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Timing of deformation in the Malaguide Complex of the Sierra Espuña (SE Spain). Geodynamic evolution of the Internal Betic Zone

M. Martín-Martín[1], B. El Mamoune[1], A. Martín-Algarra[1], J.A. Martín-Pérez[1] & J. Serra-Kiel[2]
[1]*Departamento de Estratigrafía y Paleontología, Facultad de Ciencias, Universidad de Granada, 18071 Granada, Spain;* [2]*Departament de Geologia Dinàmica, Geofísica i Paleontologia, Facultat de Geologia, Universitat de Barcelona, 08071 Barcelona, Spain*

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Abstract

New biostratigraphic data on calcareous nannoplankton and larger foraminifera of the Tertiary of the Malaguide Complex in the Sierra Espuña area show the presence of previously unknown Upper Eocene sediments. The timing of the deformation in the Malaguide Complex of the Sierra Espuña area is analysed, and a Late Oligocene to Late Aquitanian age is proposed for the main deformation.

Introduction

The Internal Zone of the Betic Cordillera may be divided into three tectonic complexes: the Nevado-Filabride Complex, formed by medium- to high-grade metamorphic rocks; the Alpujarride Complex, which overlies the Nevado-Filabride Complex and consists of low- to medium- grade metamorphic rocks; and the Malaguide Complex, the upper and mainly unmetamorphosed nappe complex of the zone.

The study of Tertiary deposits of the Internal Betic Zone is important for the reconstruction of the geodynamic evolution during the period in which the Betic-Rif Belt acquired its main tectonic features. The timing of deformation in the Malaguide Complex has been discussed and debated over the last three decades. In the Sierra Espuña area, an Eocene age for the main deformation was proposed by Paquet (1966a, b, 1968, 1969, 1970), while Hermes & Kuhry (1969), and later Mäkel (1985), suggested an Oligocene–Early Miocene age for the first important deformational event. Finally, an Eocene dating was supported by Lonergan (1991, 1993, Lonergan et al., 1994).

In the Vélez Rubio Corridor a post-Late Oligocene–Early Aquitanian, pre-Burdigalian (post-Ciudad Granada Formation, pre-Fuente-Espejos Formation) main deformation was suggested (Mac Gillavry et al. 1963, Soediono 1971, Geel 1973). In the western Betic Cordillera (Martín-Algarra 1987), and in the northern Rif in Morocco (Maaté et al. 1995), a Late Oligocene to Aquitanian main deformation was proposed for the Malaguide Complex. However, a pre-Late Oligocene dating for the main deformation is preferred by Olivier (1984), Feinberg et al. (1990) and Durand-Delga et al. (1993) for the western Betic Cordillera and the Rif.

Thus, the controversy in the Malaguide domain can be summarized as pre-Oligocene versus Oligocene–Aquitanian main deformation.

The aim of the present paper is to offer new litho and biostratigraphic data and detailed outcrop observations of the Malaguide structures in the Sierra Espuña area which support an Oligocene to Aquitanian dating for the main deformation.

The Tertiary of the Malaguide Complex of the Sierra Espuña

The Sierra Espuña represents the most complete Tertiary succession of the Malaguide Complex. We distinguish, from bottom to top, the following units (Figures 1, 2).

