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PALAEOGENE TO EARLY MIOCENE SEDIMENTARY HISTORY OF THE SIERRA ESPUÑA (MALAGUIDE COMPLEX, INTERNAL ZONE OF THE BETIC CORDILLERAS, SE SPAIN). EVIDENCE FOR EXTRA-MALAGUIDE (SARDINIAN?) PROVENANCE OF OLIGOCENE CONGLOMERATES: PALAEOGEOGRAPHIC IMPLICATIONS

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ABSTRACT

The Sierra Espuña is situated at the northern edge of the Internal Zone in the eastern Betic Cordilleras and is part of the unmetamorphosed Malaguide Complex. Palaeontological and sedimentological analysis of the Eocene to Aquitanian sediments on the northwest side of the Espuña yielded unexpected new information of importance for the reconstruction of the history of the Espuña itself and the Malaguides in general. The so-called Upper Eocene («Auversian») rocks are of Early Oligocene (P20) age and contain supermature detritus derived from outside the Malaguide realm. The hundreds of meters thick limestone conglomerate formation of the Espuña is of Middle Oligocene (P21) age and represents a backstepping fan delta complex at the margin of a carbonate platform situated to the northeast of the Espuña. Analysis of the clasts suggests that this platform was a part of the north Sardinian block given the majority of fragments of Upper Jurassic sheltered inner platform (*Clypeina-Trocholina* limestones and dolomites). Contrary to former views (Paquet, 1966; Lonergan, 1993), the conglomerates cannot be considered to be the erosional products of Malaguide imbricated units. Therefore, one of the main arguments for early (Late Eocene to Oligocene) thrusting and nappe emplacement in the Espuña area is not valid. Other arguments for early kinematics are discussed, among others the allegedly continuous sedimentation from the Late Eocene until the Langhian northwest of the Espuña. Our data indicate the existence of a stratigraphic gap, comprising the middle Aquitanian to middle Burdigalian. A new model for the development of the Espuña within the Malaguide realm during the Palaeogene to Early Miocene is presented. Main thrusting and nappe emplacement is thought to have been taken place during the late Aquitanian. Finally, the recently proposed 200° clockwise rotation of the Espuña as a coherent block during the Early to Middle Miocene (Allerton *et al.*, 1993) is discussed. It is shown that this large figure is at variance with geological data and partly due to erroneous field observations.

Key words: *Malaguide Complex, SE Spain, Espuña, Palaeogene to Early Miocene, Detritus analysis, Sardinian proximity, Tectono-sedimentary history.*

RESUMEN

La Sierra Espuña está situada al margen norte de la Zona Interna en la parte oriental de las Cordilleras Béticas y forma parte del Complejo Maláguide no metamórfico. Análisis paleontológico y sedimentológico de sedimentos de edad Eoceno al Aquitaniense del lado noroeste del Espuña han producido información nueva y de inesperada importancia respecto a la reconstrucción de la historia de la misma Sierra Espuña y del Maláguide en general. Los depósitos considerados del Eoceno superior («Auversian») son de edad Oligoceno inferior (P20) y contienen materiales supermaduros procedentes de fuera del dominio Maláguide. Los conglomerados con cantos calizos de Sierra Espuña (cientos de metros de espesor) son de edad Oligoceno medio (P21) y representan un complejo de «fan deltas» en retroceso en el margen de una plataforma calcárea situada al nordeste de Sierra Espuña. Análisis de cantos podrían indicar que esta plataforma haya sido formada

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por parte del bloque del Norte de Cerdeña dado el predominio de fragmentos procedentes de una plataforma interior de edad Jurásico superior (calizas y dolomías con *Clypeina* y *Trocholina*). Al contrario de los puntos de vista anteriores (Paquet, 1966; Lonergan, 1993), los conglomerados no pueden ser considerados como productos de erosión de unidades maláguides imbricadas. Por lo cual, uno de los argumentos más importantes en favor de una imbricación y colocación de mantos de corrimiento temprano (Eoceno superior-Oligoceno) en España es inválido. Se discuten otros argumentos en favor de movimientos tempranos, entre otros la sedimentación supuestamente continua del Eoceno hasta el Langhiense al noroeste de Sierra Espuña. Nuestros datos han demostrado la existencia de una interrupción estratigráfica desde el Aquitaniense medio hasta el Burdigaliense medio. Se presenta un modelo nuevo para la historia de Sierra Espuña dentro del dominio Maláguide durante el Palaeogeno hasta el Mioceno inferior. Se supone que imbricaciones importantes y colocación de mantos tuvieron lugar en el Aquitaniense superior. Al final, se discute la rotación de Espuña como bloque coherente de 200° en sentido horario durante el Mioceno inferior y medio (Allerton *et al.*, 1993). Se ve demostrado que esta gran rotación está en contradicción con datos geológicos y en parte resulta de observaciones erróneas en el campo.

