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THE MALALYINE PLIOCENE SUCCESSION (NE RIF, MOROCCO): SEQUENCE STRATIGRAPHY AND REGIONAL CORRELATION

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Abstract: Malalyine area (Northern Morocco, about 10 km NNE of Tetouan), located in the Rifian Internal Zone, hosts a sedimentary basin filled since the early Pliocene. The sedimentary filling of this basin comprises three members. Member 1: inner platform basal marls dated as early Zanclean. They are rich in thin-shelled pectinids (*Amussium*, mainly) and characterized by *Ophiomorpha* burrows; Member 2: a lagoonal silty sand and conglomerate alternation containing conspicuous *Thalassinoides* burrows and shows well-delineated Fe-encrusted surfaces on the conglomerate beds; Member 3: fan-delta red conglomerates experiencing a pronounced thickening and upward-coarsening trend. Member 1 corresponds to the regressive stage of a late highstand regime, while the erosional surface at its top delineates the subsequent sequence boundary. Member 2 marks the onset of a new sequence, with the lime-free basal interval and the overlying Fe-surfaces representing the transgressive interval and the condensed section respectively. Member 3 marks the subsequent highstand with the well-expressed downlap surfaces pointing to a regressive regime accompanied by a prograding fan-delta. The whole Malalyine succession proved to be correlatable with a Spanish early Pliocene counterpart known in the Malaga area where it is similarly made up of marine marls (Pl-2) and above discordantly fan-delta conglomerates (Pl-3). Based on its early Pliocene age, these deposits would correlate with the Pliocene I of the eastern Betic basins.

Key words: Early Pliocene, Sequence stratigraphy, Trace fossils, N Morocco.

Resumen: El área de Malalyine (Norte de Marruecos, a unos 10 km al NNE de Tetuán), localizada en la Zona Interna rifeña, corresponde a una cuenca sedimentaria que se rellenó a partir del Plioceno inferior. Su relleno sedimentario comprende tres miembros. Miembro 1: margas basales de plataforma interna datadas del Zancliense inferior. Estas margas son ricas en pectínidos de concha fina (principalmente *Amussium*) y muestran túneles de *Ophiomorpha*; Miembro 2: alternancia de arenas limosas y conglomerados depositados en un lagoon, conteniendo bioturbaciones de *Thalassinoides* y superficies de incrustaciones de Fe bien delineadas sobre las capas de conglomerado; Miembro 3: conglomerados rojos de abanico deltaico ordenados según una pronunciada tendencia estrato y granocreciente. El Miembro 1 corresponde a la etapa regresiva de un régimen de nivel alto tardío, mientras que la superficie de erosión en su techo caracteriza el subsecuente límite de secuencia. El Miembro 2 marca el comienzo de una nueva secuencia, con un intervalo basal sin carbonatos que representa el intervalo transgresivo y, por encima, una secuencia condensada con superficies ferruginosas. El Miembro 3 representa el subsiguiente estadio de nivel alto con claras superficies de biselamiento basal (downlap) apuntando a un régimen regresivo acompañado de una progradación de abanicos deltaicos. La sucesión completa de Malalyine podría correlacionarse con el Plioceno inferior español que aflora en la cuenca de Málaga, el cual también está compuesto por margas marinas (Pl-2) sobre las que se disponen discordantemente conglomerados de abanicos deltaicos (Pl-3). Por su edad (Plioceno inferior), estos depósitos se correlacionarían con el Plioceno I de las cuencas béticas orientales.

Palabras clave: Plioceno inferior, Estratigrafía secuencial, Trazas fósiles, Norte de Marruecos.

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The studied Pliocene marine-continental strata sit in the Alila plain (Malalyine region), located 10 km north-northeast of Tetouan. This plain derived from the Pliocene-Quaternary filling of a wide graben structure (the so-called Malalyine basin) formed between Cabo Negro massif to the northeast and the Chouikhene high to the southwest (Fig.1A). This basin extends over 12 km long and reaches 15 km wide in its southeastern part opened on the Mediterranean Sea along the present-day beaches of Cabo Negro and Martil (Fig. 1B).

It is limited in its western part by the Ghomaride nappe pile, and the Calcareous Chain Haouz range. Regionally, the studied succession transgressively covers Paleozoic schists and high-grade metamorphic rocks of the Internal Zone (Fig. 1B, C): Silurian schists of the Akaili Unit (basal Ghomaride nappe) and gneiss of the Cabo Negro massif (lower Sebtide Units). The greatest part of the Pliocene sediments is hidden below Quaternary fluvial deposits, and crop out just along narrow erosional bands bordering small gutters and streams (Fig. 1B).

Kornprobst and Durand-Delga (1985, geological map 1/50000, Tetouan sheet) recognized three stratigraphic units in the infill of the Malalyine basin. The lower unit consists of Pliocene marine marls and it is overlain by continental red conglomerates assigned to the Villafranchian (middle unit). Unconformably resting on the latter unit are recent alluvial deposits (upper unit) that extend over the entire Malayine plain.

Recently, El Kadiri *et al.* (in press) described in the same outcrop synsedimentary mineralized joints indicating a tectonic tension directed N50, generated in turn within a contractional stress field directed N140. This tension is likely to have been a critical factor in the evolution of the Malalyine basin.

The studied outcrop occurs in the eastern side of a hillock (at X = 561.6; Y = 505.7) on both sides of the highway between Tetouan and M'Diq (Fig. 1B). It offers the rare opportunity to restore the Pliocene sequence stratigraphy and the paleogeographic evolution of the Malalyine basin. Both issues are expected to give new insight into the regional correlations and restoring the tectono-eustatic history that just predates the Quaternary and Present-day architecture of the innermost part of the Rifian chain.

Stratigraphy and paleontology

In the studied outcrop three lithologically contrasting members are observed (Fig. 2A).