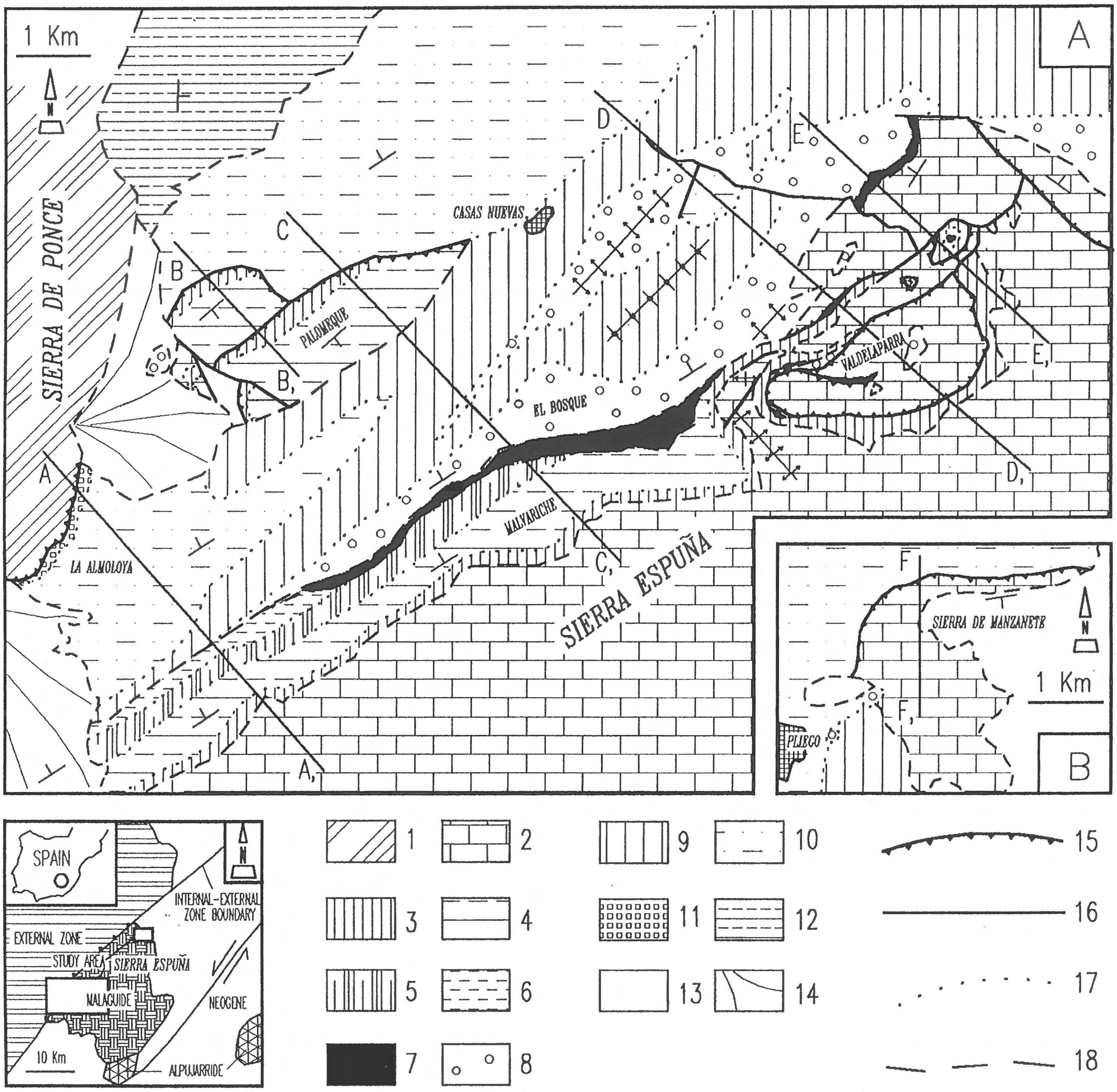

Figure 1. Synthetic geological map of Sierra Espuña and neighbouring areas. A) Sierra Espuña area. B) Sierra de Manzanete area. Key: 1: External Zone (Subbetic of Sierra de Ponce); 2: Malaguide Mesozoic; 3: Lower Eocene (Cuisian); 4: Middle Eocene (Lutetian); 5: Middle Eocene (Bartonian); 6: Upper Eocene (Priabonian); 7: Formation with quartz pebbles; 8, 9: Bosque formation, 8: conglomerates and algal limestones, 9: marls and calcarenites; 10: Río Pliego Formation; 11: Lower Burdigalian; 12: Middle Miocene; 13: Upper Miocene and Quaternary; 14: Alluvial deposits; 15: thrust; 16: fault; 17: conformable contact; 18: unconformity. A-A, to F-F,: see Figure 2.