Palabras clave: *Complejo Maláguide, SE de España, Espuña, Palaeogeno-Mioceno inferior, Análisis de detritus, Proximidad de Cerdeña, Historia tectono-sedimentario.*

Introduction

The Betic Cordilleras of Southern Spain can be subdivided into an External Zone, representing the former continental margin of Iberia, and the Internal Zone, consisting of a stack of allochthonous complexes. The structurally highest unit of the Internal Zone is formed by the Malaguide Complex, comprising unmetamorphosed rocks of Palaeozoic, Mesozoic and Tertiary age. The Sierra Espuña is situated at the northern margin of the Internal Zone, forms part of the Malaguide Complex, and represents the easternmost occurrence of that complex in Spain. The Neogene Basin of Lorca separates the Espuña from the next large outcrop of Malaguide rocks to the southwest, i.e. the Vélez Rubio Corridor (fig. 2). In the Malaguides of the Sierra Espuña, a number of imbricated units have been distinguished, i.e. lower units without and higher units with post-Triassic rocks. The higher units comprise from below upwards, the Morron de Totana, Prat Mayor and Perona units (Paquet, 1962; Mäkel, 1985). According to Paquet (1966, 1968, 1969, 1974), the Malaguide imbricated units were emplaced and juxtaposed to the External Zone before deposition of Upper Eocene (Auversian) sediments. The Eocene age for the main deformation and emplacement of the Malaguides in the Espuña was challenged by Hermes and Kuhry (1969), Hermes (1978) and Mäkel (1981, 1985). The latter author proposed an Early Miocene age for the stacking of thrust slices in the Espuña. In the Corridor of Vélez Rubio, southwest of the Espuña, Dutch workers concluded to a post-Late Oligocene to pre-Burdigalian age for main deformation in the Malaguides and juxtaposition of Internal and External Zones (Roep and MacGillavry, 1962; Geel, 1967, 1973; Soediono, 1971). Based on data from mainly the Western Betic Cordilleras, Spanish workers suggested an Aquitanian to early Burdigalian age for major thrust emplacement and juxtaposition (Martín Algarra, 1987; Sanz de Galdeano and Vera, 1992; Rodríguez Fernández and Sanz de Galdeano, 1992). Recently, English workers recurred to the model of Paquet for the Espuña with some modifications: northwestward piggy-back wise stacking of thrust slices would be Late Eocene in age, subsequently deformation would propagate northwestward during the Oligocene. No evidence was found for either extension nor for large-scale strike slip structures (Lonergan, 1993; Lonergan *et al.*, 1994).

The purpose of the present paper is to present new data on the stratigraphy of the Palaeogene to Lower Miocene of the Sierra Espuña, constraining the timing of emplacement of the Espuña Malaguides. It is based on stratigraphic fieldwork by the author and undergraduate students (T. Steens, southwest of Casas Nuevas in the Almoloya area and W. Meyboom, north and northeast of Casas Nuevas in the Bernabeles-Pliego area; fig. 2). Emphasis was on sedimentology, age and relationships of lithostratigraphic units; special attention was paid to the detritus in these units.

Palaeogene to Early Miocene stratigraphy of the Sierra Espuña; comparison with the Vélez Rubio Corridor

Early to Middle Eocene

The Palaeogene succession of the Morron de Totana unit (fig. 3) starts with Lower Eocene inner-platform *Alveolina* limestones, overlying with an erosional unconformity Senonian pelagic limestones. The basal conglomerate contains clasts of