Member 1: basal Amussium-bearing marls

This member (30 m, maximum visible thickness) consists of brown to gray homogeneous marls with interspersed thin-shelled pectinids represented near exclusively by *Amussium cristatum* Bronn (Fig. 2B and C). Most of *Amussium* shells show a good state of preservation; many of them are still articulated and unbroken, despite their thin character. Moreover, they are non-selectively oriented, arranged in a loosely-packed bioclastic fabrics. Particularly in the lower half of this member are abundant the *Ophiomorpha* burrows. They are represented by in situ horizontal tubes of up 5-10 cm in diameter, the majority of them are flattened.

Externally these tubes consist of a dense network of contiguous pastilles (the so-called lined walls, Bromley, 1996) and are filled up with fine sands material that contrasts with the hosting marly sediment. The filling material were certainly piped from overlying levels but no shaft structures were observed for instance burrows (Fig. 2D). In the upper part, the marls show intercalations of highly burrowed mudstone beds and the appearance of patched fodinichnia-domichnia clusters (Fig. 2E).

The microfauna is clearly dominated by benthic foraminiferal assemblages containing mainly *Elphidium, Nonion, Cibicides, Ammonia, Florilus* and, in some samples, rare *Nodosaria* and *Lenticulina*.

Only a few specimens of planktonic foraminifers were found (in all cases the frequencies are lower than 5 % with respect to the total of foraminifera), among which we identified: *Globigerina bulloides* d'Orbigny, *Globoturboralita decoraperta* (Takayanagi and Saito), *Orbulina universa* d'Orbigny, *Globigerinella siphonifera (*d'Orbigny) and *Globorotalia margaritae* Bolli and Bermúdez.

The upper half of this member, is cut by a 15 m wide erosional channel filled up with poorly burrowed and poor-carbonate marls (Fig. 2F), probably fed directly from a river mouth.

The top of the Member 1 is made by a small clayey interval (1-2 m) showing channelized structure (Fig.2F) that strongly resembles the underlying levels. The loss of the carbonate fraction reflects the absence of marine calcareous fauna and flora.

Member 2: white silty sand and conglomerate alternation

This member (20-30 m thick) covers the former by an erosive surface and consists of an alternation of silty fine sands and conglomerates (Fig. 2A and G). The silty sands appearing in white or light gray beds of decimetre thick (10-50 cm) are made mainly of fine quartz grains and result barren except for some rare palynomorphs.

Internally, these beds are highly homogeneous, well sorted and does not shows any sedimentary structures related to current reworking. Regularly, the last centimenters of each silty interval, become enriched in thin Fe-lamina (Fig. 2H), which give evidence of repetitive depositional breaks, i.e., just before the onset of the overlying pebbly beds.

The interlayered conglomerate beds are coarse-grained with non-oriented rounded pebbles supported in a sandy, free of muddy matrix (Fig. 2H) and, internally, show an arrangement in coarsening-fining-upwards. This predominantly quartzous material is variously inherited from the adjacent Sebtide migmatites and Ghomaride quartzites sandstones. The top surfaces show strong Fe-encrusting (see interpretation hereafter).

The silty sands are extensively crosscut by horizontal sinuous and Y-shaped *Thalassinoides* borrows (due to a domichnion crustacean tracemaker). The majority of borrows occur just below the pebbly