Lower Eocene

The Lower Eocene sediments unconformably overlie the Mesozoic, and were informally called the '*Alveolina* Unit' by Lonergan (1991). This unit, however, does not consist only of *Alveolina* limestones, but of the following shallow-marine facies, all with numerous larger foraminifera:

a) *Cream-coloured sandy limestones* with: *Alveolina fornasinii* Checchia-Rispoli 1905, *Alveolina oblonga* D'Orbigny 1826, *Nummulites burdigalensis burdigalensis* De La Harpe 1926, *N. rotularius* Deshayes 1838, *N. planulatus* (Lamarck 1804),

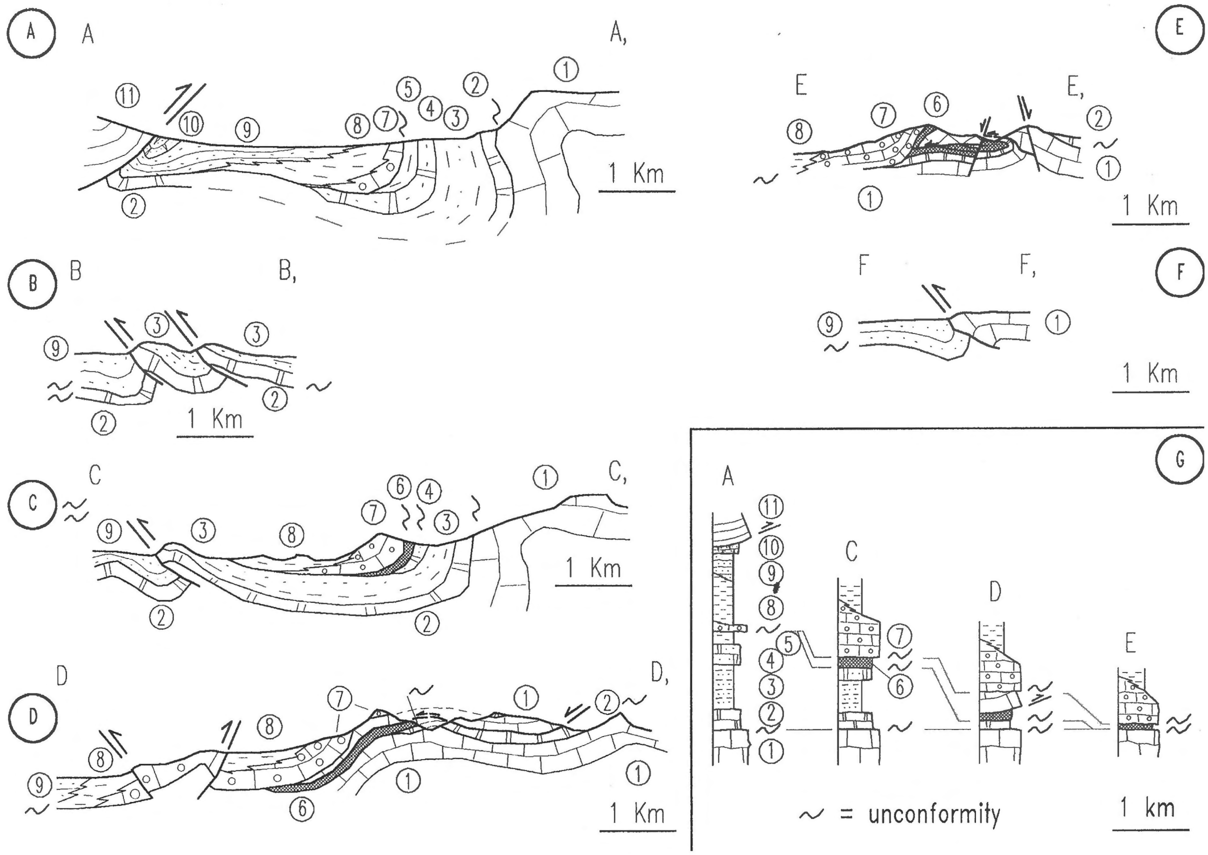

Figure 2. A to F) Cross sections of the Sierra Espuña and Manzanete areas (location in Figure 1). G) Stratigraphic columns of the sections in A, C, D and E. Key: 1: Malaguide Mesozoic; 2: Cuisian; 3: Lutetian; 4: Bartonian; 5: Priabonian; 6: Formation with quartz pebbles; 7, 8: Bosque formation, 7: conglomerates and algal limestones, 8: marls and calcarenites; 9: Río Pliego Formation; 10: Lower Burdigalian; 11: Subbetic Zone.

N. pustulosus Douvillé 1919, *N. escheri* Schaub 1981, *N. leupoldi* Schaub 1981, *Assilina placentula* (Deshayes 1838), and *A. plana* Schaub 1981. This association indicates an early Cuisian age according to the biozonations of Hottinger (1960) and Schaub (1981).

b) *Cream-coloured and white limestones* with: *Nummulites nitidus* De La Harpe 1883, *N. distans* Deshayes 1838, and *Assilina laxispira* De La Harpe 1926. This association indicates a middle Cuisian age (Hottinger 1960, Schaub 1981).

c) *Grey-blue marls and grey marly limestones with gastropodrich and lignite-bearing levels.* These types of sediments, described for the Malaguide Complex of the Málaga area in a recent paper by Serrano et al. (1995), are interpreted as lagoon to marsh deposits. In the Valdelaparra area, calcareous levels intercalated within these deposits, contain *Alveolina fornasinii* Checcia-Rispoli 1905 and other foraminifera that indicate a Cuisian age.

Middle Eocene