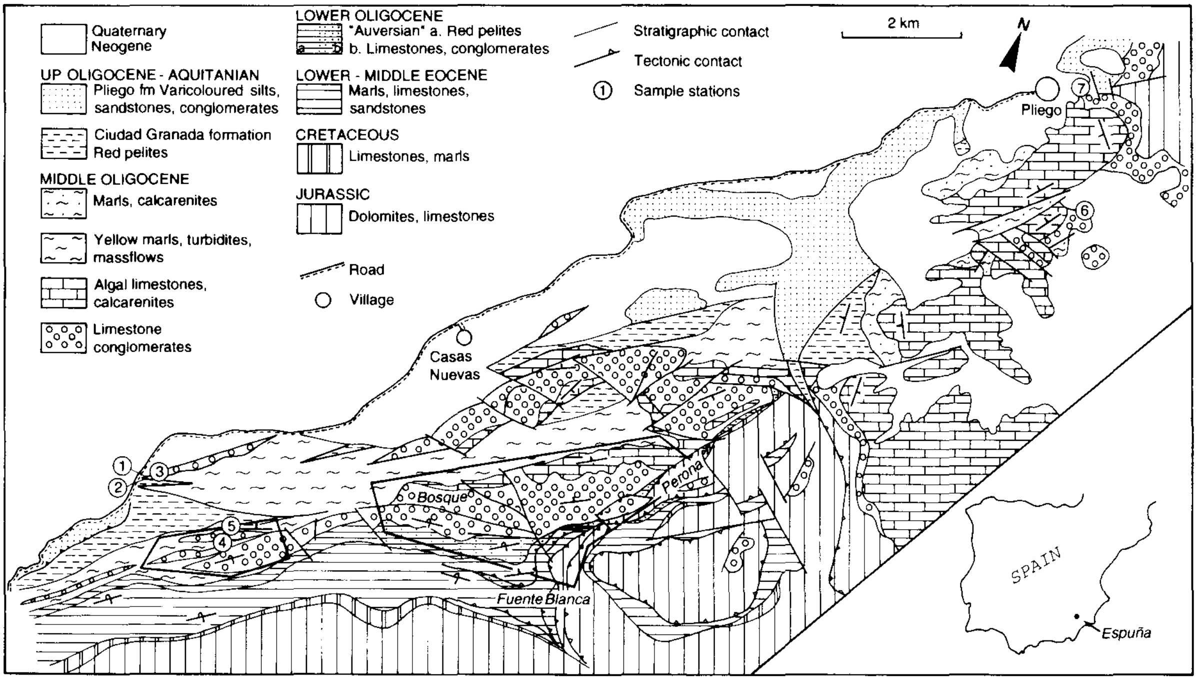

Fig. 1.—Geological map of the northwestern Sierra de Espuña (inset on fig. 2).

Jurassic, Cretaceous and Eocene limestones and rounded quartz grains reworked from the Triassic (Paquet, 1969). The Middle Eocene shows a more open shelf facies of sandy marls and limestones with large *Nummulites* and *Assilina* with some inner-platform intercalations *(Alveolina-Orbitolites)* in the northeast. In the southwest, the top of the Lutetian is formed by *Nummulites-Assilina* limestones, in the northeast by *Orbitolites-Alveolina*-miliolid limestones with gastropods. The total thickness may amount to several hundreds of meters.

In the Prat Mayor unit (fig. 3), the Eocene is but a few meters thick and composed of conglomerates (e.g. with white quartz pebbles), *Alveolina* limestones, miliolid limestones, red sandy limestones and gastropod limestones with lignite levels. By comparison with the Morron de Totana succession, it is thought that these sediments are of Early and late Middle Eocene age (IGME, 1972). Thus, there is a marked contrast between Morron de Totana and Prat Mayor units: in the former the Eocene is very thick, and open shallow marine with a tendency towards more sheltered marine in the northeast, in the latter unit the Eocene is very reduced, incomplete and with a lagoonal-continental signature. In the uppermost unit, the Perona, the Eocene is completely absent.

On the other hand, there is a striking similarity between the succession in the Vélez Rubio Corridor and that of the Morron de Totana. Near Vélez Rubio, the Palaeogene sedimentation starts likewise with Lower Eocene sandy limestones with conglomeratic levels, overlying stratigraphically Cretaceous and Upper Jurassic limestones down to upper Middle to lower Upper Jurassic oolitic limestones (never on deeper Jurassic levels, nor on the Triassic as stated by Lonergan *et al.,* 1994). The basal beds contain besides larger foraminifera, quartz and feldspar derived from the Malaguide Triassic, limestone clasts from Malaguide pelagic Upper Jurassic, and cannibalisticly, clasts of the basal Lower Eocene itself. The transgressive beds are followed by inner-platform *Alveolina* limestones which in turn are overlain by deeper, open-shelf sandy limestones and pelites with large *Nummulites* and *Assilina* (Soediono, 1971; Geel, 1973). Thus, the Vélez Rubio Corridor and Morron de Totana show exactly the same development during the Early and Middle Eocene (fig. 3). Near the end of the Middle Eocene, however, we see in the Vélez Rubio Corridor, contrary to the Morron de Totana development, a sudden change in the depositional realm. Upper Middle Eocene upper-slope sediments either conformably overlie the lower Middle Eocene carbonates, or they truncate the Jurassic-Eocene succession down to Liassic dolomites. The detritus comprises Malaguide Palaeozoic greywackes, Malaguide Triassic sandstones and minerals, and Malaguide Jurassic, Cretaceous and Lower Eocene limestones (Soediono, 1971; Geel, 1973).

