Regional correlations across the Internides–Externides front (northwestern Rif Belt, Morocco) during the Late Cretaceous–Early Burdigalian times: palaeogeographical and palaeotectonic implications

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Abstract: New insights into the palaeogeographical evolution of the Rifian Internides and their external surroundings are inferred from six key stratigraphic successions selected across the Internides–Externides front. These successions span a time interval ranging from the late Cretaceous to the early Burdigalian. The main results are: (1) important lost palaeogeographical domains should be located during the late Cretaceous–Eocene between the present-day Ghomarides and the Dorsale Calcaire, on one hand, and between the Predorsalian units and the Flysch Trough as isolated carbonate platforms, on the other hand; (2) during the late Eocene–early Oligocene an extensional tectonic event, well marked in the Dorsale Calcaire, caused the collapse of these platforms and resulted in olistostromes and coarse-grained breccias in both the Predorsalian and the Béni Ider areas; (3) by the beginning of mid-Oligocene, an overturning contractional event in the Ghomarides resulted in the regional onset of the siliciclastic depositional regime throughtout these palaeogeographical areas; (4) during the Aquitanian–early Burdigalian, the stepwise return of pelagic deposition in the Ghomarides indicates extensional phases, whereas the homogenization of the same pelagic facies over the Dorsale Calcaire and its external surroundings may indicate that the previously distant palaeogeographical areas were brought nearer (i.e. just before large-scale thrusting).

The Gibraltar arc consists of two juxtaposed structural domains: (1) the Internal Domain, (Internides) where the orogenic contractions started from Oligocene time and generally resulted in high-grade metamorphism, particularly in its innermost part; (2) the External Domain (Externides), where the outward migrating orogenic contractions during Miocene time progressively produced piggyback–foredeep basins and ramp-anticline structures. The culmination of these phenomena during the paroxysmal phase resulted in a high accretionary prism and successive large-scale gravitational processes (Chalouan et al. 2006).

The Tertiary sedimentary filling within and/or close to these forming basins was differently interpreted in both domains. Whereas there is acceptance that the filling of the main flysch depocentres in the External Domain occurred shortly before the paroxysmal nappe emplacement, or even as syntectonic deposits, competing hypotheses were presented for the equivalent strata in the Internal domain. Some workers attempted to link them to post-orogenic deposits transgressively sealing the paroxysmal structures (e.g. Durand-Delga et al. 1993), whereas others considered them as recording a near-continuous marine regime entirely predating the main orogenic events (e.g. Maaté 1996). Recently, detailed stratigraphic studies of the Oligo-Miocene cover were carried out in the Malaguides (Guerrera et al. 1993; Martin-Martin et al. 1997) and the Ghomarides (Feinberg et al. 1990; El Kadiri et al. 2000, 2001). They showed that the

Oligo-Miocene sedimentary cycles were episodically induced by extension-related marine encroachments punctuating contractional events during a polyphase tectonic scenario (Comas et al. 1992; Garcia-Dueñas et al. 1992; Chalouan et al. 1997).

The aim of this paper is to extend this approach to time-equivalent depositional series belonging to both sides of the Internide–Externide front (i.e. the Dorsale Calcaire, Predorsalian and Béni Ider series). Some of the studied series are newly dated and/or described herein. Good examples are provided by: (1) the Dradia–El Onzar and Talembote sections in the Ghomaride Domain; (2) the Hafat Srir section in the Dorsale Calcaire; (3) the well-exposed Tamezzakht succession (located in the Predorsalian zone) that belongs to this frontal zone, to which special attention will be paid here. Its extended time-range (from the late Cretaceous the early Burdigalian), gravity-flow events, and well-delineated discontinuities are used to monitor regional-scale correlations across the Internal–External Domains (see El Kadiri et al. 2005, for detailed sedimentological data).

The general interest of this approach is to promote the correlation between the internal and the external zones in deciphering the tectonic and/or eustatic significance of their coeval deposits. Thus, these two domains can no longer be taken as two independent geological realms when reconstructing the tectonosedimentary evolution of the Gibraltar arc evolution.

Geological background

The Rifian Internal zones (Fig. 1) consist of a complex nappe pile resulting from the westward-vergent stacking of three distinct units: the Sebtides, Ghomarides and the Dorsale Calcaire.

The Sebtides consist of varied metamorphic nappes, including a granulitic–mantle ultramafic unit, which is underlain (Sebta massif) and overlain (Béni Bousera massif) by gneiss and schists of upper-crustal affinities. These in turn are overthrust or are overlapped by detached high-pressure–low-temperature metapelitic strata, mainly of late Palaeozoic–Triassic age (Federico units; Bouybaouène et al. 1995), a fact that supports the attribution of the Sebtide nappe emplacement to the Alpine orogeny. The ultramafic rocks of Béni Bousera essentially consist of spinel-bearing
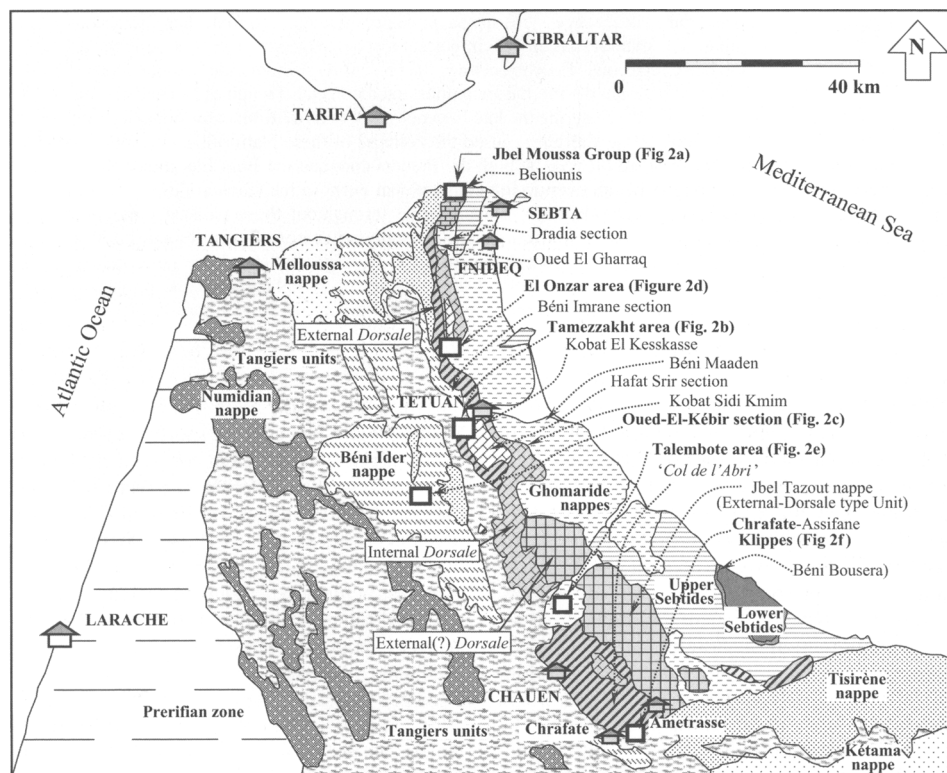

Fig. 1. Geological map of the northwestern Rif belt and location of the study areas (see Fig. 2 for details).

lherzolites. They were interpreted as a hot astheno-spheric dome (Loomis 1975; Platt & Vissers 1989) or conversely as pre-Alpine slivers uprooted from Precambrian infracrustal levels and emplaced in the upper crust (Kornprobst 1974). Integrated approaches including detailed structural field-survey (Reubert et al. 1982; Saddiqi et al. 1988) and geochronological analyses (Sanchez-Rodriguez & Gebauer 2000) showed that the lower Sebtide lherzolites were initially derived from a lithospheric mantle, and were subsequently emplaced as tectonic slivers within upper crustal levels. This scenario occurred in two main stages, during Tethyan rifting at about 183–131 Ma, and during Palaeogene subduction–collision (Chalouan et al. 2001; Michard et al. 2002). Geochemical data (Targuisti 1994), and even the stratigraphic record (El Kadiri et al. 1992, 1995), support the idea that the Béni Bousera–Ronda perido-tites derived from an asthenospheric dome, the ascent of which started as early as Mesozoic time (Sanchez-Rodriguez & Gebauer 2000). The conditions and kin-ematics of their final exhumation as well as of that of the surrounding metamorphic rocks are still a matter of debate (see, for example, the discussion by Balanya & Garcia-Dueñas 1987; Lonergan & White 1997; Azañon et al. 1998; Morales et al. 1999; Azañon & Crespo-Blanc 2000; Calvert et al. 2000).

The Ghomaride nappes (Kornprobst 1974; Chalouan 1986) generally thrust the Sebtides. They mainly consist of Palaeozoic schists, which compositionally resemble their Hercynian homo-logues known at present in the eastern Moroccan Meseta (Chalouan 1986), a fact that supports a palaeogeographical reconstruction in which they originally derived from an eastern domain, where they formed the westernmost part of the 'AlKa-PeCa' palaeoplate (Bouillin et al. 1986; Chalouan & Michard 1990; Guerrera et al. 1993). Lithofacies, metamorphism and the position within the nappe pile allow four main nappes to be distinguished (Chalouan 1986; Chalouan & Michard 1990).

The Dorsale Calcaire was first interpreted as cor-responding to the Alpine Ghomaride cover (Durand Delga et al. 1962; Kornprobst 1974) detached from its Palaeozoic basement during Tertiary thrusting. However, characterization of an independent Meso-zoic Ghomaride cover with respect to the carbonate Jurassic strata of the Dorsale Calcaire, on one hand (Maaté 1984, 1996; El Kadiri 1991; El Kadiri et al. 1992), and detailed stratigraphic analyses of the entire Mesozoic successions of both the Internal and the External Dorsale, on the other hand (Nold et al. 1981; El Kadiri 1984, 1991; Olivier 1984; El Hatimi 1991; Maaté 1996), led to the two latter being assigned to the palaeomargin bordering west-wards and/or southwards the Rif 'Internal zones'. This result appears in accordance with the concept of a 'Predorsalian zone' (Didon et al. 1973) that

palaeogeographically corresponded to the deepest part of this palaeomargin (e.g. Chrafate Klippes units, Assifane units, El Hatimi 1982; El Kadiri 1984; El Hatimi et al. 1988; Ben Yaïch et al. 1988). Triassic–earliest Jurassic, thick-bedded, shallow-water carbonate limestones make up the main massifs of the Dorsale Calcaire. They may be topped with polyphase palaeokarst surfaces in the Internal Dorsale (El Kadiri 1991; Maaté 1996) and with Fe-encrusted hardgrounds in the External Dorsale (El Kadiri 2002a,b).