In the Middle Eocene sediments, which Lonergan (1991) informally called 'Malvariche formation', and which appear to overlie conformably the Lower Eocene (Figure 1A), we distinguish the Lutetian and Bartonian.

Lutetian

The Lutetian consists mainly of open-platform sediments:

a) Brownish to reddish calcarenites with numerous larger foraminifera. Four associations have been distinguished:

- Early Lutetian, with: *Nummulites lehneri* Schaub 1962, *N. verneuili* D'Archiac & Haime 1853, and *Assilina tenuimarginata* Heim 1908.
- Early Middle Lutetian, with: *N. aspermontis* Schaub 1981, *N. boussaci* Rozlozsnik 1924, *N. alponensis* Schaub 1981, *N.* aff. *millecaput* Boubée 1832, *N. hilarionis* Schaub 1981, *N. beneharnensis* De La Harpe 1926, and *Assilina* aff. *exponens* Sowerby 1840.
- Late Middle Lutetian, with: *N.* aff. *deshayesi* D'Archiac & Haime 1853, and *N.* aff. *tavertetensis* Reguant & Clavell 1967.
- Late Lutetian, with: *N. herbi* Schaub 1981, *N. deshayesi* D'Archiac & Haime 1853, and *N. praepuschi* Schaub 1981.

b) Pinkish to reddish marls with larger foraminifera, planktonic foraminifera and, especially, calcareous nannoplankton: *Braarudosphaera bigelowii* Deflandre 1947, *Coccolithus pelagicus* Schiller 1930, *Discoaster barbadiensis* Tan 1927, *D. binodosus* Martini 1958, *Sphenolithus furcatolithoides* Locker 1967, *S. moriformis* Bramlette & Wilcoxon 1967, *S. radians* Deflandre 1952, *S. spiniger* Bukry 1971, *Reticulofenestra dictyoda* Stradner & Edwards 1968, and *Zygrhablithus bijugatus* Deflandre 1959.

Bartonian
The Bartonian sediments conformably overlie the Lutetian (Figure 1A). They consist mainly of *pinkish to reddish bioclastic sandstones and calcarenites* with numerous larger foraminifera that indicate sedimentation in an open platform realm. Two larger-foraminifera associations can be distinguished:

- Early Bartonian, with: *Nummulites perforatus* De Montfort 1808, *N. praegarnieri* Schaub 1981, *N. beaumonti* D'Archiac & Haime 1853, *N. hottingeri* Schaub 1981, and *Assilina exponens* (Sowerby 1840).
- Late Bartonian, with: *Nummulites biedai* Schaub 1962 and *N. striatus* (Bruguière 1792).