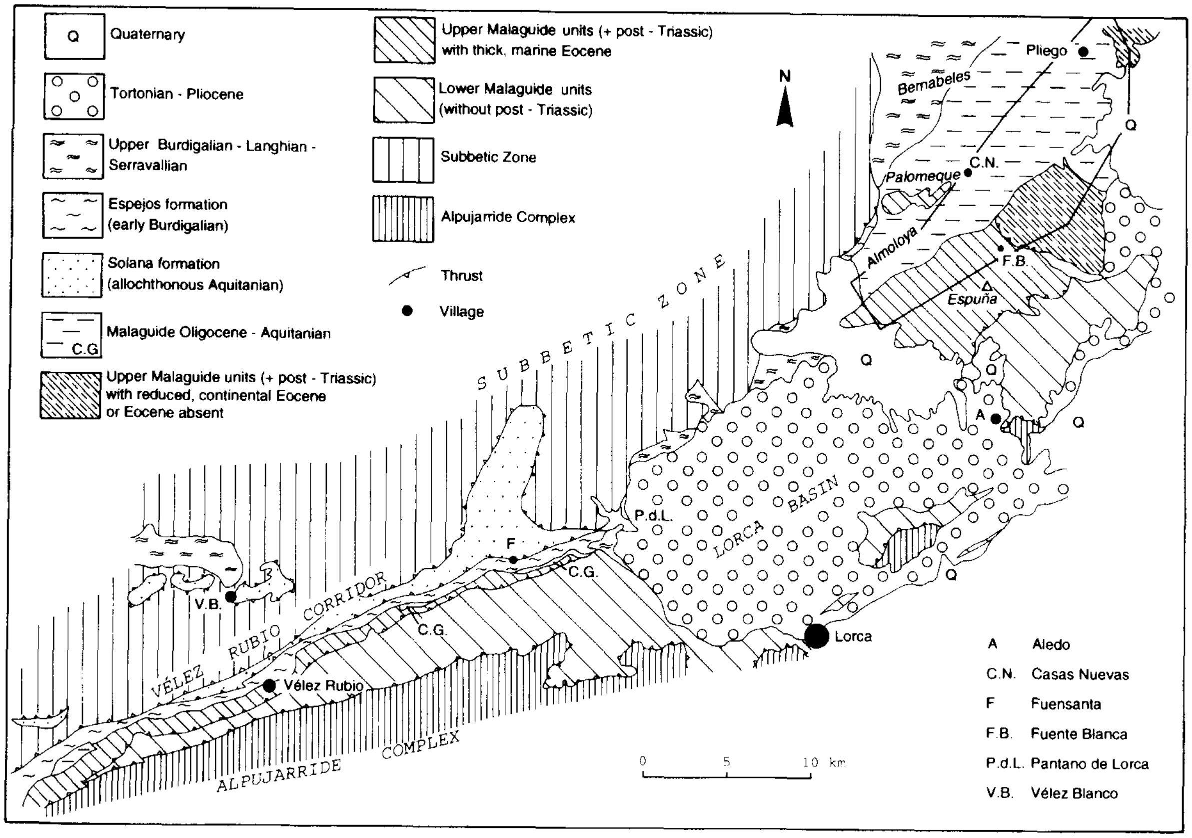

Fig. 2.—Map showing the distribution of the Malaguide Complex in the Eastern Betic Cordilleras. For details of the northwestern Espuña (inset), see fig. 1.

It is of importance to note that during the Early and Middle Eocene, the source area of the detritus in the Vélez Rubio Corridor was situated within the Malaguide realm. From the Morron de Totana and Prat Mayor units, however, also clasts with middle Cretaceous *Orbitolina* are reported from the Lutetian (Paquet, 1962; IGME, 1972). This shallow-water foraminifer is unknown in the Malaguide realm, where the Middle Cretaceous always shows a pelagic facies (Roep, 1980).