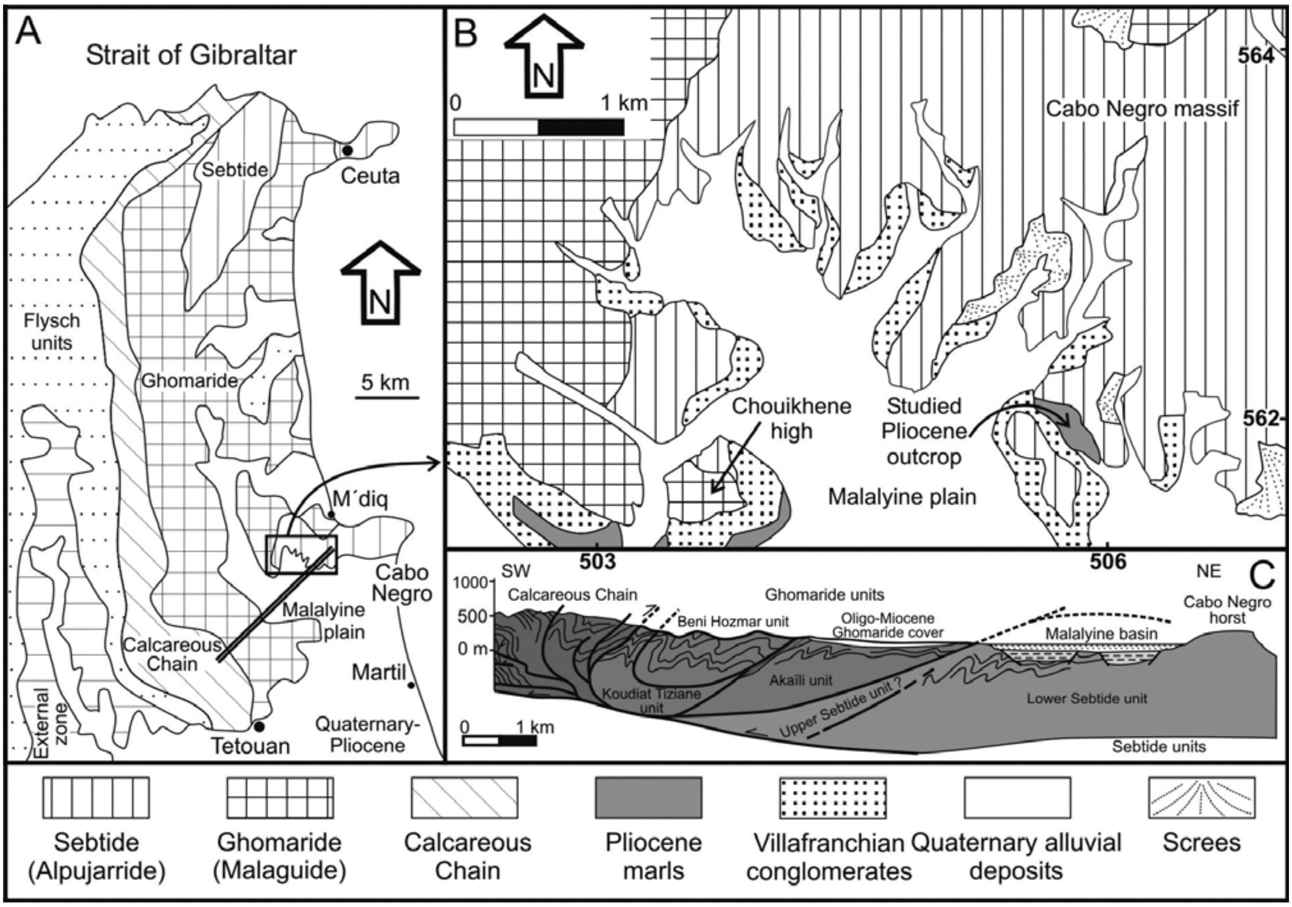

Figure 1.- Location maps of the studied outcrop and tectonic cross section over the Malalyine depocenter. **A)** Simplified sketch of the Northeasternmost part of the Rif Chain, **B)** Geological map showing the location of the Pliocene-Villafranchian outcrop between the lower Sebtides (Cabo Negro massif) and the Paleozoic Ghomaride basal unit (Akaili nappe), **C)** Geological cross section over the Malalyine area showing two main Pliocene grabens formed southwest of the Cabo Negro horst.

beds and subordinately within the silty sand intervals (Fig. 2I) where they are uniformly filled up by a quartzous material piped from the immediately overlying conglomerates.

Member 3: red conglomerates

This member (20-30 m thick) overlies the former one by means a downlap surface (Fig. 3D) and gradually upward evolves a progressive disappearence of silty sand intervals in favor of a clear dominance of conglomeratic beds (Fig. 2A). Internally record neither *Thalassinoides* tunnels nor Fe-encrusted surfaces on the top of the pebbly intercalations.

The well-rounded conglomerates consist of clast-supported deposits showing mega-crossing stratification. Internally, they develop poorly sorted and ungraded fabrics. Vertically, this lithofacies shows a twofold sedimentary trend due to both a coarsening-up and closeness-up of downlap elementary sequences stacked in a northeast/southwest progradational pattern (Fig. 3D). On the contrary, the sand beds in the lower part show no internal arrangement structures, although they contain thin gravelly intercalations (Fig. 2J). In contrast, the upper part of the Member 3 is characterized by clast-supported and weakly stratified conglomerates without interbedded sand beds.

Interpretation and discussion

Sedimentary environment and chronology

Regarding Member 1, the benthic foraminifer assemblage mainly made up by *Elphidium*, *Nonion*, *Cibicides*, *Ammonia*, and *Florilus* suggests inner marine shelf environments. The rare presence of *Nodosaria* and *Lenticulina*, generally inhabiting in deeper waters, as well as of the delicate pectinid *Amusium cristatum* Bronn, mainly recorded in fine-grained off-shore settings (Aguirre *et al*., 1996) can coexist with the former assemblage in shallow shelf areas unaffected by the wave activity, although is not ruled out intervals of hardly deeper deposition, about 70-100 m depth. The occasional presence of few planktonic foraminifers is also compatible with these environments located below the storm wave base but receiving distal tempestite marly suspensions. These marls were originally deposited through settling from clay clouds fed by river input, in a sea-bay setting where the upper water column consists of mixed fresh and marine water. This condition is met in coastal semi-confined basins partly disconnected from the fully open marine water, and explains why the planktonic foraminifera are very scarce. The abundance of *Ophiomorpha* borrows, particularly in the lower half of the Member 1, is in accordance with the above described depositional regime as the corresponding tracemakers are adapted to loose substrates and resist repetitive burial under terrigenous muds thanks to their lined walls (Uchman, 1995, 1999). The fact that all the *Ophiomorpha* tubes are diagenetically flattened gives evidence of the soft consistency of the original hosting sediment. The upper half of the marly interval, a relative decrease in the sedimentation rate is indicated by: **i**) the intercalations of highly burrowed mudstone beds, which point to small-scale sedimentary breaks, **ii**) the appearance of patched fodinichnia-domichnia clusters, which indicate relatively quiet bottoms free of the bulldozing pascichnia traces.