Upper Eocene

Upper Eocene sediments were hitherto unknown in the Malaguide Complex. In the Sierra Espuña area, they crop out in a restricted area and conformably overlie the Bartonian (Figures 1A, 2A). They consist of open-marine, pinkish to yellowish marls and silts, and contain:

- Priabonian planktonic foraminifera (foraminifera zone P15): *Globigerina galavisi* Bermudez 1961, *G. tripartita* Koch 1926, *G. venezuelana* Hedberg 1937, *G. eocaena* Gumbell 1968, *G. corpulenta* Subbotina 1953, *G. gortanii* Borsetti 1959, *Globorotaloides suteri* Bolli 1957, *Catapsydrax unicavus* Bolli, Loeblich & Tappan 1957, *Globigerinatheka* sp. and *Turborotalia cerroazulensis* Cole 1928;
- calcareous nannoplankton (nannoplankton zones NP18–20): *Chiasmolithus oamaruensis* Mohler & Wade 1966 (Figure 3h), *Coccolithus pelagicus* Schiller 1930, *Dictyococcites bisectus* Bukry & Percival 1971, *D. scrippsae* Bukry & Percival 1971, *Discoaster barbadiensis* Tan 1927 (Figure 3n), *Helicosphaera compacta* Bramlette & Wilcoxon 1967 (Figure 3k), *Reticulofenestra umbilica* Martini & Ritzkowski 1978 (Figure 3g), *Sphenolithus moriformis* Bramlette & Wilcoxon 1967, *Sphenolithus radians* Deflandre in Grassé (Figure 3l) and *Zygrhablithus bijugatus* Deflandre 1959 (Figure 3m).

Formation with quartz pebbles

This formation consists of limestone conglomerates and shallow-water calcarenites containing abundant rounded quartz pebbles and numerous fragmented Eocene larger foraminifera. It corresponds to the 'Auversian sediments' of Paquet (1969, 1970), which should correspond to the Bartonian according to Cavelier & Pomerol (1986). Paquet (1969), and later Lonergan (1991), considered this formation to be unconformable and younger than the nappe emplacement in the area, whereas according to Hermes & Kuhry (1969) the formation conformably overlies the Middle Eocene, and is considered as pre-orogenic. Figure 1 and the cross sections of Figure 2 show that, in the Malvariche area, this formation progressively overlies the Priabonian, the Bartonian, the Lutetian, the Cuisian and, finally, the Mesozoic (Figure 2G). In the Valdelaparra area, however, the formation is clearly overthrust by Mesozoic carbonates (Figures 1A, 2D, E). Thus, the formation with quartz pebbles unconformably overlies the older deposits, but clearly pre-dates thrusting and nappe emplacement in the area.

In the formation, we found two Oligocene forms: *Lepidocyclina* sp. (Figures 3a–c) and *Halkyardia maxima* Cimerman 1969 (Figure 3e) together with numerous reworked Eocene forms (*Nummulites* ex gr. *perforatus* (De Montfort 1808), *Discocyclina* sp. (Figure 3d), *Asterocyclina* sp., *Gyroidinella magna* Le Calvez 1949, and *Fabiania cassis* (Oppenheim 1896)). The presence of lepidocyclinids in the absence of miogypsinids indicates, according to the zonation of Drooger & Laagland (1986), that this formation belongs to the late Early to early Late Oligocene, and not to the Eocene.

Bosque formation

The Bosque formation, informally defined by Lonergan (1991), consists of limestone conglomerates, algal limestones, yellow to whitish bioclastic calcarenites, and yellowish silty marls. It unconformably overlies the partially tectonized, older part of the Malaguide succession (Figures 1, 2D). Facies and fossil associations (see below) indicate sedimentation on a carbonate platform with a marginal fan-delta system for which the source area is located to the southeast (according to present-day coordinates).