In the Internal Dorsale, reduced pelagic series may diachronously onlap the massive carbonate formations. The most noteworthy of these are developed in rosso-ammonitico facies during the Domerian–Toarcian, and in Saccocoma- and/or Calpionella-rich mudstones during the Tithonian–Berriasian. A long-lasting palaeokarst history occurred in the intervening time span (El Kadiri 1991; El Kadiri et al. 1992), a feature that recalls the Mid–Late Jurassic 'Main Gap' found by Farinacci (1996, 2002) and Farinacci et al. (1997) in the Central Mediterranean Apennine areas. The most distinctive features of the External Dorsale are: (1) the rosso-ammonitico facies and cherty limestones, which can start as early as the Sinemur-ian (e.g. Arnioceras-rich strata, Fallot 1937; Griffon 1966); (2) the red and/or green radiolarites, the onset of which occurred as early as the Liassic–Dogger transition (El Kadiri 1984, 1991). For this reason, they were considered as being amongst the earliest continental-margin-related Jurassic, biosiliceous deposits in the Tethyan realm (De Wever et al. 1985). They continued until early Tithonian time (El Kadiri 1991).

In both Dorsale units, Cretaceous succes-sions recorded important hiatuses during the Hauterivian–Albian pro parte and the early Seno-nian, the best characterized ones being the Campa-nian and Maastrichtian Globotruncana-rich marly mudstones referred to as 'Capas Rojas' and 'Capas Blancas', respectively (El Kadiri 1991). Palaeogene successions consist of: (1) thin nodular black shales of Paleocene age; (2) varie-gated marl–nummulitic sand alternations of Eocene–mid-Oligocene age (Griffon 1966; Raoult 1966; Nold et al. 1981; Maaté et al. 1993; Hlila 1994, 2005; Maaté 1996); (3) micaceous rust-coloured sandstones, during the late Oligocene–(?)early Aquitanian.

Tectonically, the fact that the latter deposits are considered as being the youngest strata trapped between different slices (Nold et al. 1981) suggested a first phase of thrusting during the Aqui-tanian. Later, characterization of early Burdigalian marine strata involved in both the internal and external fronts of the Dorsale Calcaire (Feinberg & Olivier 1983; Ben Yaïch et al. 1986; Feinberg
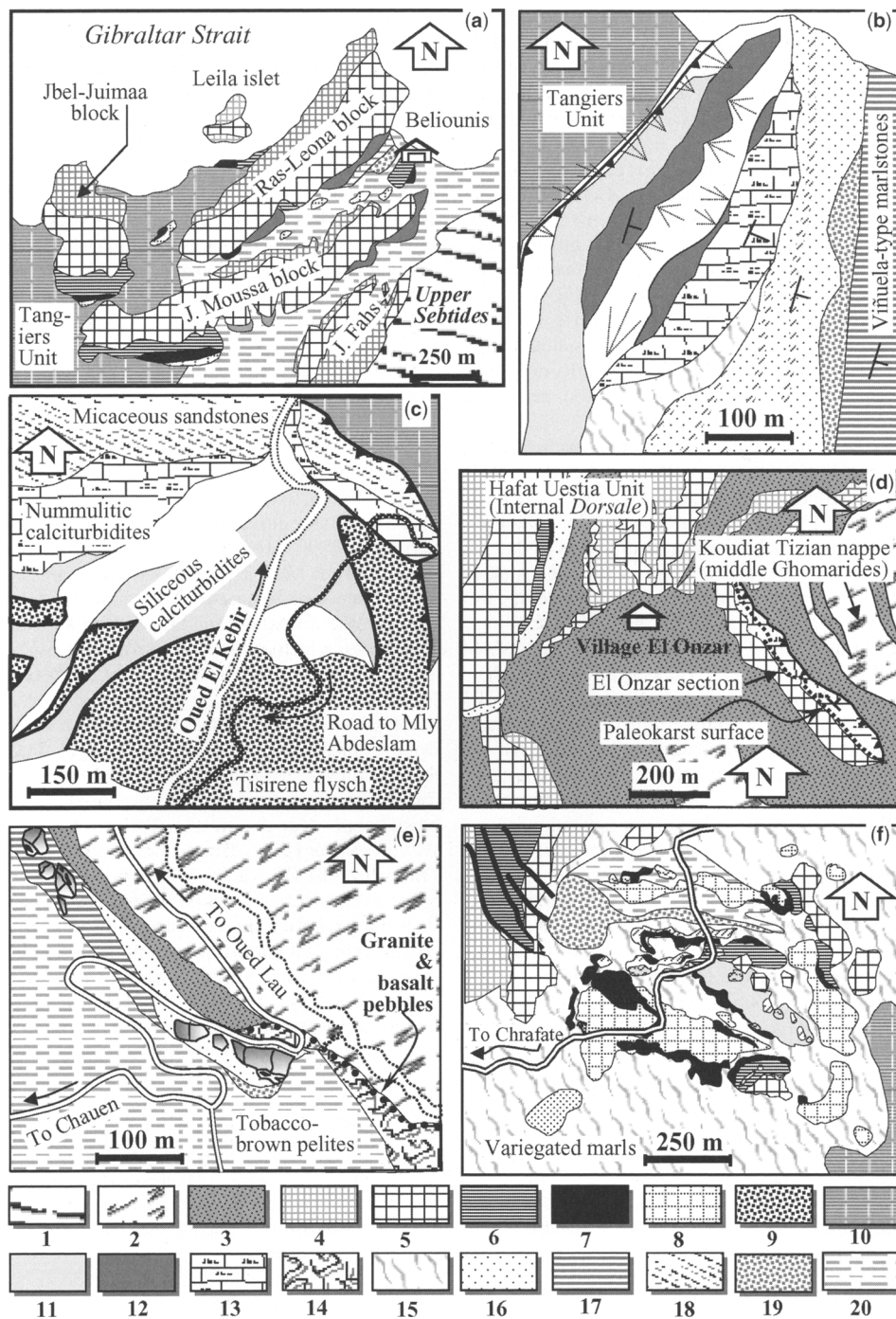
Fig. 2. Geological–structural setting of the areas including the investigated successions. (**a**) Jbel Moussa Group (modified from Kornprobst & Durand Delga 1985); (**b**) northern part of the Tamezzakht sector (this work); (**c**) main lithological components of the Mauretanian series cropping out the vicinity of the Oued-El-Kébir in the Béni Ider area (simplified from Didon 2006); (**d**) example of a residue of the karstified Ghomaride carbonate cover close to the Internal Dorsale (El Onzar succession, simplified from Raoult 1966); (**e**) Ghomaride siliciclastic cover in the Talembote area (simplified from El Kadiri *et al.* 2001), (**f**) western Chrafate Klippes, a good example of the Predorsalian olistostromes

et al. 1990; El Kadiri *et al.* 2001) led researchers to envisage a second phase, during which the whole Dorsale nappe pile underwent large-scale thrusting before being trapped between the Ghomaride terranes and the flysch—nappe domain. In some segments (Haouz chain), the latter event resulted in a double 'encapuchonnement' process (e.g. Raoult 1966; Hlila 1994, 2005), a kinematic scenario that explains the backthrusting and related fan-shaped structures.

The northern part of the Rif calcareous chain (Dorsale Calcaire) is occupied by the Jbel Moussa Group, which is dominated by four kilometre-scale juxtaposed tilted blocks (J. Moussa, J. Juimaa and Ras Leona and Leila) of a Jurassic continental passive palaeomargin (El Kadiri *et al.* 1990; El Hatimi 1991). All these blocks exhibit Triassic—early Cretaceous successions that strongly recall the Spanish Penibetics (Fallot 1937; El Hatimi 1991), the Gibraltar and Los Pastores massifs (Durand Delga & Villiaumey 1963), and/or the Southern Middle Subbetics (El Kadiri *et al.* 1990). The fact that the J. Moussa Group is thrust directly over the Tangiers units and its Spanish equivalents (Gibraltar and Pastores, both occurring in the external Campo de Gibraltar area), led Durand-Delga (1972, p. 274) to assign all these calcareous blocks to an external 'Cretaceous cordillera' separating the Mauretanian and the Massylian basins. This palaeogeographical setting proved to be identical to that proposed by Raoult (1974) for the Algerian 'Prekabyle basement'. Concurrently, Didon *et al.* (1973) defined the Predorsalian units as corresponding to a narrow basin externally bordering the Dorsale Calcaire units. It is noteworthy that the Predorsalian zone was characterized by the Aquitanian Numidian-like sandstones (the so-called 'Beliounis sandstones'), which were fundamentally defined in the J. Moussa Group itself. Thus, this Group implicitly bears the double definition of a

Predorsalian zone and an external ridge. The 'Tariquide Ridge' is herein used in the strict sense of a high palaeogeographical zone delivering shallow-water carbonate material (calciturbidites) to both the Predorsalian and the Mauretanian trough during the late Cretaceous—early Oligocene.

The External zones are dominated by large-scale 'parautochthonous' terranes (the Tangiers, Ketama and Loukous units, mainly), and their overriding sandstone—flysch nappes. These in turn may thrust each other along well-delineated parallel structures, which act as the topographical lines of the Gibraltar arc. Although palaeogeographical reconstructions of the External zones still remain a subject of debate, especially for the Mesozoic, there is agreement that their tectonosedimentary evolution during the Tertiary was primarily conditioned by piggy-back basins and ramp-anticline structures, both generated by deep detachment planes (e.g. Morley 1987, 1988, 1992; Ben Yaïch 1991).

Close to the internal border, the External Domain (the so-called Intrarif) was strongly deformed so that its parautochthonous units locally show schistosity (Andrieux 1971; Frizon de Lamotte 1985) and the flysch successions were totally uprooted. The deformation style is predominantly characterized by duplex structures and imbricate slices.