«Auversian» (sensu *Paquet, 1966)*

In the Morron de Totana unit, the «Auversian» overlies, without a noticeable angular unconformity on outcrop scale, deeper open-shelf or inner-platform Middle Eocene. In the Prat Mayor-Perona units, the «Auversian» is often tectonically bounded (see Discussion), but locally it lies undisturbed upon either continental Middle Eocene or pelagic Cretaceous (figs. 1, 4). In the central part of its outcrop (Morron de Totana), the «Auversian» consists according to Paquet (1962, 1966, 1969) from bottom to top of 15 m of ferruginous conglomerates with centimeter-sized, white, well-rounded quartz pebbles and minor amounts of Jurassic, Lower Cretaceous and Eocene limestones; 20 m of red sandy limestones and 25 m of yellow limestones and algal limestones devoid of quartz. Paquet *(op. cit.)* reported the occurrence of *Nummulites, Discocyclina, Asterocyclina, Aktinocyclina, Heterostegina, Chapmannina, Baculogypsina, Halkyardia* and *Lepidocyclina* and assigned an Auversian-Late Eocene age to this succession.

The basal conglomerate is rather peculiar in composition. The gravels are well-sorted and consist predominantly of small, well-rounded, polished clasts («dragées») of rock types that are very resistant to wear and decomposition (quartz, quartzite, chert), that is, the materials are supermature, chemically inert residues. Only a very small amount of metastable components (limestones reworked from subjacent sediments) is present. Mature gravels are the product of prolonged mechanical and chemical erosion under conditions of low relief or along high-energy, transgressive beaches (Roep, pers. comm.). If the pebbles were reworked from the