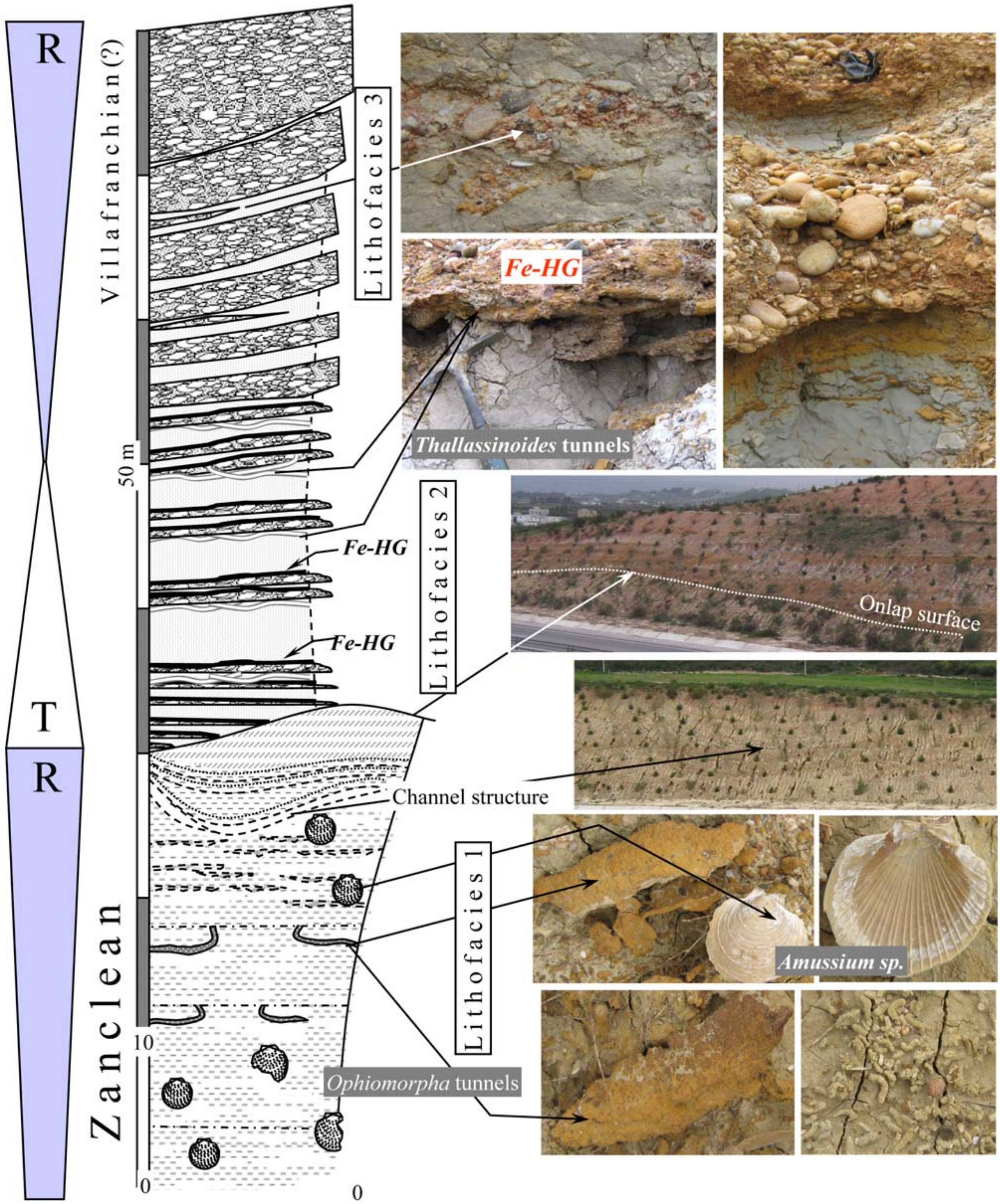

Figure 2.- Detailed stratigraphic column of the Malalyine Pliocene succession. Some key surfaces and ichnological signatures are illustrated. Remark the clear contrast between the Member 1 with *Ophiomorpha* and the Member 2 with *Thalassinoides*. Photographs: see details in the text.

Based on the scarce planktonic foraminifers, the presence of the key species *Globorotalia margaritae* Bolli and Bermúdez suggests an early Pliocene age for this member. Although *G. margaritae* is cited from late Messinian sediments of the Guadalquivir Basin (Andalusian by Perconig 1966, 1974) and the South Rifian Corridor (Benson *et al*., 1995; Krijgsman et el., 2004), its presence is only recorded at the beginning of the Pliocene in the Mediterranean realm. Moreover, the non-presence of *Globorotalia puncticulata* (Deshayes) must be considered, since it is usually much more frequent than *G. margaritae* in the Mediterranean sediments of the upper part of the early Pliocene. This suggests that the Member 1 could be probably deposited during the early Zanclean (Zone de *G. margaritae* by Cita, 1975).

The clayey interval at the top of the *Amussium*-bearing marls is a prelude to an important change in the sedimentary regime from marine conditions to the predominance of the terrestrial input.

The presence of *Thalassinoides* in the Member 2 suggests a deposition in a lagoonal or shallow-marine environment (Seilacher, 1967), but the shallow-water column remained sufficiently oxygenated to prevent the development of anoxic water conditions. The frequent interlayered conglomerates could indicate inputs of gravitacional fluxes in this proximal setting. The downlap surface and mega-cross bedding observed in the lower part of the Member 3 (Fig. 3D), as well as the predominance of coarse-grained sediment, is related to the progradation of a Gilbert-type fan delta (Massari and Colella, 1988). This association of facies characterized by sand/conglomerate alternations is correlated to the g4-S5 division described by Benvenuti (2003), that occur in the distal, subaqueous parts of the fan delta systems. Thus, the Member 2 could represent the prodelta (bottomset), whereas the lower part of the Member 3 could correspond to the delta front (foreset). In contrast, the upper part of the Member 3 would be equivalent to the facies g2 described by Benvenuti (2003), corresponding to the proximal part of alluvial fans representing the deltaic plain (topset). Together, Member 2 and 3 would correspond to the deposit of Gilbert-type fan delta by Ethridge and Wescott (1984).

No biostratigraphic data from the Members 2 and 3 are available.

Sequence stratigraphic interpretation and paleogeographic evolution

Figure 3 attempts to restore the sequence stratigraphic and the paleogeographical evolution as can be inferred from the studied succession. Both orographic features and the distribution of the Pliocene outcrops in the Tetouan-Cabo Negro area give evidence of an irregular coastal morphology during the Pliocene times. While close to Tetouan the Pliocene sea flooded an E/W-directed *Paleoria*, like other more southerly (Oued Laou, Oued Tihissasse, Oued Amter, see Wildi and Wernli, 1977; Loget and Van Den Driessche, 2006), in the Malalyine area it corresponded to a kilometer-scale bay (Fig. 3A).

As highlighted by Savrda *et al*. (2001a, b), ichnological data are among the most powerful criteria to argue a sequence stratigraphic interpretation. Indeed, the studied succession exhibits a clear-cut ichnological contrast between the *Ophiomorpha* marls (Member 1) and the overlying *Thalassinoides* Fe-encrusted pebbly sands (Member 2). Both ichnological signatures proved to be mutually exclusive as already highlighted by many authors (Uchman, 1995, 1999), so reinforcing the strong contrast between the *Amusium*-bearing Member 1 and the Member 2 barren in microfauna.

Within the basal *Amusium*-bearing marly lithofacies, the presence of *Ophiomorpha* borrows is the most noteworthy ichnological feature. The corresponding crustacean tracemaker is well-known to require well oxygenated waters (Savrda *et al*., 1991) and to consume plant detritus (Uchman, 1999). It acts as a multi-layer colonizer adapted to loose clayey substrate and to marine bottoms undergoing storm conditions (tempestites, turbidites, etc), within which it reinforces the borrows in fixing on their inner wall muddy pellets (Bromley, 1996;

Uchman, 1995, 1999). *Ophiomorpha* characterizes high rate sedimentary regimes due to high frequency terrestrial input in channels and submarine canyon mouths (Bromley, 1996; Uchman, 1995, 1999).