The algal limestones contain larger foraminifera, including: *Lepidocyclina* sp., *Halkyardia maxima* Cimerman 1969, *Nummulites fichteli* Michelotti 1841, and *N. vascus* Leymerie 1848, which indicate according to Drooger & Laagland (1986) a late Early to early Late Oligocene age.

The silty marls contain two different Oligocene calcareous nannoplankton associations:

- At the bottom of the formation: *Dictyococcites bisectus* Bukry & Percival 1971, *Helicosphaera recta* Haq 1966, *H. euphratis* Haq 1966, *Sphenolithus predistentus* Bramlette & Wilcoxon 1967 (Figures 3i, j), and *Zygrhablithus bijugatus* Deflandre 1959. This association indicates an early Late Oligocene age (zones NP23 and NP24 of Martini 1971).
- At the top of the formation: *Coccolithus pelagicus* Schiller 1930, *Cyclicargolithus floridanus* Bukry 1971, *Dictyococcites bisectus* Bukry & Percival 1971, *D. scrippsae* Bukry & Percival 1971, *Discoaster deflandrei* Bramlette & Riedel 1954, *Helicosphaera bramlettei* Müller 1970, *H. euphratis* Haq 1966, *H. perch-nielseniae* Haq 1971, *H. recta* Haq 1966, *Ilselithina fusa* Roth 1970, *Pontosphaera multipora* Roth 1970, *Pyrocyclus orangensis* Backman 1980, *Sphenolithus ciperoensis* Bramlette & Wilcoxon 1967, *S. moriformis* Bramlette & Wilcoxon 1967, and *Zygrhablithus bijugatus* Deflandre 1959. This association indicates an Oligocene–Aquitanian boundary age (zone NP25).

Río Pliego Formation

The Río Pliego Formation was defined by Jerez-Mir (1979) and consists of pelagic reddish marls, clays, siltstones, turbiditic immature sandstones, and polygenic conglomerates constituted essentially by Palaeozoic and Triassic Malaguide clasts (Martín-Martín et al. 1996). Palaeocurrents indicate siliciclastic supply to the basin from the northwest (Martín-Martín 1996). The Río Pliego Formation laterally changes into the Bosque formation which unconformably overlies the older part of the Malaguide succession (Figure 2A). These two formations had opposite source areas, but were deposited in the same basin. The Río Pliego Formation was considered by Martín-Algarra (1987) as a syntectonic deposit belonging to his Ciudad Granada Group. Nevertheless, it was also thought to be a relatively post-nappe or a late-orogenic formation by Lonergan (1991, 1993).

In the Palomeque and Sierra de Manzanete areas, this formation is overthrust by Mesozoic and Paleogene Malaguide successions (Figures 2B, C, F). According to Martín-Pérez et al. (1994) the Río Pliego marls contain:

- At the bottom of the formation: *Dictyococcites bisectus* Bukry & Percival 1971, *Helicosphaera recta* Haq 1966, *H. euphratis* Haq 1966, *Sphenolithus ciperoensis* Bramlette & Wilcoxon 1967, *S. distentus* Bramlette & Wilcoxon 1967, and *Zygrhablithus bijugatus* Deflandre 1959. This nannoplankton association indicates the Upper Oligocene (zone NP24).
- At the top of the formation: *Cyclicargolithus abisectus* Wise 1973, *C. floridanus* Bukry 1971, *Helicosphaera euphratis* Haq 1966, and *Reticulofenestra gartneri* Roth & Hay 1967. This association indicates the Upper Aquitanian (zone NN1b of Martini 1971, emended by Martín-Perez et al. 1994).

