Both oceanic branches were separated by a crustal block: the Mesomediterranean Microplate [29], where the Malaguide Complex is located. Thus, microplate was located between Iberia and Africa Plates [29]. The main tectonic processes during the Eocene and the Oligocene in the Betics are related to the closing of the Nevado-Filabride Ocean by a subduction [29] below the Mesomediterranean Microplate. This tectonic scenario is related to the compressive Alpine Cycle at the same time as the Iberian Range and Pyrenean Belt formation [30].

The existence of early tectonics in the External Betic Zone during the Eocene and Oligocene, easily correlated with evidence from convergence processes in the Internal Betic Zone in the same period, make necessary to related that tectonic situation to the subduction of the oceanic crust from the Nevado-Filabride Ocean below the Mesomediterranean Microplate, this oceanic crust being connected to the continental crust from the South-Iberian Palaeomargin and especially with the Subbetic Domain.

8. Conclusions

Our reconstruction of the Alicante Trough is based on eight stratigraphic successions (Figs 3; 4; 5; 6) on opposite external-platform slopes and to the deep central part of the basin have led us to divide the basin into two depositional realms: an Eocene to Oligocene narrow sedimentary basin with a deep central part, and two active margins. These were located to the north during the Eocene and to the south and/or southeast during the Oligocene. Today, the latter margin is lost under the Mediterranean Sea, and it is only recognized by the Oligocene slope sediments, consisting of shallow unstable platforms.

According to the Jurassic substratum (deep or shallow), the age of the sedimentary record, the subsidence amount and the source areas, the depositional areas are the subsident Western Depositional Area (*WDA*) and the not subsident Eastern Depositional Area (*EDA*). The infilling of the basin has been also divided according to the sequence boundaries (Early Eocene, Cuisian- and the Eocene/Oligocene boundary) into two depositional sequences: Eocene p.p. (*EDS*) and Oligocene p.p. (*ODS*) in age. The Palaeocene represented only in the deeper areas (Agost section), constitutes the continuation of the Upper Cretaceous conditions and hence is considered to be in the same sedimentary cycle. The *EDS* and the *ODS* are made up of turbiditic and olistostromic deposits with slumping, evidencing major tectonic activity on the margins of the basin during the sedimentation.

The tectono-sedimentary evolution of the Alicante Trough agrees well with that reported in other sectors of the External Betic Zone (Middle Subbetic sub-Domain of Murcia and Granada provinces and the Middle-Inner Subbetic sub-Domain of Malaga province) as the answer to a generalised geodynamic compressive situation throughout the South-Iberian Palaeomargin.

The aforementioned Paleogene tectonics was previous to the most active and generalized tectonic phase, which structured the External Betic Zone by thrusting during the middle to upper Miocene. The South-Iberian Palaeomargin and especially the Subbetic Domain could be connected with the oceanic crust from the Nevado-Filabride Ocean, the Paleogene tectono-sedimentary evolution being the response to the processes undergone by the oceanic crust from the Nevado-Filabride Ocean during the its subduction below the Mesomediterranean Microplate during the compressive Alpine Cycle at the same time to the Iberian Range and Pyrenean Belt formation.

Acknowledgements

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