The *Thalassinoides* tracemaker is similarly known to require well-oxygenated marine waters, and to act as a multi-layer colonizer excavating down through several pre-consolidated layers (Uchman, 1995). But contrary to *Ophiomorpha*, *Thalassinoides* is a diagnostic criterion for the omission firmground conditions (i.e., *Glossifungites* ichnofacies surfaces, initially defined in lagoonal and shallow-water conditions; Seilacher, 1967) that characterize transgressive minor flooding surfaces (MacEachern and Burton, 2000; MacEachern *et al*., 1999; Pemberton and MacEachern, 1995; Savrda, 1995; Savrda *et al*., 2001a, b).

Accordingly, the grain-flow beds hosting *Thalassinoides* borrows can be interpreted here as derived from high density turbidity currents triggered by shoreface storms. This phenomenon occurs when transgressive pulses flood alluvial areas where a neighbouring inland pebbly material is prone to the basinward export (e.g. «transgressive washing concept»; El Kadiri *et al*., 2006). The domichnion *Thalassinoides* trace-maker subsequently inhabited this storm pebbly material during the early phase of each long-lasting omission history that postdates its deposition, precisely when the water column was still well oxygenated, i.e. before the spreading of the stagnation-related anoxia responsible for the Fe-encrusting processes (e.g., El Kadiri, 2002a, b).

Fe-coating processes were additionally observed in the same outcrop around cracks and extensional joints, and disappear gradually when leaving these tectonic planes (El Kadiri *et al*., in press). This fact points to fluid circulations through the whole studied sequence, mainly driven along the tectonic planes themselves. The Fe-encrusting on conglomerate bed tops strictly occurs in the member 2 and sharply disappears in the dominantly conglomeratic overlying member (Member 3, see below). On the contrary of the gradually distributed joint-related Fe-coating, the bed top-related Fe-encrusting develops in a heavily concentrated and

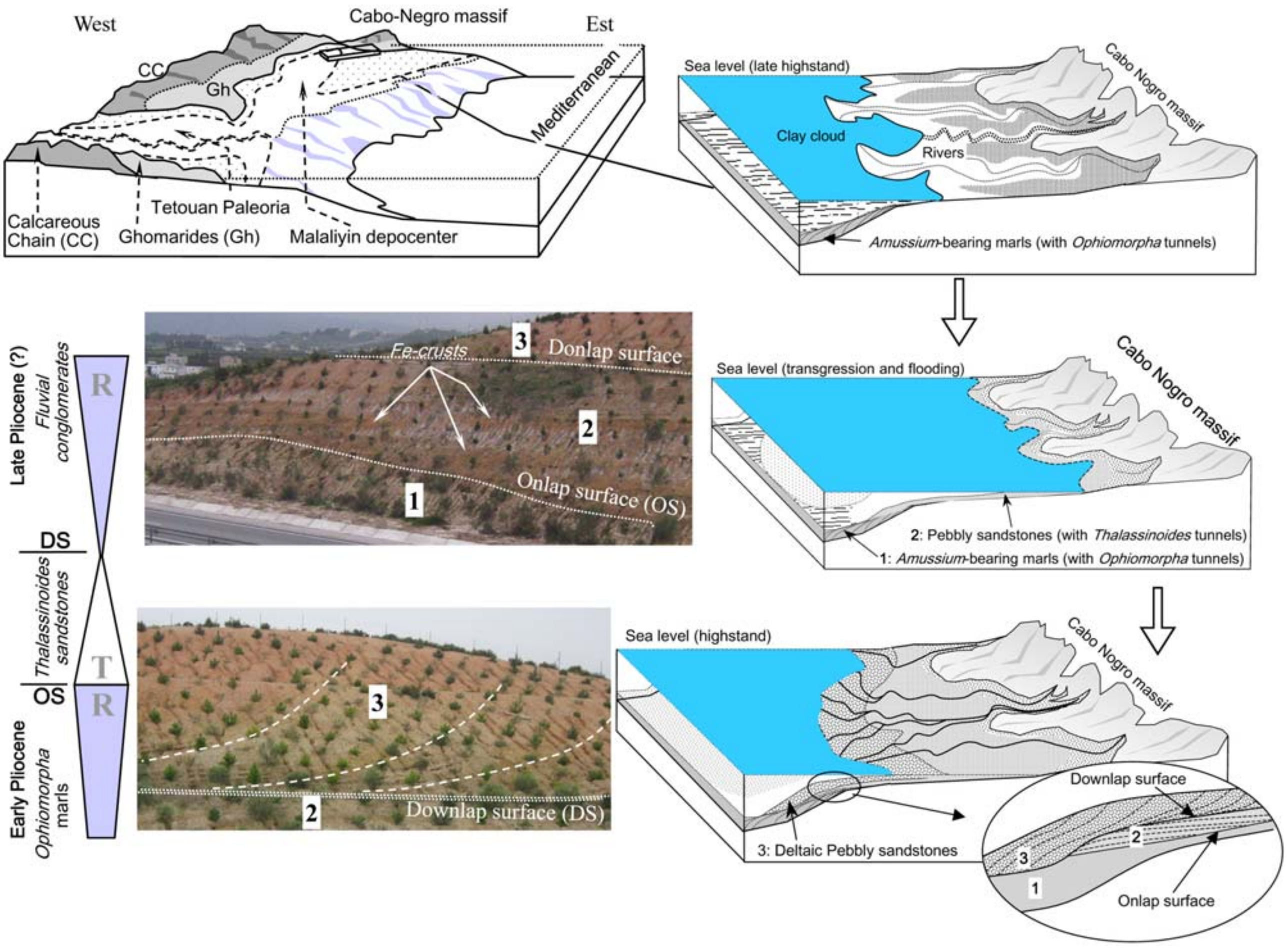

Figure 3.- Paleogeographic interpretation and sequence stratigraphy of the studied succession. A: 3D skech locating the Malalyine depocenter with respect to the Tetouan paleoria, B: Sequence stratigraphic interpretation of the whole studied succession (see Figure 2) in terms of third-order Transgressive/Regressive cycles (T/R cycles; Graciansky *et al.*, 1998), C and D: Photographic illustrations of the onlap and downlap surfaces at the base of the member 2 and 3 respectively, E-F-G: Restoration of the paleogeographic evolution at the SW side of the Cabo Negro massif (NE of the Malalyine depocenter). Note that the regressive phases (Member 1 and 3) do not resulted in similar depositional regime.