In the Sierra Espuña area, the Río Pliego and Bosque formations represent the latest deposits of the Malaguide Complex. These are followed by a thin succession composed of white to greenish marls, sandstones and siliceous pelites (Figures 1A, 2A), which is early Early Burdigalian in age, and belongs to the Viñuela Group (Martín-Algarra 1987). In the study area, this succession lies conformably on the Río Pliego Formation. Regionally, however, the Lower Burdigalian lies unconformably on both the Malaguide and Alpujarride terrains. These terrains are overthrust by the Subbetic Zone, and pre-date the collision

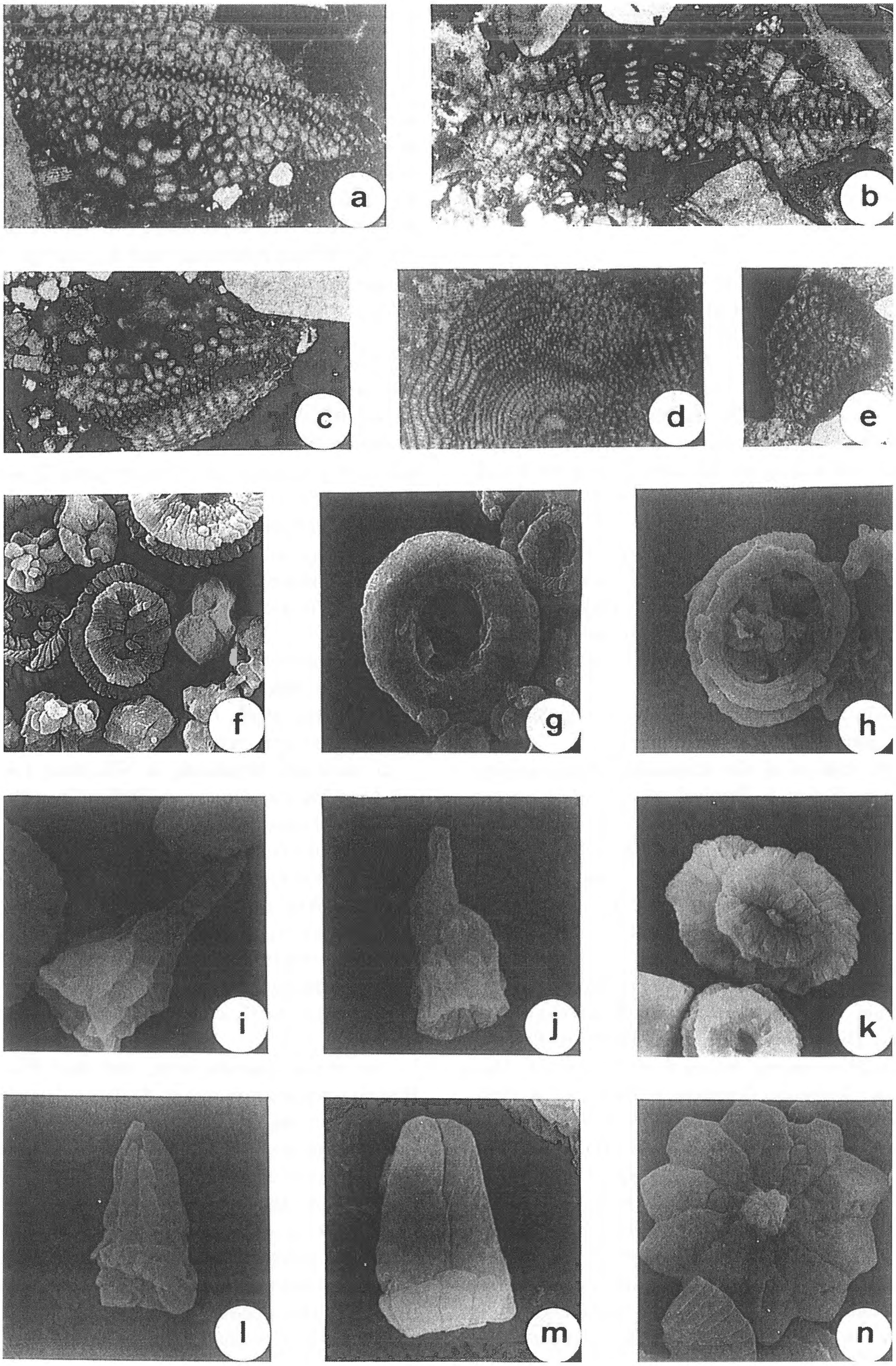
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Figure 3. Photos a to e) Larger foraminifera from the formation with quartz pebbles (all specimens are from the same thin section; sampled in Malvariche area, Figure 1A); a–c: *Lepidocyclina* sp. × 25 (Oligocene), a, b: oblique section; c: axial section; d: *Discocyclina* sp. × 25 (Eocene, reworked), equatorial section, slighly oblique; e: *Halkyardia maxima* × 50 (U Eoc–Oli), tangential section. SEM Images f to n) Eocene and Oligocene calcareous nannoplankton (sampled in Malvariche area); f: *Dictyococcites scrippsae* × 5000 (M Eoc–U Oli); g: *Reticulofenestra umbilica* × 3000 (M Eoc–L Oli); h: *Chiasmolithus oamaruensis* × 3000 (U Eoc–L Oli); i, j: *Sphenolithus predistentus* × 10000 (M Eoc–U Oli); k: *Helicosphaera compacta* × 6000 (M Eoc–U Oli); l: *Sphenolithus radians* × 10000 (Eoc); m: *Zygrhabilithus bijugatus* × 10000 (Eoc–U Oli) n: *Discoaster barbadiensis* × 60000 (Eoc).