Stratigraphic reconstructions carried out mainly by Durand-Delga (1972) and Durand Delga & Didon (1984*a,b*) led researchers to recognize the two main flysch successions previously defined in the Kabylian domains (Bouillin *et al.* 1970): (1) the Mauretanian series, which includes in its lower half the Tisirène early Cretaceous calciturbidites and holoquartzous sandstones, and in its upper half the Béni Ider late Cretaceous—Aquitanian calciturbidites and micaceous sandstones; (2) the Massylian series, which may encompass in a single stratigraphic column the Barremian—Albian olive—green sandstone flysch (Massylian *sensu*

Fig. 2. *Continued.*   (simplified from El Kadiri 1984). 1, low-grade-metamorphosed Triassic strata (Federico units, upper Sebtides); 2, Palaeozoic schists; 3, Verrucano-type Triassic red sandstones; 4, late Triassic dolomites; 5, earliest Liassic massive limestones; 6, mid- to late Liassic pelagic successions (cherty limestones and/or rosso-ammonitico facies); 7, mid- to late Jurassic red radiolarites; 8, latest Tithonian—Berriasian *Aptychus*-bearing calciturbidites; 9, Aptian—Albian, thick-bedded, fine-grained sandstones (Tisirene flysch); 10, carbonate-poor, green pelites (Tangiers units, Campanian—Maastrichtian mainly); 11, Campanian—Maastrichtian (mainly) calciturbidites of the Mauretanian series and the Chrafate Klippes; 12, *Microcodium*-bearing Paleocene calcarenites; 13, Nummulite-rich, white massive grainstones (El Onzar succession, (d)) and calciturbidites (Tamezzakht and Oued-El-Kébir areas; (b) and (c), respectively); 14, late Oligocene chaotic mixture of the Talembote area, reworking Triassic strata, with a basal coarse-grained conglomerate rich in granite and basalt pebbles; 15, latest Eocene—mid-Oligocene variegated marls with large-scale olistoliths, particularly in the Predorsalian zone; 16, late Oligocene—Aquitanian yellow soft marls with large-scale olistoliths inherited from Triassic and Eocene massive carbonates (Tamezzakht and Talembote successions, (b) and (e), respectively); 17, early Burdigalian Viñuela-type green pelagic marlstones with similar large-scale olistoliths (in Tamezzakht and Talembote areas); 18, late Oligocene—early Burdigalian micaceous sandstones (the so-called 'Béni Ider' Flysch); 19, late Oligocene—Aquitanian holoquartzose yellow sandstones (the so-called 'Beliounis' sandstones); 20, early Burdigalian, carbonate-poor, tobacco brown pelites and holoquartzose tobacco brown channelized sandstones (Talembote and Chrafate Klippes).

stricto) and the late Oligocene–Aquitanian Numidian sandstones. However, in the latter case upper Cretaceous transitional strata are not yet clearly characterized.

On the whole, these flysch series were used to define the Maghrebian 'Flysch Trough' (Didon *et al.* 1973; Bourgois 1978; Durand-Delga 1980; Martin-Algarra 1987), along which the Mauretanian flyschs were located, close to the AlKaPeCa palaeomargin (Bouillin *et al.* 1986). In contrast, the Massylian flyschs were located close to the African palaeomargin (e.g. Raoult 1974). In the Rif domain the latter palaeomargin is represented by the Jurassic terrigenous series (mainly 'Ferrysch' successions, Wildi 1981) known in the Mésorif and Prérif zones (e.g. compiled data of Ben Yaïch 1991; Benzaggagh 1996).

On the basis of the stratigraphic data given below, we shall see that the Flysch Trough can no longer be considered to be formed by a single, large-scale homogeneous basin, as the existence of external isolated platform(s) subdivided it into at least two elementary basins (see also El Kadiri *et al.* 2003).

Stratigraphic framework of the selected successions

Six study areas (Fig. 2) have been selected from the principal domains known in the Internal zones and the surrounding External ones, namely the Ghomarides, the Dorsale Calcaire, the 'Tariquide Ridge' and the Flysch Trough. Their stratigraphic successions are thoroughly reassessed (Fig. 3) and their possible juxtaposition during the early Burdigalian is outlined to better assess the sources of the carbonate clastic material. The Tamezzakht succession appears to be the most complete, as it spans a wide time-interval ranging from the latest Cretaceous to the early Burdigalian. Thus, it provides a rare opportunity to appraise a long-term tectonosedimentary evolution through a single stratigraphic column.

In the Ghomaride domain

The El Onzar and Dradia successions (Figs 2d and 3) crop out close to the Ghomaride–Dorsale boundary in the northernmost part of the Ghomaride domain, north of the city of Tetuan. They provide some of the best evidence known for the Ghomaride Eocene cover. In addition to the lithostratigraphic description and dating controls given by several workers (e.g. Raoult 1966; El Kadiri *et al.* 1992; Maaté 1996) and completed herein, we have found two complex discontinuity surfaces in these successions, at the very base of the Eocene strata and at their top.

In both outcrops, white nummulitic sandstones and Nummulite-rich massive grainstones rest on early Liassic white massive limestones after a conspicuous palaeokarst discontinuity (palaeokarst surface 1, Figs 2 and 3). This may indicate that the Ghomaride terranes experienced a protracted emersion history during the Mesozoic–Paleocene, resulting in the near-complete removal of their carbonate cover.

The stratigraphic top of the nummulitic white limestone bar (10–30 m) in turn shows an important palaeokarst surface (palaeokarst surface 2, Fig. 3). In some cases (El Onzar succession), karstic relief (small-scale kamenitzas and palaeo-sinkholes) is filled with red to brown sandstones made up of the 'en-echarde'-type quartz, which originated from pedological processes (Meyer 1987). An algal–*Discocyclina*-rich grainstone bed (0.10–1 m) transgressively rests on the palaeokarst surface. It is generally capped with a remarkable Fe-crust (Fe-HG, Fig. 3), from which bacteria-produced Fe-epigenesis processes (e.g. Préat *et al.* 2000; El Kadiri 2002*a*) may extend several decametres downwards into the host rock, which becomes rust coloured. Outcrop survey shows that this Fe-crust also may directly cap the underlying nummulitic bar when the transgressive *Discocyclina*-rich deposition is laterally lacking, as occurs in many transgressive deposits (e.g. lag gravel of Plint (1988), transgressive lag deposit of Fürsich *et al.* (1991), transgressive lags of Burkhalter (1995) and hiatal shell concentrations of Rivas *et al.* (1997), among others). Thus, the double discontinuity (palaeokarst + HG) at the top of the nummulitic bar may best be classified as a rock-ground surface in the sense of Clari *et al.* (1995).

Dating controls based on benthic Foraminifera lead us to assign the stratigraphic top of the nummulitic bar to the late Lutetian (e.g. Raoult 1974; see also Table 1, sample ONZ 5).

Yellow to rust-coloured marls (20–30 m) sharply overlie the Fe-hardground surface. In their upper half they contain fine-grained sandstone intercalations, which progressively dominate the depositional regime (see the possible interpretation below). They yield planktonic Foraminifera indicating a latest Lutetian–Early Bartonianage (Table 1, sample ONZ 10)

In the Talembote area (Fig. 2e) located 40 km south of the city of Tetuan close to the Internide–Externide front, decametre-scale sedimentary klippes are embedded within an Aquitanian–early Burdigalian siliciclastic matrix (Fig. 3). They exhibit an identical Liassic–Eocene stratigraphic succession with the same discontinuities and lithological components, and their presence here may have an important bearing on the palaeogeographical reconstructions (see below).
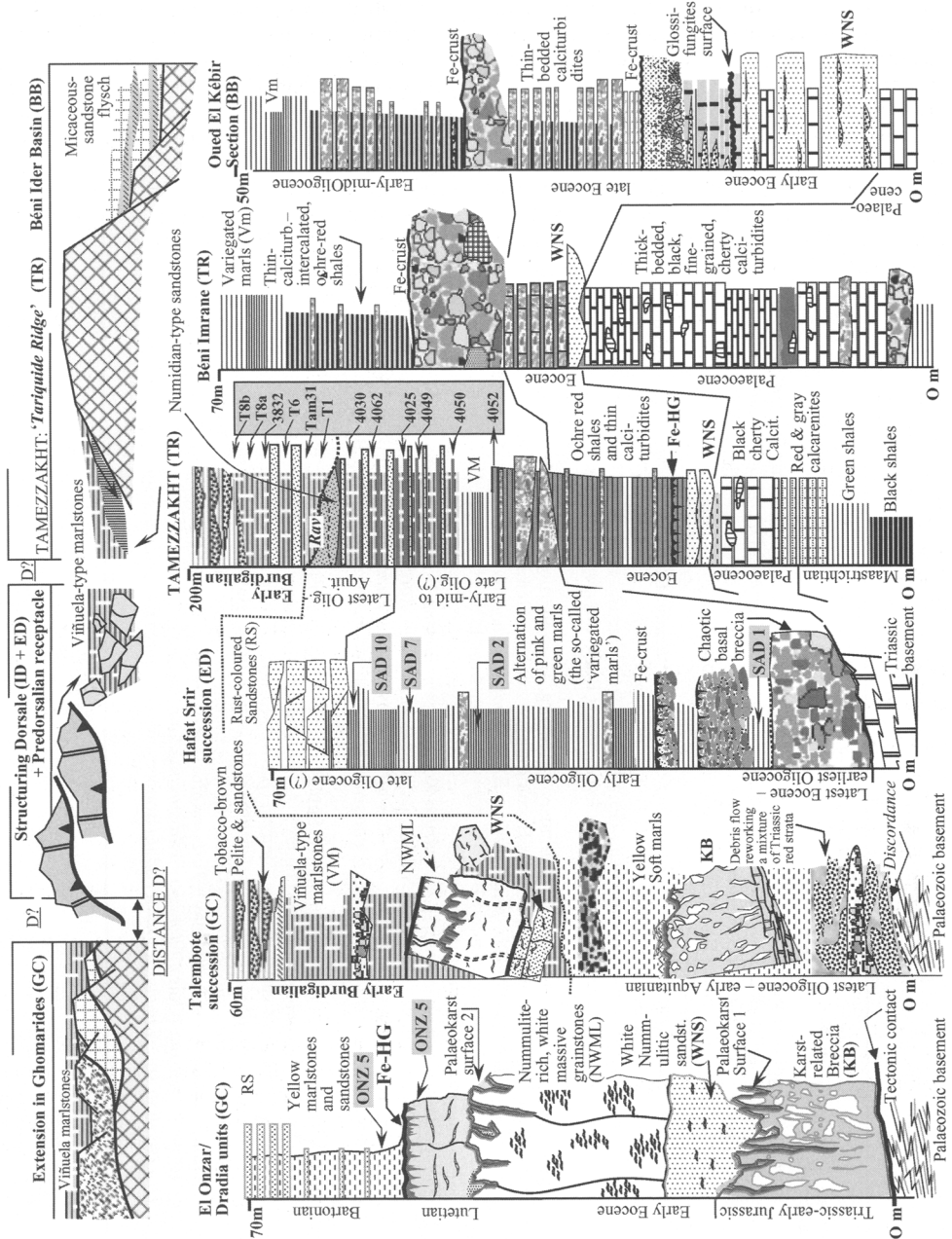
Fig. 3. Stratigraphic correlation of the studied successions, selected from distinct domains of the northwestern Rif belt: the Ghomaride domain (Dradia–El Onzar units, Talembote succession), the (Calcareous) Dorsale Calcaire (Hafat Srir succession) of the Internal zones; the Predorsalian fringe (Béni Imrane succession), and the Béni Ider area (Oued-El-Kébir section) of the External zones (see text for details). The upper part of the figure tentatively proposes a possible reconstruction of this scenario during the early Burdigalian, i.e. just before the orogenic paroxysm (the shortening distance D? remains uncertain). Grey shading indicates the sampling levels from which new biostratigraphic dates are given in Tables 1 and 2.