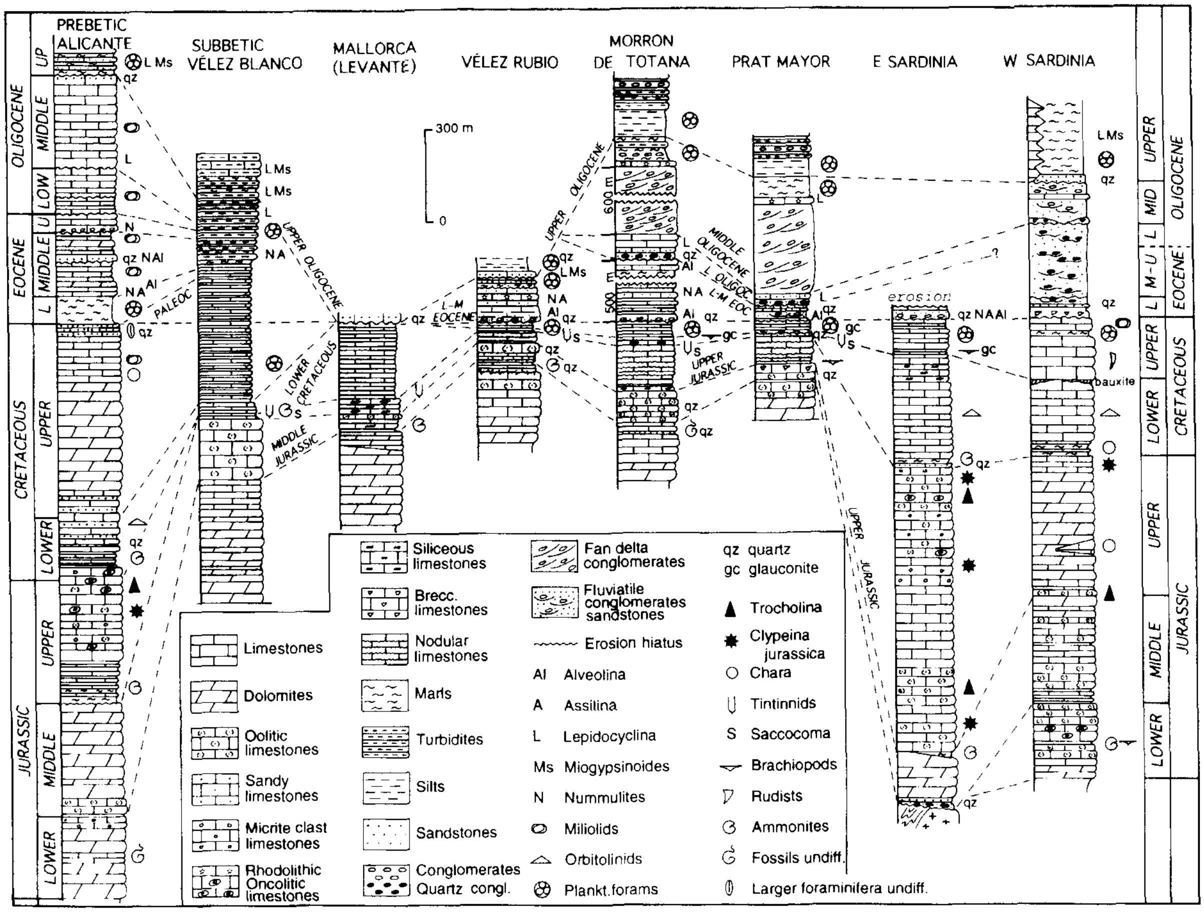

Fig. 3.—Stratigraphic columns of the Jurassic to Oligocene (Early Miocene) of the Prebetic of Alicante (after Azéma *et al.*, 1979; Geel *et al.*, in press; Geel, 1995); Subbetic of Vélez Blanco (after Geel, 1973); Mallorca (Levante) (after Fourcade *et al.*, 1977); Malaguide Complex of Vélez Rubio (after Geel, 1973); Morron de Totana unit (after Paquet, 1969; this paper); Prat Mayor unit (after Paquet, 1969; IGME, 1972); East and West Sardinia (after Fourcade *et al.*, 1977; Cherchi and Montadert, 1982).

immature, badly sorted Carboniferous greywacke conglomerates of the Malaguides, a long time of wear and decomposition is required to remove instable materials (metamorphites, granites, etc.) and enhance sorting. Another possibility would be that the pebbles are inherited from the somewhat more mature Malaguide Triassic conglomerates, but Triassic clasts are more faceted and the conglomerates poorly sorted, again implying a certain period of time of residence in for instance a coastal environment, to improve rounding and sorting. A third possibility is, that they have an extra-Malaguide origin. Whatever the case, the gravels are certainly not simply the erosional products of Malaguide Palaeozoic basement, deposited during thrusting as suggested by Lonergan and Mange-Rajetzky (1994) (see also the Discussion).

The more shallow-water development of the «Auversian» passes towards the southwest rather abruptly into soft lithologies, the facies transition accentuated by a transverse fault (fig. 1). In the southwestern spur of the Espuña, the «Auversian» is represented by 70 m of purple-red sandy calcisiltites, wherein smaller benthonic foraminifera indicate a depositional depth of 100 to 200 m. The silts contain in their lower part intercalations of ferruginous, fine, matrix-supported conglomerates with fossil fragments and granules of quartz, sandstone and limestones. In the upper part some beds occur with larger foraminifers and macrofossils (gastropods, pelecypods, hermatypic and ahermatypic corals, etc.). The larger foraminiferal fauna consists of a mixture of late Paleocene-Middle Eocene *(Assilina)*, late Paleocene-Eocene *(Nummulites, Discocyclina, Asterocyclina, Aktinocyclina)*, Late Eocene-Recent *(Heterostegina)*, and Oligocene-Early Miocene *(Lepidocyclina)* forms. The silts yielded a planktonic foraminiferal fauna containing, among others, *Globorotalia cerroazulensis, G. centralis, Globigerapsis index* (Late Eocene), *Globoro-*

talia ampliapertura (latest Eocene-Early Oligocene), and *Globigerina gortanii* (Early Oligocene). Given these data, and the report of *Lepidocyclina* by Paquet *(op. cit.)* from the «Auversian» further to the northeast, it is likely that the alleged Late Eocene is in reality of Early Oligocene age (P20 or younger), the mixed Middle-Late Eocene fauna being reworked. Sediments of Early Oligocene age are not known to occur in the Corridor of Vélez Rubio, nor elsewhere in the Malaguides, where the Late Eocene to Middle Oligocene is a period of erosion.

Espuña limestone conglomerates

According to Paquet (1966, 1969) there is a gradual transition from the top of his «Auversian» towards a very thick (several hundreds of meters) sequence of limestone conglomerates, the topmost limestones of the «Auversian» already containing Jurassic pebbles. The main body of the conglomerate suite contains exclusively pebbles of Jurassic limestones and dolomites, allegedly derived from the Malaguides. Only at the very base also some clasts of Middle Eocene limestone and Permo-Triassic red sandstone occur.

As is illustrated on figures 1 and 5, the limestone conglomerates rest upon «Auversian» (= Lower Oligocene) silts, or truncate «Auversian» (= Lower Oligocene) conglomerates and limestones. Near Pliego, they rest upon Liassic oolitic limestones or dolomites. In the southwest, the conglomerates interfinger with and are overlain by yellow marls with turbidites and massflows. The marls contain smaller benthonic foraminifera indicating a water-depth of more than 100 m. In the central part of the outcrop, the conglomerates are separated from the yellow marls by algal (rhodolithic) limestones.