faintly laminated fabrics. This phenomenon that points to biolamination processes, classically occurs in Fe-hardground and firmground surfaces (e.g., Fürsich, 1979, Fürsich, *et al.* 1991, 1992, Mamet *et al.*, 1997, Mamet and Perret, 1994, Corbin *et al.*, 2000, El Kadiri, 2002a,b). Accordingly, the systematic presence of a dense network of *Thallassinoides* tubes just below the Fe-encrusted levels (Figure 2I) positively points to the sedimentary origin of these Fe-encrusted surfaces. Indeed, *Thallassinoides*, which is a substrate consistency-related trace is a diagnostic criteria of firmground to hardground surfaces since it belongs to the to the Glossifungites ichnofacies (as emphasized by Savrda, 1995; Savrda *et al.*, 2001a-b and MacEachern & Burton, 2000, among others).

On the other hand, the Glossifungites ichnofacies is commonly used to delineate key stratigraphic surfaces, and many authors emphasized its sequence-stratigraphic significance (Bromley, 1996; MacEachern & Burton, 2000; MacEachern *et al.*, 1999; Pemberton & MacEachern, 1995; Savrda, 1995; Savrda *et al.*, 2001a, b). Depending on the time scale considered, these surfaces are thought to mark minor or major transgressive pulses, i.e., **i**) parasequence-bounding minor flooding surfaces (van Wagoner *et al.*, 1988) or **ii**) omission surface(s) within the amalgamated condensed section, respectively (e.g., Loutil *et al.*, 1988). In this context the conspicuous Fe-encrusted bed-tops fit well with the successive flooding surfaces that characterize parasequence-bounding surfaces within both a transgressive interval and the overlying condensed section (Loutit *et al.*, 1988).

To sum up, the Member 1 despite the apparently «transgressive» role it seems to play on the metamorphic basement, its evolution corresponds to the regressive stage of a late highstand regime (Fig. 3B and E). This interpretation is based on the «lithological prediction» method (in the sense of Posamentier and James, 1993) that attempts to draw the sequence stratigraphic interpretation based directly on the sediment himself. Thus, it appears consistent with its marly nature and the presence of *Ophiomorpha,* a twofold lithofacies and ichnological criteria that commonly characterizes late highstand intervals (Savrda *et al.*, 2001a, b). Accordingly, the channel structure and the erosional surface at its top (Fig. 2) delineate the subsequent sequence boundary (in the sense of Van Wagoner *et al.*, 1988) onto which the onlap architecture of the following transgressive interval (Member 2, Fig. 3C) marks the onset of a new sequence (Members 2 + 3).

The Member 2 is likely to encompass both the corresponding transgressive interval and the condensed section as it is a rule in the inner platform areas (Fig. 3B and F). A similar good example was cited by Loutit *et al*., (1988) in the Mississippi delta material, where Fe-hardground surfaces, representing the condensed section, directly cover an SB.1-type sequence boundary fashionned into the underlying marly highstand. Finally, the member 3 shows well-expressed downlap surfaces (Fig. 3D) pointing to a regressive regime accompanied by a prograding fan delta (Fig. 3G).

Stratigraphic correlation

Before the attempt to establish the regional stratigraphic correlation, must be considered: **i)** the Malalyine area displays two third-order depositional sequences separated by an erosive surface; **ii)** the first depositional sequence (Member 1) is directly resting on the Paleozoic basement and corresponds to the regressive stage of a late highstand regime, whereas the second depositional sequence (Member 2 and 3) represents a trangressive-regressive cycle; and **iii)** the planktonic foraminiferal assemblages suggest that deposition of the Member 1 occurred during the early Zanclean.

Marly sediments of the Member 1 could be correlated with the fine sedimentation that in a transgressive-regressive cycle filled the Tetouan paleoria during the early Pliocene, as described by Ben Moussa *et al*. (1992). This filling is made up at the base and in the marginal areas of the paleoria by bivalve-bearing conglomerates, which evolve gradually fining upwards up to sandy sediments (Boujarah section). The middle part comprises sandy marls and clays as observed in the Azla, Teffaline, and Tamouda sections. In these two last sections is also registered the regressive, upper part of the cycle, which is represented by alternations of sands and rich in pectinid and ostreid calcarenites. The complete cycle could be equivalent to the Member 1 of Malalyine, whereas the second sequence of Malayine (Member 2 and 3) would not be represented in the Tetouan paleoria. Southeastwards, Oued Laou shows Pliocene marls deposited in another paleoria («Marnes de Tassefete» by Wildi and Wernli, 1977), which were attributed to the *G. margaritae* zone, thus suggesting a correlation with the marly sedimentation of Member 1 of Malalyine. Above, the marls are covered by yellowish sands reflecting the shallowing of the paleoria environment.

In the easternmost Boudinar basin, El Kharim (1991) and Azdimousa *et al*. (2006) describe a lower Pliocene sequence beginning by fluvial red conglomerates with subsidiary sand and clay intercalations, which are overlain by conglomerates bearing marine fauna (bivalves and shallow benthic foraminifers, as *Ammonia* and *Elphidium*) and, above, sandy marls dated of the early Pliocene by means planktonic foraminifers (Barthoun y Wernli, 1999). The top of the marly sedimentation is broken by a stratigraphic discontinuity marking a basal progradation surface, which is the onset of a second stratigraphic unit made up by a rhythmic alternation of fine sands and borrowed (*Skolitos*) clays with lenticular conglomeratic bodies in the upper part showing erosional basal surfaces. These two units separated by the stratigraphic discontinuity could be correlated respectively with the Member 1 and Member 2 of the Malalyine succession.