Table 1. *Foraminifera assemblages found in the El Onzar succession (Ghomaride Eocene cover) and the latest Eocene–mid-Oligocene Hafat Srir succession (Internal Dorsale south of the city of Tetuan)*

Sections samples and levels	Planktonic and benthic Foraminifera	Age
Hafat srir section (Internal Dorsale)		
SAD 10 (topmost level of the marly succession)	*Globigerina galavisi* Bermúdez, *G. tripartita* Koch, *G. ampliapertura* Bolli, *G. increbescens* Bandy, *G. venezuelana* Hedberg, *G. euapertura* Jenkins, *G. eocaena* Gumbel, *G. corpulenta* Subbotina, *G. praebulloides* Blow, *Globigerina ouachitaensis* H. & Wall, *G. ciperoensis* Bolli, *Neogloboquadrina opima* Bolli (?), *N. nana* Bolli, *Globorotaloides suteri* Bolli, *Catapsydrax unicavus* B. Loeb. & Tap., *C. dissimilis* Cush. & Berm	Late mid-Oligocene
SAD 7 (upper part of the marly succession)	*Globigerina galavisi* Bermúdez, *G. tripartita* Koch, *G. venezuelana* Hedberg, *G. euapertura* Jenkins, *G. ampliapertura* Bolli, *G. increbescens* Bandy, *G. angiporoides* Hornibrook. *G. eocaena* Gumbel. *G. corpulenta* Subbotina. *G. praebulloides* Blow, *G. ouachitaensis* H. & Wall. *G. ciperoensis* Bolli, *Neogloboquadrina nana* Bolli, *Globorotaloides suteri* Bolli, *Catapsydrax unicavus* Loeb. & Tap, *C. dissimilis* Cush. & Berm	Late early Oligocene
SAD 2 (middle part of the marly succession)	*Globigerina galavisi* Bermúdez, *G. venezuelana* Hedberg, *G. euapertura* Jenkins, *G. ampliapertura* Bolli, *G. increbescens* Bandy, *G. angiporoides* Hornibrook, *G. eocaena* Gumbel, *G. corpulenta* Subbotina, *G. ouachitaensis* H. & Wall, *G. praebulloides* Blow, *Neogloboquadrina nana* Bolli, *Globorotalia gemma* Jenkins, *Globorotaloides suteri* Bolli, *Catapsydrax unicavus* B. Loeb. & Tap, *C. dissimilis* Cush. & Berm, *Psuedohastigerina micra* (Cole)	Early Oligocene
SAD 1 (yellow-marl-intercalated basal breccias)	*Globigerina galavisi* Bermúdez, *G. tripartita* Koch, *G. venezuelana* Hedberg, *G. increbescens* Bandy, *G. eocaena* Gumbel. *G. corpulenta* Subbotina, *Globigerina praebulloides* Blow, *Globigerinatheka* subconglobata (Shut.), *Globigerinatheka index* (Finlay), *Globigerinatheka seminvoluta* (Keijzer), *Turborotalia cerroazulensis* Cole, *T. cocaensis* Cushman, *Globorotaloides suteri* Bolli	Latest Eocene
El onzar section (Ghomaride cover)		
ONZ 10 (lower part of the marl–sandstone alternation)	*Subbotina linaperta* (Finlay), *S. frontosa* (Subbotina), *S. inaequispira* (Subbotina), *Muricoglobigerina senni* (Beckman), *Acarinina primitiva* (Finlay). *A. broedemanni anapates* (Cus & ber.). *A. bullbrooki* (Bolli), *A. spinuloinflata* (Bandy), *A. cuneicamerta* (Blow), *Morozovella spinulosa* (Cushman), *M. lehneri* (Cush. & Jarvis), *Trucarotaloides topilensis* (Cushman), *T. pseudodubia* (Bandy), *Clavigerinella eocanica* (Nuttall), *Globigerinatheka subconglobata* (Shut.) *Globigerinatheka kugleri* (Bolli, Loeb. & Tapp.), *Globigerinatheka index* (Finlay), *Turborotalia pessagnoensis* (Tou. & Bol.), *Neogloboquadrina griffinae* Blow, *N. wilsoni* (Cole), *Globigerinella subangulata* Eugeno	Latest Lutetian to early Bartonian
ONZ 5* (stratigraphic top of the nummulitic bar)	*Discocyclina* sp., *Nummulites millecaput* (Boubee), *N. maximus* D'Archiac, *Assilina* sp., *Asterigerina* sp.	Late Lutetian

*Benthic Foraminifera.

The most noteworthy feature of the Talembote Tertiary succession is the facies contrast, which is well marked in the field, between its four sedimentary formations ranging from the late Oligocene to the early Burdigalian (El Kadiri et al. 2001, and Fig. 2e). For regional correlation, it is relevant to note the sharp facies change from the yellow soft marls of the second formation (latest Oligocene–Aquitanian pro parte) to the green pelagic marlstones of the overlying third formation (earliest Burdigalian). The former facies is particularly rich in planktonic Foraminifera (El Kadiri et al. 2001) and contains in its upper half spaced intercalations of yellow Alozaina-type sandstones, a facies widespread in the Aquitanian Malaguide cover and that of the northern part of the Ghomaride terranes. The second contains siliceous horizons and strongly recalls the Viñuela-type pelagic deposition (El Kadiri et al. 2001).

Various coarse-grained breccia flows are intercalated within the Talembote pelagic successions. All exhibit the same mixture of carbonate and metamorphic clastic material, with the ubiquitous Nummulite-rich and reefal boundstone blocks derived from a lost Palaeogene carbonate platform. Also ubiquitous are granitic and alkaline-basalt pebbles. The former were discovered in situ within the Carboniferous Marbella conglomerates, from which they are presumed to have been derived. In contrast, the origin of the alkaline basalts still remains unclear.

In the Internal zones of the Betic Cordillera, the coeval early Burdigalian Las Millanas–Viñuela Formation contains a basal conglomerate exhibiting the same clastic mixture. This may indicate that the source of supply was the same and had a wide palaeogeographical extent. Otherwise, it is relevant to note the presence, within the Spanish early Burdigalian conglomerates, of almost unaltered blocks and pebbles of the usual Alpujarride–Sebtide facies, namely peridotites and garnet gneiss. Such pebbles have not yet been discovered in the Ghomaride cover.

In the Dorsale Calcaire

In the Dorsale Calcaire the most pronounced discontinuity is delineated by the widespread late Eocene–early Oligocene Breccias Nummuliticas (Nold et al. 1981) that independently rest on normal-fault-denuded Triassic or Jurassic strata, which pinpoint a regional extensional event. The Hafat Srir section, cropping out in the northern part of the Internal Dorsale (south of the city of Tetuan), provides a good example of this: it starts with a 5 m thick, ungraded, coarse-grained nummulitic breccia bed (facies R1 of Lowe 1982; facies F3 of Mutti 1992) that directly reworks pedologically

pre-altered, rust-coloured Triassic dolomites. This basal breccia passes up into a thinning-upward alternation (c. 150 m thick) of pelagic marls and graded breccias. Well-developed Fe-crusts carpet near all the basal breccia beds. Yellowish pelagic marls, between them, yield planktonic Foraminifera indicating a latest Eocene age (Table 1, sample SAD 1). The overlying marly succession, which spans the early to mid-Oligocene interval (Maaté et al. 1993; Table 1, samples SAD 2, 7 and 10), comprises a rhythmic metre-scale alternation of carbonate-rich green marls and carbonate-poor pink marls, a fact that may be ascribed to cycles related to the calcite compensation depth (CCD) fluctuation, redox and/or productivity (Eicher & Diner 1991; Einsele & Ricken 1991). The Hafat Srir marly alternation may satisfactorily be used to interpret the origin of the widespread early to mid-Oligocene 'variegated marls' as the result of reworking and mixing by slope processes of the same kind of cyclic deposits.

These marly deposits are sharply overlain, after an erosive surface, by micaceous, wood-debris-bearing, rust-coloured sandstones, probably of late Oligocene–Aquitanian age (Hlila 2005). The onset of this siliciclastic depositional regime may be ascribed to a second extensional event, as shown by numerous synsedimentary normal faults. In thin section the rust colour is proved to be due to the presence of a large amount of pre-rubefaction, palaeosoil-derived carbonate clasts together with white and black quartz grains.