The conglomerates are organized into thick, massive beds, sometimes showing thickening-up sequences on the order of 10 meters in thickness. The conglomerates are predominantly clast-supported, densely packed (pressure solution), and poorly sorted. The clasts are well-rounded and commonly on the order of 1 to 18 cm in size, but outsized clasts of 50 or even 150 cm in diameter are common. The matrix consists of silty-sandy calcarenite. Towards the top also matrix-supported pebbly calcarenites are found.

A giant-scale geometry has mainly been deduced from aerial photographs (figs. 4, 5).

Along the crest of the Bosque ridge, the beds are steeply dipping, thus figure 4 represents effectively a vertical section of the conglomerates along the crest. On the northern flank of the ridge the dip diminishes rapidly towards 50° NW (normal position); on the southern flank the dip rotates towards 50° SE (overturned position). The aerial photographs reveal the existence of two main fan bodies. The lower body (A on figs. 4, 5) consists of a rapidly southwestward prograding fan delta, at first with a convex geometry, changing to concave towards the front. Height of sets is on the order of 50 to 100 m. Several relatively small, stacked fans occur in the southwest on top of the front of fan delta A, indicating cessation of the progradation during lowstand or slow rise of relative sea level and start of rapid rise of relative sea level. The upper body (B on figs. 4, 5) is formed, after the transgressive interlude, by a more complex, prograding-aggrading delta system, the front of which is located near the summit of the Bosque. Its base is constituted by southwestward prograding fan lobes (1 on figs. 4, 5), with a height of the sets on the order of up to 50 m. These are truncated and overlain by distinctly bedded aggradational beds (2 on figs. 4, 5) at present, after steep tilting and erosion, forming acute cuestas. The beds of the top member (3 on figs. 4, 5) cause at present a more smooth topography. They are likewise aggrading but were originally slightly less inclined than the beds of member 2, suggesting onlap. Member 3 is topped by shallow-water algal-and *Heterostegina* limestones in the Bosque ridge. Towards the northeast, the upper member wedges out and the algal-*Heterostegina* limestones rest directly upon, successively, member 2 and member 1 of delta B. The shallow-water limestones are abruptly overlain by deep-water marls in the Bosque ridge and by deep-shelf sediments near Pliego.

From geometry, setting and sedimentology it can be concluded that the Espuña limestone conglomerates represent a backstepping fan delta complex at the margin of a platform situated to the northeast in an overall transgressive setting interrupted by two successive lowstands in relative sea level. At the end of the first, larger fall, fan delta A was produced, interpreted to be a lowstand prograding wedge deposited during slow rise in relative sea level. The second, lesser lowstand gave rise to delta B, more of the shelf-margin-wedge type.

Though Paquet (1962) mentioned the presence of pebbles with *Clypeina jurassica* and *Pseudocyclammina,* unknown in the Malaguides, he assumed that the source area of the conglomerates was entirely within the Malaguide realm. This interpretation was followed by Lonergan (1993) and Lonergan and Mange-Rajetzky (1994). In order to ascertain the relative amount of clasts with genuine Malaguide signature, we undertook the analysis of the microfacies of the clasts, with surprising results. Quantitati-