between the Internal and the External Zone. Finally, late Late Burdigalian to Serravallian, white to yellowish marls and calcarenites (Figure 1A) sealed the Internal-External Zone Boundary and overlie unconformably both the Subbetic and the Río Pliego Formation (Martín-Martín et al. 1996).

Timing of deformation

The above data indicate that no major orogenic event can be recognized in the Sierra Espuña area before the late Early Oligocene. The formation with quartz pebbles that unconformably overlies the older part of the Malaguide succession was deposited before the Malaguide Complex began to fold and thrust. The first deposits that overlie the thrust structures are Upper Oligocene and belong to the Bosque formation (Figures 1, 2). Therefore, the *beginning* of the deformation must be early Late Oligocene.

On the other hand, in the Palomeque and Sierra de Manzanete areas, the Río Pliego Formation is clearly overthrust by Mesozoic and Paleogene Malaguide formations. These facts lead us to believe that deformations continued during deposition of the Bosque and Río Pliego formations, probably in piggy-back-like basins. Therefore, Late Oligocene to Late Aquitanian sedimentation in the area of the Malaguide Complex was contemporaneous with the end of the nappe emplacement of the Internal Betic Zone, as pointed out by Guerrera et al. (1993) and Martín-Martín (1996).

Conclusions

Previous stratigraphic work in Sierra Espuña (Paquet 1969, Lonergan 1991, 1993, Lonergan et al. 1994), in the western Internal Betic Zone (Durand-Delga et al. 1993) and in the northern Rif (Feinberg et al. 1990), favours a pre-Oligocene age for the Alpujarride metamorphism and the geodynamic evolution in the Betic-Rif Internal Zone (see also Platt & Vissers 1989). Nevertheless, in our opinion, the Malaguide Complex acquired its main tectonic features, and ended its emplacement in the uppermost part of the pile of nappes of the Internal Zone, during the interval between the late Early Oligocene and the latest Aquitanian. This evolution was synchronous with the end of the highest-temperature metamorphism in the lower units of the Internal Zone (higher Alpujarrides and Sebtides, Michard et al. 1983, Zeck et al. 1989), and is in good agreement with the data of other authors in Sierra Espuña (Hermes & Kuhry 1969, Mäkel 1985, Martín-Martín 1996, Martín-Martín et al. 1996), in the Velez Rubio Corridor (MacGillavry et al. 1963, Soediono 1971, Geel 1973), in the western Betic Cordillera, and in the northern Rif in Morocco (Martín-Algarra 1987, Maaté et al. 1995).

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