In the Predorsalian zone

The most representative successions of the Predorsalian zone crop out in the well-studied Chrafate klippe area (Didon et al. 1973; Lespinasse 1975; Nold et al. 1981; El Kadiri 1984, 1991; Olivier 1984; Ben Yaïch et al. 1988) where the early Oligocene 'variegated marls' (Fig. 2f) form decametre-to hectometre-scale sedimentary klippes, inherited from Dorsale-type lost units, and pass upward into late Oligocene–Aquitanian Numidian-like sandstones (i.e. Beliounis sandstones, Didon et al. 1973). These two stratigraphic components (olistostromes and sandstones) are separately known in the Internal domain and the External one, respectively. As part of this peculiar zone we would like to consider the Tamezzakht stratigraphic succession (Figs 1, 2b and 3), which also combines features separately known in the Internal domain and the External one. This succession displays in its lower half a late Cretaceous–early Oligocene calciturbidite–shale alternation, similar to that of the external Béni Ider series. In contrast, its upper half is chiefly made up of early to mid-Oligocene variegated pelagic marls and rust-coloured

sandstones. The latter are developed in the same Dorsale-type facies (see Table 2 for dating controls). They pass upward into late Oligocene–early Burdigalian pelagic deposits made up of yellow marls–green marlstone couplets identical to those previously described in the early Miocene Ghomaride cover. In addition, the intercalation within the late Oligocene–Aquitanian levels of the Beliounis-type sandstone facies supports the attribution of the Tamezzakht succession to the Predorsalian zone.

In thin section, the calciturbidite flows commonly reveal the presence of carbonate clasts, whose facies strongly recalls the Internal Dorsale Jurassic series, namely the shallow-water white massive grainstones (earliest Liassic) and the *Calpionella–Saccocoma*-rich mudstones (Tithonian–Berriasian). However, the interposition of the External Dorsale between the Internal one and the Predorsalian zone, on the one hand, and the proximal character of the calciturbidite discharges, on the other, lead us to suggest a distinct carbonate source with respect to the Internal domain. Palaeocurrent directions that we have measured on the bed surfaces of the calciturbidite interval are N70°–N80°, with the current flowing towards the internal zones (from WSW to ENE, i.e. from an external source). In the overlying siliciclastic interval the current direction is N20°–N60°, mainly N30°–N40°, flowing from SW to NE. Thus, the clastic material of the Tamezzakht succession could be sourced from an external lost terrane, a result that fits well with the 'Tariquide Ridge' hypothesis (Durand-Delga 1972) and recalls the Penibetic and/or Ultra-Internal Subbetic seamounts of the southern Betic Cordillera.

The most noteworthy feature of the Tamezzakht pelagic marly deposits (late Oligocene–early Burdigalian) is the rhythmic alternation of yellow soft marls and green marlstones. In the Ghomaride cover, both facies are strictly limited to the latest Oligocene–Aquitanian and the early Burdigalian, respectively.

Surrounding External Domain

Two Paleocene–mid-Oligocene successions with stratigraphic features similar to those previously described can be selected from the surrounding External Domain: the Béni Imrane succession, which crops out north of the city of Tetuan between the Predorsalian zone and the Tangiers unit, and the Oued-El-Kebir succession cropping out along the main river crossing the Béni Ider area, 25–30 km SW of the city of Tetuan (Fig. 2c).

Black, thick-bedded cherty mudstones rich in small planktonic Foraminifera (*Subbotina pseudobulloides* (Plummer) and *Planorotalites compressa* (Plummer)) of Paleocene age make up the lower

half of the Béni Imrane succession (*c.* 30 m). They can be accompanied by a channelized, coarse-grained basal division, which reveals that the black mudstones came from up-slope pelagic muds. They are sharply overlain by *c.* 5 m thick, thin-bedded calciturbidites with the sandy fraction being rich in penecontemporaneous Nummulites of Eocene age. Hence, there has been an important environmental change affecting the source area across the Paleocene–Eocene boundary, from exporting plankton-dominated muds into producing and shedding shallow-water-rich bioclastic sands together with an important lithoclastic fraction deriving from its carbonate substratum. A channelized white, Nummulite-bearing sandstone bed (WNS, Fig. 3) occurs in the intervening the stratigraphic levels. The latter facies also appears at the very base of both the Eocene deep-sea calciturbidites of the Tamezzakht succession and the Eocene shallow-water, limestone bar of the Ghomaride cover, a result that suggests key strata of regional correlation potential (WNS, Figs 3 and 4).

A 3–5 m thick, coarse-grained, poorly graded conglomerate bed sharply overlies the calciturbidite interval. It is covered with an Fe-crust and probably pinpoints the same extensional event that resulted in the latest Eocene–early Oligocene chaotic breccias in the Internal Dorsale and the Tamezzakht succession. The Béni Imrane Palaeogene series ends with a shaly interval (most probably of early to mid-Oligocene age, by comparison with dating controls obtained from Tamezzakht similar levels), made up in its lower half of ochre–red, lime-poor shales with thin intercalations of calciturbidites, and in its upper half of variegated marls.

The Oued-El-Kébir section exhibits the same lithostratigraphical features, particularly: (1) the WNS key strata; (2) the Fe-crust-capped, chaotic breccia overlying the Eocene calciturbidites; (3) the early to mid-Oligocene ochre–red shales, a facies well known in the remainder of the external Béni Ider area (the so-called 'flysch coloré').

Regardless of the relative palaeogeographical position of the Oued-El-Kébir section, the entire Palaeogene stratigraphic evolution outlined in the Internal domain and close to its border seems to have been strongly influenced by a neighbouring carbonate platform. By the beginning of the late Oligocene, the total disappearance of the clastic carbonate material was combined with the onset of the siliciclastic depositional regime. Thus, at that time, the supplying carbonate platform(s) was (were) probably destroyed and/or drowned under the siliciclastic accumulations. In both cases, the sharp contact between the early–mid-Oligocene calciturbidite-intercalated red shales and the late Oligocene sandstone-intercalated yellow marls may be regarded as a depth-equivalent of the

Table 2. *Foraminifera assemblages found in the upper half of the Tamezzakht succession (Predorsalian zone)*

Main facies and samples	Planktonic Foraminifera and Calcareous nannoplankton	Age
Viñuela-type marlstone-dominated alternation		
T 8b*	Helicosphaera carteri, H. kamptneri, Sphenolithus gr. abies/neoabies, Cyclicargolithus floridanus, C. abisectus, Reticulofenestra pseudoumbilica	Late early-Burdigalian
T 8a*	Helicosphaera carteri, H. kamptneri, Sphenolithus gr. abies/neoabies, Cyclicargolithus floridanus, C. abisectus, Reticulofenestra cf. pseudoumbilica	
3832 and 3822	Globigerina venezuelana Hedberg, G. praebulloides Blow, G. woodi Jenkins, Globigerinoides altiaperturus Bolli, Neogloboquadrina nana (Bolli), N. siakensis (LeRoy), Globoquadrina baroemoenensis (LeRoy), Globorotaloides suteri Bolli, Catapsydrax unicavus Bolli, Loeblich & Tappan, C. dissimilis (Cushman & Bermúdez)	Early Burdigalian
T 6*	Helicosphaera ampliapertura, H. scissura, Sphenolithus gr. abies/neoabies	
Tam 31*	Helicosphaera ampliapertura (small variety), H. carteri, H. kamptneri, Sphenolithus gr. abies/neoabies, Cyclicargolithus floridanus, C. abisectus	
T 1*	Helicosphaera ampliaperta (small variety), Discoaster druggii, D. deflandrii, Cyclicargolithus floridanus, C. abisectus, E. formosa	
Beliounis-type sandstones		
4030	Planktonic Foraminifera as in sample 4049, but with N. siakensis (LeRoy)	Aquitanian (?) to Late Olig.
Yellow-marl-dominated alternation		
4062	Planktonic Foraminifera as in sample 4049, but with N. siakensis (LeRoy)	Late mid-Oligocene
4025	Planktonic Foraminifera as in sample 4049	
4049	Globigerina galavisi Bermúdez, G. tripartita Koch, G. venezuelana Hedberg, G. euapertura Jenkins, G. ampliapertura Bolli, G. increbescens Bandy, G. eocaena Gumbel, G. corpulenta Subbotina, Neogloboquadrina opima (Bolli), N. nana (Bolli), Globorotaloides suteri Bolli, Catapsydrax unicavus Bolli, Loeblich & Tappan, C. dissimilis (Cushman & Bermúdez)	
4050	Globigerina galavisi Bermúdez, G. corpulenta Subbotina	
Nummulitic sand-intercalated red shales		
4052	Globigerina galavisi Bermúdez, G. venezuelana Hedberg, G. euapertura Jenkins, G. ampliapertura Bolli, G. prebulloides Blow	Early to mid-Oligocene

*Calcareous nannoplankton.

drowning–suffocation discontinuity in the sense of Schlager (1989, p. 7).

Petrographical evidence from the very base of the graded sandstone beds shows a mixture of basement-derived detrital fragments, namely, filonian-type quartz, schist, feldspar and micas. They are probably sourced from a tectonically raised, new source area(s). Regional correlations with both the External domain and the Internal one support such an assumption (see below).

Discussion: regional correlations

Figure 4 summarizes the facies contents of the palaeogeographical domains outlined in Figure 3, and highlights the recognized discontinuities (erosional, palaeokarstic and Fe-hardground-type surfaces) and the main calciturbidite and tectono-sedimentary events. It should be noted that the Tamezzakht succession appears to be the most complete, with its facies being more clearly contrasted in the field (El Kadiri *et al.* 2005). Its position in a transitional area between the Internal domain and the External one makes it a useful starting point for regional correlations. From the latest Cretaceous onwards the main lines of comparison are described below (see also Fig. 3).

The latest Maastrichtian–early Paleocene pelagic-dominated strata (black shales and reduced ochre–red shales, facies 5 and 6, respectively, Fig. 4) at the base of the Tamezzakht succession strongly recall their time-equivalent strata known in (1) the Dorsale Calcaire as Capas Blancas (facies 3, Fig. 4), made up of dark-coloured marl–limestone alternations (of Maastrichtian–(?)Paleocene *pro parte* age, Griffon 1966; El Kadiri 1991); (2) the Jbel Moussa Group in the facies of ochre–red and black, lime-poor shales of lower Paleocene age (facies 6b, Ras Leona and Taoura sections, El Kadiri *et al.* 1990); (3) the southernmost External Dorsale ('Col de l'Abri' section, Nold *et al.* 1981; El Kadiri 1984) in the facies of variegated to ochre–red lime-poor shales of Maastrichtian–(?)Paleocene *pro parte* age (facies 4). In contrast, the Maastrichtian–Paleocene strata in the Béni Ider area are represented by thick packages of mixed carbonate–siliciclastic turbidites (facies 7, El Kadiri *et al.* 2003), but within which intercalations of ochre–red lime-poor shales are a very common component.