Regarding the basins of South of Spain, where the Pliocene sedimentation is more extended, various authors (Montenat, 1990; Aguirre, 1995a; and references therein) differentiated two units in the Pliocene deposition of the eastern Betic basins: **i)** a Pliocene I unit, in where the successive planktonic foraminifer biozones of *G. margaritae*, *G. puncticulata* and, in the uppermost part, *G. crassaformis* were recognized, thus dating the Zanclean and the earliest Piacenzian in age; and **ii)** a Pliocene II unit made up by littoral and shallow marine deposits, from which no planktonic foraminifers have been noted for assigning the biozonal range. However, based on the stratigraphic framework (overlying discordantly the Pliocene I and below Quaternary deposits) a late Pliocene age has been attributed for this unit.

From the Pliocene deposition in the Golfo de Cadiz area, Aguirre (1995a and 1995b) differentiated three stratigraphic units so-called informally units I, II and III. Based on biostratigraphic and paleomagnetic data, this author correlated the Unit I with the Pliocene I recognized in the eastern Betic basins, whereas the units II and III could be correlated with the Pliocene II. The unconformity separating units I and II is located about the Zanclean/Piacenzian boundary. This stratigraphic frame has been largely accepted and extended to other basins where two Pliocene units appear separated by unconformity. However, an ample lack of biostratigraphic data exists for spreading this stratigraphic setting to the whole of the Betic basins, while notable discrepancies exist related to the adscription of the sediments to the established units. Moreover, Van de Poel (1994), Barragán (1997) and Guerra-Merchán *et al* (2000, 2010) indicated the existence of unconformities affecting internally to lower Zanclean sediments.

In the Alboran satellite basins of the Betic region, the stratigraphic scheme for the Pliocene deposits is well different. Guerra-Merchán *et al*., (2000, 2008) described in the Malaga basin a Pliocene succession made up of three sedimentary sequences (named Pl-1, Pl-2, and Pl-3 units) bounded by discontinuities. The transgressive Pl-1 unit, overlying in some sites latest Messinian Lago-Mare deposition (Guerra-Merchán *et al*., 2010), is related to the re-establishing of the normal marine conditions at the beginning of Pliocene. Biostratigraphic and paleomagnetic data allow to assign this unit to the MPL1 biozone of the earliest Zanclean.

The Pl-2 and Pl-3 units represent two transgressive–regressive cycles separated by a tectonic and erosive phase. The lower levels of the Pl-2 unit show of planktonic foraminifer assemblages similar to those of the Unit Pl-1, but towards the middle part is noticed the common occurrence of *G. margarite*, thus indicating its belonging to the MPL2 biozone of the early Zanclean.

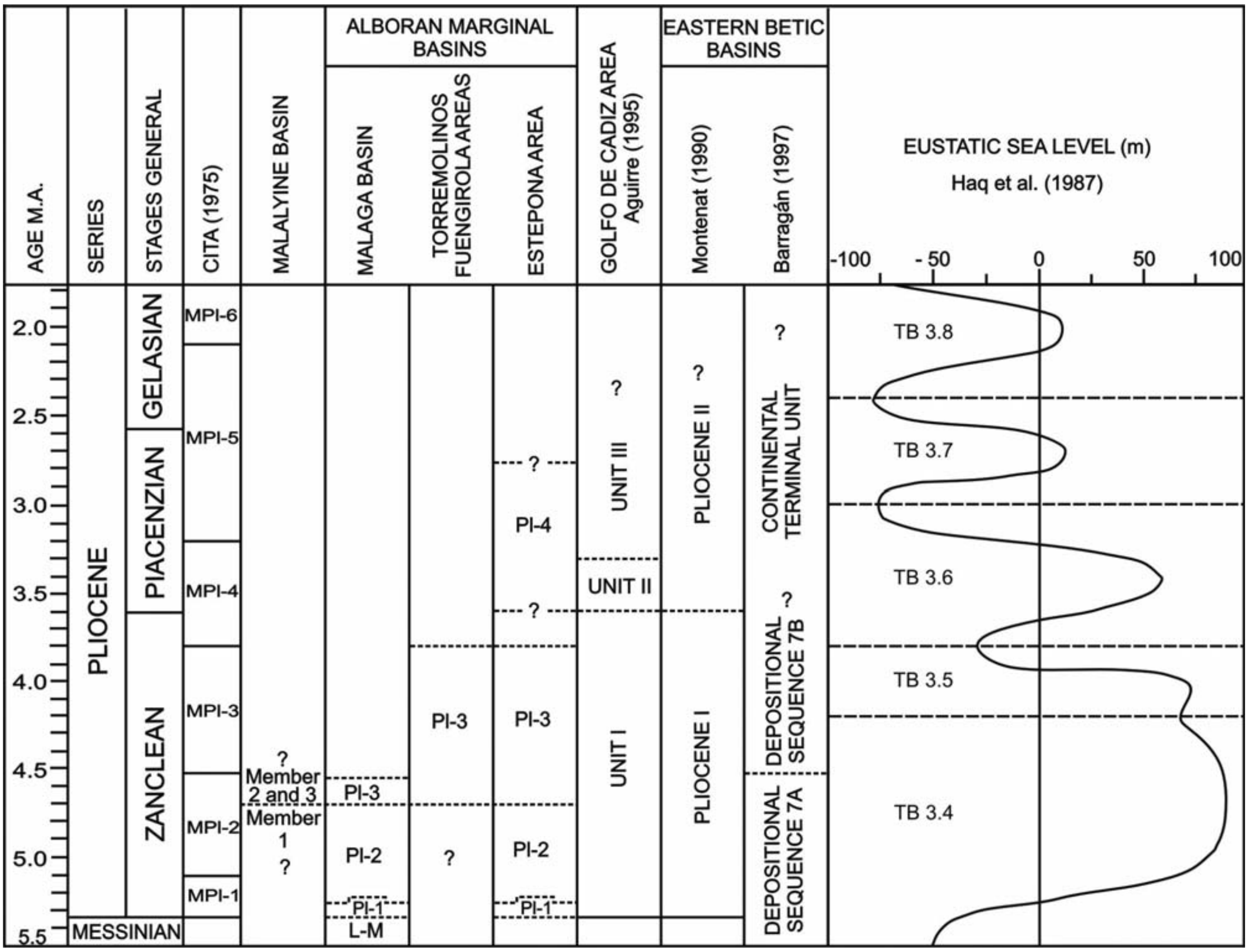

Figure 4.- The Malalyine succession in the general frame of the Pliocene sedimentation of the Betic-Rifain basins correlated with the eustatic cycles by Haq *et al*. (1987).