The thick-bedded late Paleocene dark-coloured calciturbidites (facies 11) present a striking lithofacies analogue in the Béni Imrane area located 5 km NW of Tetuan, which may correspond to a lateral equivalent of the Tamezzakht succession. In the southern Dorsale Calcaire units Paleocene strata are generally poorly characterized and in most cases dating controls do not allow us to distinguish them from the underlying condensed late Cretaceous pelagic deposits or the overlying Eocene marly strata (Nold *et al.* 1981, p. 134). In its northern part, near the Kobat Sidi Kmim slice, a coarse-grained chaotic breccia (*c.* 15–20 m thick, facies 9) unconformably overlies a Campanian–Maastrichtian Capas Rojas–Capas Blancas pelagic series (facies 1 and 3). Dark-coloured marls intercalated between the basal breccia flows contain planktonic Foraminifera of late Paleocene age (El Kadiri *et al.* 2003). The most conspicuous example of Paleocene gravity-flow events was found in the J. Moussa Group: as noted by El Hatimi (1991) and El Kadiri (1991), its largest elements, of up 1 km in length (Ras Leona and J. Moussa Blocks), are partly embedded within ochre–red and black shales of Late Maastrichtian–Paleocene age (facies 12). All these Paleocene chaotic breccia were probably linked to regional tectonic pulses, as they form also a widespread key stratum in the Kabylian domain (e.g. Raoult 1974). In many places throughout the northern Dorsale Calcaire (Haouz Belt), Raoult (1966) noted a Paleocene age for the *Microcodium*-bearing calcareous sandstones (facies 10, Fig. 4), which transgressively overlie the massive carbonate formations. Ben Yaïch *et al.* (1986) and Hlila (2005) described and dated in the Oued El Gharraq section an interesting dark-coloured glaucony-rich, bioclastic level (*c.* 30 cm, facies 8), which transgressively erodes late Cretaceous 'Capas Blancas'-type strata, and lies at the very base of the white massive Nummulite-rich grainstones (facies 14b). Similarly, *Microcodium*-bearing calciturbidites characterize the late Paleocene calciturbidites in the Flysch Trough (facies 13).

Petrographical evidence from the Maastrichtian–Eocene Tamezzakht calciturbidites (facies 6–11) and from the Béni Ider Flysch Trough (facies 2, 7 and 13), show that the reworked lithoclasts were inherited from Triassic–early Jurassic, massive carbonate formations, mainly dolomites and white massive limestones, as well as from latest Jurassic–earliest Cretaceous pelagic series, namely *Calpionella*- and/or *Saccocoma*-rich mudstones. Complementary results have been obtained from equivalent late Cretaceous–early Oligocene calciturbidite strata of the Béni Ider area by Blumenthal *et al.* (1958), and recently by El Kadiri *et al.* (2003, 2006). Interestingly, such facies make up precisely the successions known in the Internal Dorsale units (e.g. Griffon 1966; Raoult 1966; Nold *et al.* 1981; El Kadiri *et al.* 1989; Maaté 1996) and the Jbel Moussa Group (El Kadiri *et al.* 1990). In contrast, lithoclasts derived from key facies of the External Dorsale (red radiolarites, *Aptychus*-rich mudstones) are lacking despite the fact that the
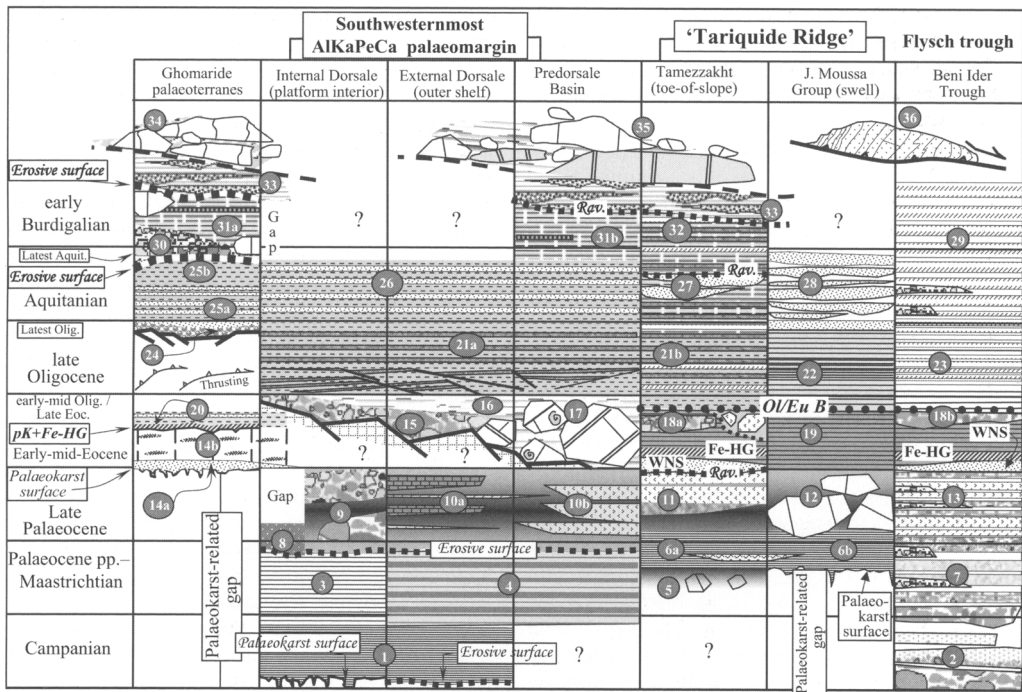
Fig. 4. Facies correlation and the tectonosedimentary events in the southwesternmost AlKaPeCa palaeomargin, the Tariquide Ridge and the Flysch Trough, based on selected data from: the Talembote area (Ghomaride terranes), Oued El Gharraq and Hafat Srir sections (Internal Dorsale), J. Lakraa, Hafat Nator, Saaden and Ametrasse—Bettara units (External Dorsale), Chrafate Klippes (Predorsalian domain), Beliounis and Ras Leona Klippes of the eastern part of the J. Moussa Group (Tariquide Ridge) and the Oued-El-Kébir successions (Béni Ider trough). 1, 'Capas Rojas'-type marlstones; 2, thick-bedded calciturbidites; 3, 'Capas Blancas'-type marlstones; 4, variegated marls (scaglia rossa facies); 5, black shales and resedimented blocks; 6, ochre—red marlstones and slope calcarenites in Tamezzakht (6a) and the eastern J. Moussa Group (6b); 7, calciturbidite—black shale alternation; 8, glaucony-rich bioclastic wackestones of the Oued El Gharraq section; 9, chaotic megabreccias and black shales (Kobat Sidi Kmim section); 10, black-shale pelagic limestone alternation (10a) and *Microcodium*-bearing turbidites and pelagic mudstone (10b); 11, *Microcodium*-rich, thick-bedded calciturbidites; 12, hectometre-scale olistoliths, i.e. eastern elements of the J. Moussa Group; 13, medium- to thick-bedded *Microcodium*-rich calciturbidites (late Paleocene); 14a, early Eocene, Nummulite-bearing white sandstones; 14b, Nummulite-rich massive white limestones; 15, latest Eocene—earliest Oligocene coarse-grained conglomerates (the so-called Breccias Nummuliticas); 16, variegated marls; 17, large-scale olistoliths embedded within the latest Eocene—early Oligocene variegated marls (i.e. Chrafate Klippes, Assifane blocks, etc.); 18a, 18b, coarse-grained calciturbidites and olistoliths; 19, ochre—red lime-poor shales (RSF); 20, yellow soft marls with thin intercalations of sandstones (Bartonian); 21a, micaceous, wood-debris-bearing, carbonate sandstones, i.e. the so-called 'Grès Roux' (late Oligocene—(?)early Aquitanian); 21b, 'Grès Roux'—micaceous sandstones alternation and yellow soft pelagic marls (mid- to late Oligocene); 22, green and yellow pelagic marls underlying the Beliounis sandstones; 23, thin-bedded micaceous sandstones and yellow marls; 24, holoquartzose puddingstones, with scarce granite pebbles (basal conglomerate of the Alozaina-type formation): latest Oligocene—early Aquitanian; 25a, yellow sandstone—marl alternation; 25b, yellow soft pelagic marls (late Aquitanian *pro paste*); 26, fine-grained yellow sandstones (Aquitanian); 27, channelized Beliounis-type sandstones (late Oligocene—Aquitanian); 28, Aquitanian Beliounis sandstones (cropping out in the village of Beliounis); 29, thick-bedded micaceous sandstones; 30, chaotic basal breccias and olistoliths containing a mixture of carbonate clasts as well as granite and basalt pebbles; 31, early Burdigalian Viñuela-type marlstones with thin chert levels, cropping out in the Talembote area (31a) and in the Predorsalian Chrafate Klippe zone (31b); 32, 'Grès Roux'—micaceous sandstones alternation and Viñuela-type marlstones (early Burdigalian); 33, tobacco brown pelites and Numidian-type sandstones (early to mid-Burdigalian) with resedimented blocks inherited from lost Ghomaride terranes; 34, chaotic complex reworking a mixture of blocks inherited from the Internal Dorsale and the Ghomaride cover; 35, chaotic complex reworking blocks from both the Internal and the External Dorsale; 36, nappe emplacement, probably triggered from late Burdigalian time.

latter domain was palaeogeographically placed between the Internal Dorsale and the Tamezzakht area. Thus, calciturbidites of the Tamezzakht succession (and those of the Béni Ider succession) are likely to have been derived from an external shallow-water high area and not from the neighbouring Dorsale Calcaire. Support is given to this assumption by the following three criteria. (1) Both the Internal Dorsale and the external Dorsale during this time interval were completely drowned, as is clearly shown by the three ubiquitous pelagic facies: 'Capas Rojas' (Campanian), 'Capas Blancas' (Maastrichtian) and black shales (mainly of late Paleocene age). In contrast, the petrographical evidence shows the abundance of rust-coloured, palaeo-altered clasts in the Béni Ider and Tamezzakht Paleocene calciturbidites, which indicates that this clastic material was reworked from an adjacent emerged area. (2) The east-moving slump structures in the late Cretaceous–Paleocene calcarenites point to east-dipping (towards the internal zone) palaeoslopes. (3) The palaeocurrent directions indicate currents flowing towards the internal domain and directed N70°E–N85°E, mainly N80°E.

In contrast to the late Paleocene black shales and *Microcodium*-bearing pelagic black mudstones of the Dorsale Calcaire (facies 9 and 10a) the coeval thick-bedded black calciturbidites of the Predorsalian (facies 10b), Tamezzakht (facies 11) and Béni Ider series (facies 13) are almost exclusively made up of *Microcodium* crystal grains. The *Microcodium* colonies (originally defined by Glück 1912) are known to correspond to microbial mats 'decaying' limestones on palaeosoils (Freytet 1970; Bodergat 1974) and palaeokarst surfaces (Meyer 1987; El Kadiri et al. 1992). Thus, the latter *Microcodium*-rich calciturbidites were sourced from large-scale emerged karstic areas, which cannot be envisaged in the Dorsale Calcaire, as the latter was totally drowned during Campanian–Paleocene times (El Kadiri et al. 1989, 1992). It is noteworthy that the basinward export of the greatest volume of *Microcodium* material was mostly triggered during the late Paleocene transgressive regime (compare the. 'transgressive washing' process described by El Kadiri et al. 2006).

These important results are in accordance with the 'Tariquide Ridge' hypothesis of Durand-Delga (1972), which postulates that an isolated pelagic platform should be reconstructed in the northernmost part of the External zones (i.e. Jbel Moussa Group). The above-mentioned petrographical data strongly suggest that the 'Tariquide Ridge' would have had an important southward prolongation in the external zones and therefore would have separated the Predorsalian zone from the Mauretanian Flysch Trough during Jurassic–early Oligocene times. Thus, the Predorsalian zone significantly

differs from the initial Predorsalian scheme of Didon et al. (1973) and Olivier (1984) who reconstructed the Predorsalian as a narrow transitory palaeogeographical zone directly connected to the external Flysch Trough. The scheme proposed here may explain why the Predorsalian zone did not receive the widespread early Cretaceous sandstone flysch (i.e. Tisirene flysch). Interestingly, the fact that the Predorsalian series received intercalations of Numidian-like sandstone flysch during latest Oligocene–Aquitanian times may indicate that an important tectonic event occurred during the mid- to late Oligocene and resulted in the disappearance of the so-called 'Tariquide Ridge'. We shall see below that this turning event: (1) was immediately preceded by large-scale resedimentation phenomena (latest Eocene–early Oligocene), partly reworking the material of the above-mentioned ridge itself; (2) was coeval with the onset of the widespread micaceous sandstone flysch (i.e. Béni Ider flysch), which indicates a tectonically raised new clastic source.

At present, late Cretaceous–Paleocene marine strata are unknown in the Ghomaride domain (Maaté 1984, 1996; El Kadiri 1991). In almost all the patched outcrops of the carbonate cover, discovered in this domain, white Nummulite-bearing carbonate sandstones (WNS, Fig. 3) of earliest Eocene (Illerdian) age (facies 14a, Fig. 4) directly fill the karstic cavities developed in the Liassic carbonate successions (e.g. El Onzar unit, El Kadiri et al. 1992). It is noteworthy that all the early Eocene transgressive shallow-water limestones at present known in the Ghomaride domain are never found directly discordant on the Palaeozoic schists. The fact that they are fundamentally linked to early Jurassic strata (e.g. El Onzar and Talembote sections, Fig. 3) and frequently occur as olistolithes within the Alozaina- and Viñuela-type Tertiary formations (e.g. Talembote section, Fig. 3), strongly suggests that these fragments of the assumed early Eocene 'Ghomaride cover' were originally derived from Ghomaride-like lost terranes and not from the at present defined Ghomaride units. A similar conclusion may be inferred from the basal conglomerates of these two Tertiary formations (El Kadiri et al. 2001; Hlila 2005) and from coeval conglomerates overtopping the Tertiary Ametrasse unit (southern external Dorsale, Nold et al. 1981; Hlila 2005), which are, in both cases, rich in granite, basalt pebbles and reefal blocks of unknown origin. The fact that these conglomerates preferentially occur close to the Ghomaride–Dorsale contact (e.g. Talembote, Béni Maaden) and within the Dorsale Calcaire itself, strongly suggests that their source was located between the Ghomaride terranes and the Dorsale Calcaire.

Regarding the successive transgressive peaks shown in the long- and short-term eustatic curves by Haq et al. (1987) and Hardenbol et al. (1998, charts 1 and 2), the late Cretaceous–Paleocene transgressive peaks were markedly higher than those of Eocene times. This leads us to suggest that: (1) the Ghomaride realm (sensu lato) experienced a long-term Mesozoic karstic regime (El Kadiri et al. 1992); (2) the onset of the Tertiary marine regime from the beginning of the Eocene was driven by a regional-scale tectonic collapse. Interestingly, equivalent transgressive Nummulite-bearing sandstones that developed in a strikingly identical lithofacies make up a metre-scale interval at the base of the Eocene calciturbidites in many sections throughout the Béni Ider area (Fig. 3). They can serve as key strata not only because of their high correlation potential, but also as they allow the onset of a transgressive regime to be delineated even within near-homogenous base-of-slope calciturbidite packages. In the Oued-El-Kébir section (Fig. 3) a conspicuous Thallassinoides-burrowed firmground surface (i.e. Glossifungites-type surface; e.g. Savrda 1995; MacEachern & Burton 2000; Savrda et al. 2001a,b) immediately follows the WNS facies, and probably marks the related transgressive peak.

Importantly, the same light-coloured carbonate sandstones exist in the Tamezzakht section. They clearly erode the lime-free siliceous green shales of the underlying facies (facies 11), upon which they unconformably rest along a low-angle hidden discontinuity (in the sense of Clari et al. 1995). Two Fe-encrusted surfaces cap the immediately overlying beds and may be regarded, in the same way, as corresponding to the consequent transgressive peak. Hence, the following thin-calciturbidite-intercalated ochre–red shales could normally correspond to the late highstand–lowstand regime, during which terrigenous-mud-dominated packages are the most common components (e.g. Savrda et al. 2001a).

Within the Tamezzakht succession, conspicuous grain-flow events occur in the upper part of the ochre–red shales of Eocene–early Oligocene age (facies 18a), probably close to the Eocene–Oligocene boundary. They laterally evolve into a discontinuous olistostrome-like formation, which can rest uncomfortably on the underlying strata of late Cretaceous–Paleocene age (facies 5 and 6). This collapse event may correlate with the regional-scale onset of chaotic breccias in both the Dorsale Calcaire (facies 15, Breccias Nummuliticas, Nold et al. 1981) and the Flysch Trough. In the former (e.g. Hafat Srir section, Fig. 3) they unconformably rest on the Triassic–Liassic massive carbonate formations and seal large-scale extensional structures (see also the geological maps of Kornprobst et al. 1975,

1979). In the second, chaotic breccias cap the Eocene calciturbidites before being buried under an ochre–red shale-dominated succession (facies 18b). In addition, El Kadiri (1984), De Wever et al. (1985) and Ben Yaïch et al. (1988) showed that the sedimentary Chrafate Klippes (facies 17), which represent the southernmost part of the Predorsalian domain, were embedded within variegated marls of latest Eocene–early Oligocene age (facies 16). Concurrently, the absence of coeval marine strata in the Ghomaride domain is noteworthy. Marine sedimentation seems not have returned before the onset of the widespread latest Oligocene transgressive holo-quartzose puddingstones (facies 24), which lie at the base of the Aquitanian yellow marl–sandstone alternation (facies 25, i.e. Ciudad-Granada–Fnideq Formation).

In the northernmost part of the Ghomaride domain, the Fnideq sandstones commonly seal normal faults at different scales, which points to a regional extensional event. In the Dorsale–Predorsalian couplet, the rust-coloured sandstones (facies 21a) that start shortly before, during the late Oligocene, also seal normal faults at different scales. A more comprehensive assessment of the regional-scale tectonic controls that might be proposed for the whole late Oligocene history needs to account for other time-equivalent events known throughout the whole Betic–Rif Internal zones, which is beyond the scope of this paper. It should be noted, for instance, that this extensional event in both the Ghomarides and Dorsale Calcaire occurred just after the mid- to late Oligocene paroxysmal phase that is well documented in the Ghomaride units (e.g. Chalouan 1986; Durand-Delga et al. 1993).

The abrupt facies change that is well delineated in the field between the 'oligotrophic' ochre–red shales (facies 19 in the Tamezzakht, J. Moussa and Béni Ider areas) and the 'eutrophic' green pelagic marls (oligotrophy–eutrophy boundary, Ol/Eu B, Fig. 4) is seemingly linked to the well-documented global-scale climatic change that occurred close to the Eocene–Oligocene boundary. It is evidenced by the turnover of planktonic Foraminifera (see examples by Molina et al. 1986, 1988, 1996, amongst others) as a result of a sudden global cooling event paired with enhanced ocean circulation (e.g. Pomerol 1985; Marty et al. 1988; Zachos et al. 1993, 1995; Diester-Haass & Zahn 1996; Barnes 1999). These climatic events were essentially induced by the immediately preceding tectonic collapses, which resulted in the opening and/or rearrangement of intercontinental seaways (e.g. between Antarctica and South America, Pomerol 1985; Wilson et al. 1998). Thus, the successions selected in this study provide an interesting record of such a twofold tectonic and climatic event: the coarse-grained

conglomerates (facies 15, 17 and 18) and olistos-tromes (facies 17) fit well with this scenario.

We would like to compare this Oligocene scen-ario with two strikingly near-identical events, which occurred close to the Jurassic–Cretaceous boundary and at the Turonian–early Senonian boundary, respectively. The former was recorded similarly by an abrupt facies change between the 'oligotrophic' ochre–red radiolaritic shales (late Jurassic) and the coccolith-formed yellow hemi-pelagic marls (late Tithonian–early Cretaceous). This is the Kuenen event (Roth 1989), which is known throughout the Tethyan realm to be similarly induced by a tectonic-mediated ocean-circulation intensification (De Wever et al. 1986; El Kadiri 2002b). In the latter case the early Senonian eutrophic green pelites sharply seal normal faults affecting the immediately underlying ochre–red Turonian shales and calciturbidites (El Kadiri et al. 2003). These examples support the causal link proposed above between tectonics and abrupt facies change. In the case of the onset of the early to mid-Oligocene eutrophic shales (Dorsale calcaire; Tamezzakht, Béni Ider), the related tectonic event may obviously be linked to the Ghomaride paroxysmal phase.