In the Malaga basin is exposed only the first part of the Pl-3 unit, where no new biostratigraphic events observed in relation to the middle and upper part of the Pl-2 unit. However, to the southwest, the Pliocene sediments near to the coast (Torremolinos, Fuengirola, Estepona, Manilva areas) belonging the Pl-3 unit are more thick and is registered the presence of *G. puncticulata* jointly with *G. margaritae*, thus characterizing the MPL-3 biozone. In the uppermost levels of this unit is also noted the common presence of *Globigerinoides ruber* (d'Orbigny)–*Globigerinoides elongatus* (d'Orbigny), an event occurring in the upper part of the zone MPL3 (Serrano *et al*., 1999) within Zanclean. Locally, in the Estepona area (Guerra-Merchán *et al*., 2002) a Pl-4 unit overlying discordantly the Pl-3 yielded planktonic foraminifer assemblages with abundant *G. ruber–G. elongatus*, *Globorotalia bononiensis* Dondy and, in some levels, *Globorotalia aemiliana* Colalongo and Sartoni, and morphologically primitive forms of *Globorotalia crassaformis* (Galloway and Wissler). These assemblages seem characterize the upper part of the MPL-4 biozone by Cita (1975) of the early Piacenzian. In summary, based on the bio- and chronostratigraphy, Pl-1, Pl-2 and Pl-3 units differentiated in the Malaga region must be correlated to the Pliocene I of the eastern Betic basins, whereas the Pl-4 unit could correspond to the Pliocene II (Fig. 4).

According to the abovementioned, the Member 1 of the Malalyine succession could be correlated with Pl-2 unit of the Malaga basin. Above, the Members 2 and 3 feature a new transgressive-regressive cycle that would be correlated with the Pl-3 unit of the Malaga basin (Fig. 4). Consequently, the whole Malalyine succession could correlate with the Pliocene I of eastern Betic basins.

Regarding the Zanclean age of both, Malaga and Malalyine successions can be in turn sensitively correlated with the TB 3.4 cycle of Haq *et al*. (1987). Since the cycle TB 3.4 starts by 5,5 Ma (within the Messinian times) and the end occurred in the Zanclean at 4,2 Ma, in the Malaga basin this cycle is represented respectively by Lago-Mare deposits of late Messinian age and the whole of the Pliocene deposition. Thus, this cycle would be roughly equivalent to Depositional Sequence 7A by Barragán (1997) established from the Vera basin in the eastern Betic (Fig. 4). In the Malalyine region, the basal transgressive levels of this cycle are not observed, and the subsequent upper part (Member 1) directly rests on the Paleozoic basement. As indicated above, in Malalyine and Malaga basins, the sedimentary successions end just before the first appearence of *Globorotalia puncticulata* (Deshayes), by about 4,52 Ma (Hilgen, 1991; Sprovieri, 1993), so its upper boundary does not correspond to that of the cycle TB 3.4 (4,2 Ma). On the contrary, in Torremolinos, Fuengirola and Manilva areas the Pliocene marine deposition of the Pl-3 unit is maintained until near the end of the biozone MPL-3, comprising the last part of TB 3.4 cycle and the complete TB 3.5 cycle (Fig. 4). Thus, the interruption of the sedimentation can be related to the sea-level fall of about 100 m marking the final of the TB 3.5 cycle (3.8 Ma).

Conclusions

The studied Malalyine succession allows restoring the stratigraphic sequence, as well as the palaeogeographic evolution of the region located to the northeast of Tetouan during the Pliocene.

The depositional filling is made up by three members comprising two sedimentary cycles: the first cycle represented by the Member 1, and the second cycle composed by the Members 2 and 3.

The basal Amusium-bearing marls (Member 1), newly dated here as early Zanclean thanks to planktonic foraminifers, correlate well with marly deposits of the same age in the Spanish Malaga basin (Pl-2 unit). They proved to have been deposited in an inner marine shelf under a relatively high-rate marly regime as pointed out by the *Ophiomorpha* burrows. Such a deposit typically corresponds to late highstand conditions after a previous transgressive phase, whose deposits do not outcrop. The channel structure at their upper levels corresponds to a regressive deposit and the erosional surface on its top indicates a sequence boundary.

The Member 2 that onlaps the preceding erosional surface represents a transgressive phase of a new cycle. The *Thalassinoides* burrows and the successive Fe-crusts intercalations indicate repetitive omission-related firmground conditions. The subsequent regressive phase (Member 3) did not result in the returning of the marly deposition, but in the progradation of fan-delta red conglomerates.

The fact that the Malalyine succession can closely be compared with its Spanish equivalent well developed in the Pliocene Malaga basin, allows framing the studied sedimentation in the Zanclean. The absence of biostratigraphically significant fossils in Members 2 and 3 results in a undetermined age for these deposits. The Member 3 recall to the Villafranchian red conglomerates widespreading in the Atlantic Rahrb basin. But similar deltaic conglomerates overlying early Zanclean marly sediments are found at the Malaga basin still below of the *G. puncticulata* first occurrence datum (Pl-3 unit). This second option seems in accordance with the gradual transition between the Members 2 and 3. As in Malaga basin the end of Pliocene sedimentation in the region of Malalyine could be related to the sea level fall of about 25 m, within TB 3.4 cycle, which occurred in 4.6 Ma, slightly before of *G. puncticulata* datum (4.52 Ma). Thus, these two sedimentary cycles of the Malalyine succession correlate with the Pliocene I of the eastern Betic basins.

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