The rust-coloured sandstones (the so-called 'Grès Roux'; Fallot 1937; Griffon 1966) typify the late Oligocene siliclastic regime in all the stratigraphic series known in the Dorsale Calcaire (facies 21a) and last until the early Burdigalian in the Tamez-zakht succession (facies 21b and 32). Petrographi-cal evidence shows that this regime reworks a mixture of metamorphic-rock-derived, immature lithoclasts that do not seem to be sourced from the Rifian Sebtide–Ghomaride terranes or from their Betic counterparts. Their petrographical features seem to us similar to those described by Puglisi et al. (2001) in both the Tertiary Ghomaride cover and the time-equivalent strata in the Béni Ider flysch successions. About 10 palaeocurrent direc-tions measured on the sole of the sandstone beds indicate currents directed N20°–N60°, mainly N30°–N40°, and flowing from the SW to the NE (i.e. towards the internal domain from an external source). Thus, like the underlying calciturbidites, these sandstone flows could be sourced from (an) external lost terrane(s). Seemingly, the same may be true for the Dorsale-Calcaire 'Grès Roux', the sole of which gives evidence of north-flowing cur-rents (our measurements were taken in the Tamez-zakht area, i.e. in the Hafat Srir section along the road to the television mast). In the latter domain the current directions were probably modified by a near north–south-directed half-graben physiogra-phy. However, reconstruction of the late Oligo-cene–Aquitanian sandstone source(s) remains a hard task and requires more dating controls and careful regional-scale correlations (partly involving sedimentological and environmental data as a com-parison tool) throughout both the Internal and External zones. For instance, it is noteworthy that: (1) a tectonic event (i.e. the mid- to late Oligocene paroxysmal phase in the Ghomaride domain) could be responsible for the emplacement (and/or emer-gence) of new supplying terranes close to or partly on the previous nummulitic carbonate source, which resulted in its complete and irrevers-ible drowning under the siliciclastic accumulations; (2) the whole palaeogeographical setting was likely to undergo significant modifications (i.e. in placing together previously distant areas). Concurrently with the rust-coloured sandstones, this result may additionally be supported by the interlayered metre-scale micaceous sandstones, which undoubt-edly reflect the rise of another juxtaposed terrige-nous source.

In the Ghomaride domain, the chaotic, coarse-grained conglomerate lying at the very base of the early Burdigalian marlstones (i.e. Viñuela For-mation) is well documented in the Betic Internal zones as transgressively onlapping the Palaeozoic terranes (Sanz de Galdeano et al. 1993; Serrano et al. 1995; López-Garrido & Sanz de Galdeano 1999). These rocks erode the Aquitanian yellow pelagic marls of the underlying formation (Alozaina Formation) and could indicate a tectonically con-trolled collapse. This large-scale event resulted in the generalization of the siliceous marlstones of hemipelagic signature throughout the Betic–Rif Internal zones. The fact that this facies of high cor-relation potential makes up decametre-thick inter-vals in the upper third of the Tamezzakht succession (facies 32) and the Predorsalian units (facies 31b) leads us to the conclusion that the palaeogeographical setting of the latter external units became relatively close to the structuring of the Internal zones during the late Aquitanian–early Burdigalian.

With regard to the pelagic sedimentation regime, it seems possible that there are three lines of comparison between the Tamezzakht succession and that of the Talembote area recently described by El Kadiri et al. (2001) close to the Internide–Externide front (Fig. 3). (1) In the Tamezzakht area, the entire mid-Oligocene–early Burdigalian pelagic marly depo-sition develops in a rhythmic alternation of centimetre to decimetre intervals of yellow marls and 'early' Viñuela-type green marlstones, with the latter cyclic component being dominant in early Burdigalian time. In the Talembote area, these two facies are clearly separated in time as two contrasted lithologi-cal intervals, with an erosional discontinuity between them close to the Aquitanian–Burdigalian transition (see Fig. 3). Thus, the difference between the Tamezzakht pelagic deposition (i.e. close to the

External Domain) and the Talembote one (Internal Domain) may basically be related to the diachronism of the Viñuela-type marlstones. (2) Lithofacies and biostratigraphic dating allow us to distinguish in the Predorsalian domain two types of early Miocene holoquartzose sandstones: the first corresponds to the classical Numidian-like, yellow to rust-coloured sandstones (facies 27 and 28, Fig. 4) defined by Durand–Delga (1972) and Didon et al. (1973) in the village of Beliounis (J. Moussa Group) as characterizing the depositional regime of the Predorsalian zone during the late Oligocene–Aquitanian, (i.e. synchronously with the external Numidian flysch deposition). This facies, sometimes poorly consolidated, is generally poorly graded and all the quartz grains are rounded and may be white, red or black. Very similar yellow sandstones coevally spread over the Ghomaride–Malaguide domains (Fnideq and Alozaina Formations, respectively, facies 25a, Fig. 4). We have found identical facies within the late Oligocene–Aquitanian levels of the Tamezzakht succession, a result that lends additional support to ascribing the Tamezzakht area to the Predorsalian zone. The second type of sandstone facies corresponds to tobacco brown holoquartzose sandstones, in which the quartz grains may be rounded or not and are predominantly glass-green coloured. Individual beds may show graded bedding into fine pelites. This second sandstone facies strictly occurs within the tobacco brown pelites of early to mid-Burdigalianage (El Hatimi 1982; El Kadiri et al. 2001; Hlila 2005) and its distinction fits well with the early 'Neonumidian'-sandstone concept defined by Bourgois (1978) in the Internal zones of the Betic Cordilleras.

The upper levels of early Burdigalian tobacco brown pelites receive increasing gravity-flow discharges that evolve into huge olistostrome complexes carrying large olistoliths. These derived from either the Ghomaride–Internal Dorsale couplet (facies 34, example in the Talembote area) or the External Dorsale (facies 35; for the examples occur in Tamezzakht, Chrafate Klippes and Kobat El Kesskasse olistostrome) with Palaeogene variegated marly strata being trapped between them. The immediately superimposed Dorsale nappe pile may tentatively be considered as resulting from the culmination of the same phenomenon.

Conclusion

The aim of this paper was to provide a basis for synthesizing the more significant facies, discontinuities and gravity-flow discharges from the Rif Internal Domain and its surroundings. It seems that almost all the data point to tectonic events of regional or global scale. The above interpretation provides the three following results.

(1) Apart from certain widespread facies of high correlation potential, the late Cretaceous–early Oligocene strata studied above exhibit important differences, so that their respective depocentres should be located in distant palaeogeographical areas. We can retain the possibility that: (a) important Ghomaride-like lost terranes could be located between the present-day defined Ghomaride units and the Internal Dorsale; (b) symmetrically, one or several isolated carbonate platforms could be located within the external zones, i.e. 'Tariquide'-like ridge(s), which have played a major role in the source delivering, at a large scale, calciturbidites to the Predorsalian and Flysch basins.

(2) The relationship between the internal and the external zone, which has long been considered as being marked by a narrow transitional zone (the classical Predorsale concept), was likely to have involved more than a simple palaeogeographical area, as shown by the Chrafate klippes and the J. Moussa Group, which are remains of a wider and more complex area. The latter probably underwent successive palaeogeographical modifications with time. For instance, it should be noted that during late Cretaceous–Eocene times, the Predorsalian zone(s) were separated from the Flysch Trough by the above-mentioned 'Tariquide'-like ridge(s). The collapse and final disappearance of the latter occurred during the latest Eocene–early Oligocene, i.e. concurrently with (a) the disappearance of the external prolongation of the external Dorsale units (i.e. Chrafate Klippe olistostromes), (b) the onset of the Dorsale calcaire megabreccias (Breccias Nummuliticas) and (c) other large-scale gravity events (e.g. Talembote olistostromes).

(3) The major discontinuities, coarse-grained discharges and facies changes (e.g. newly raised sources) may be ascribed to distal reverberations of the contractional phases that occurred in the old Ghomaride realm during the early to mid-Oligocene–early Burdigalian time interval. The progressive homogenization of some key facies (rust-coloured sandstones, Beliounis and Neo-Numidian ones as well as the Viñuela-type marlstones) to previously distant palaeogeographical zones during Aquitanian–early Burdigalian times may be paralleled by the shortening processes that resulted in a new palaeogeographical setting.

However, reconstructing a reliable tectonosedimentary evolution requires new insights into the following issues.

(1) What was the triggering mechanism(s) of the chaotic, coarse-grained gravity flows? Despite these commonly occuring as deposits that transgressively

overlie previous emerged areas, their intercalation within and/or at the top of pelagic marly successions leads us to raise the question of contractional (nappe front) versus extensional (normal fault) tectonic controls. A eustatic signature cannot be excluded, as megabreccias are generally ascribed to lowstand phases (e.g. Haas 1999; Ineson & Surlyk 2000).

(2) What is the significance of the four Palaeogene–early Miocene formations (with discontinuities between them), well documented in the Malaguide–Ghomaride domain, in terms of eustatic controls (i.e. Exxon sequence) versus a tectonic one?

(3) What is the extent of the entirely disappeared palaeogeographical zones? Indeed, the clastic mixture reworked in the Alozaina and Viñuela formations (Betic Cordillera) and in their Rif counterparts, points to very extensive lost source areas. This leads us to question how far we can still maintain the classical scheme that immediately juxtaposes the Sebtides, Ghomarides, Dorsale, Predorsale and Mauretanian flysch?

(4) Was the kinematics of nappe emplacement determined by tectonic driving forces (subduction phases, Lonergan & White 1997; Chalouan *et al.* 2001) or by gravitational ones (Weijermars 1987; Doblas & Oyarzun 1989; El Kadiri *et al.* 1995)? A possible continuum process and/or causal link between them may tentatively be suggested in the case of the large-scale gravity flows proved to immediately precede the nappe-pile emplacement.

Integrated approaches involving sedimentology, sequence-stratigraphic interpretation, comprehensive inventory of sedimentary discontinuities, close biostratigraphic dating and detailed mapping, as well as more extended regional correlations, are expected to shed additional light on these issues, and are in progress.

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