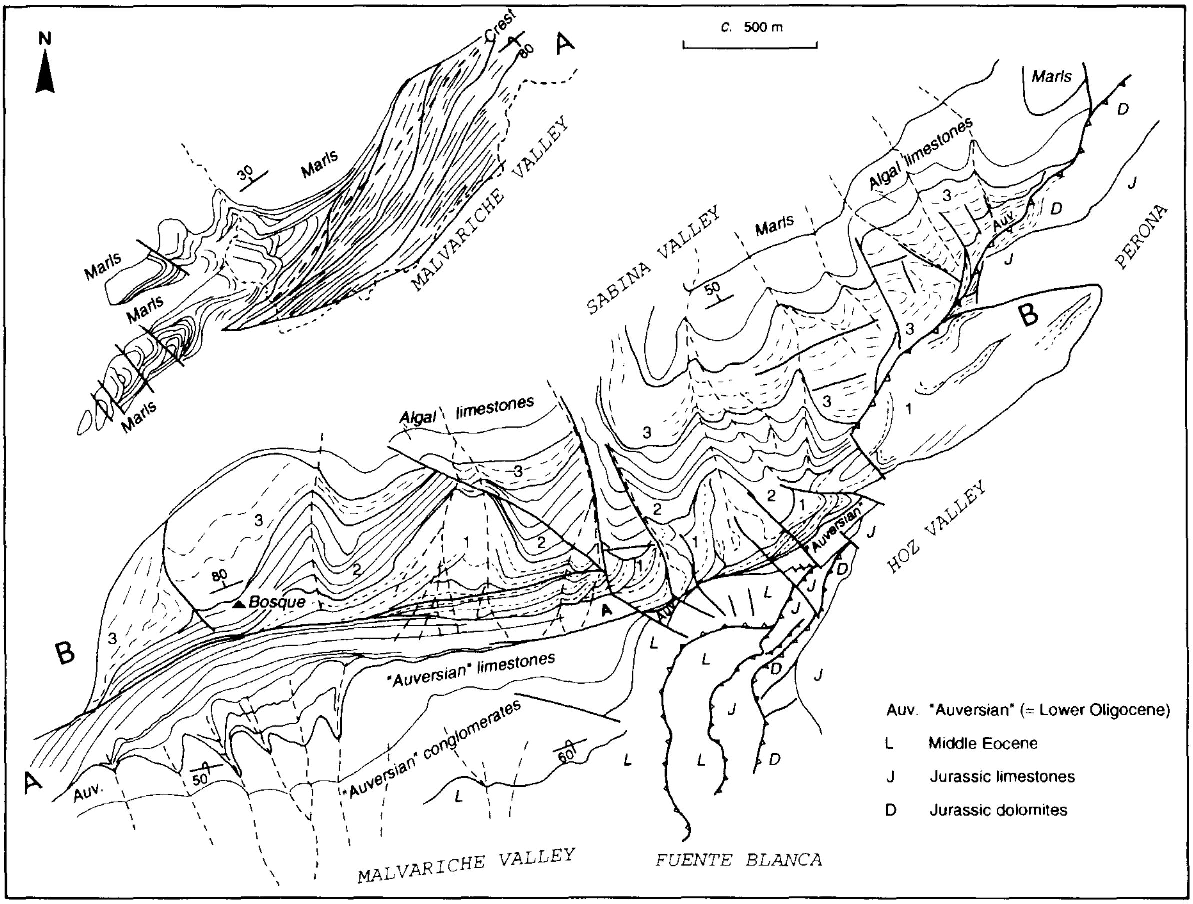

Fig. 4.—Sketches after aerial photographs showing giant-scale geometry of the Espuña limestone conglomerates in the Bosque-Perona ridge (right inset on fig. 1) and (upper left) the southwestern spur of the Bosque ridge (left inset on fig. 1). Explanation in the text.

ve analysis of the conglomerates is hardly possible, since the massive beds are weathered into smooth surfaces and the nature of the majority of the pebbles cannot be recognized on the weathered surface. Therefore, as much pebbles as possible were sampled in several localities to get an impression of the percentage of various rock types present (sample stations 1-7, fig. 1: station 1, massflow at the base of a turbidite, 14 pebbles; station 2, massflow on the front of delta A, 30 pebbles; station 3, front delta A, 40 pebbles; station 4, small fan at front of delta A, 20 pebbles; station 5, massflow on top of the front of delta A, 20 pebbles; station 6, base of delta B, 40 pebbles; station 7, base of delta B, 30 pebbles; totalling to 194 pebbles).

The following microfacies have been recognized in the pebbles.

a) *Dolomites and dolomitized limestones.* Dark grey, dark brown and creme coloured, fine to coarse crystalline dolomite clasts are dominant near Pliego at the base of delta B. Further southwest, in fan delta A, they are less prominent, but they still form in both massive conglomerates and isolated massflows an important amount of the clasts. Microscopically, the dolomites are largely crystalline, but many clasts show ghosts of ooids, foraminifera, gastropods and oncolites. Some are only partly dolomitized limestones of the following group. The dolomites and dolomitized limestones are macro- and microscopically dissimilar from Malaguide Liassic dolomites, which are light coloured and dense (in thin section sublithographic to finely crystalline, not showing the kind of ghosts described above; Geel, 1973). Given the narrow association with the next group, the majority of the clasts is thought to be of Late Jurassic age. Some, however, may be of Cretaceous age (see group e).

b) *Clypeina-Trocholina limestones.* Macroscopically, creme coloured, poorly to well sorted oolitic, oncolitic or bioclastic grainstones form in all sample stations the majority of the limestone clasts by far. Microscopically, they can be classified as

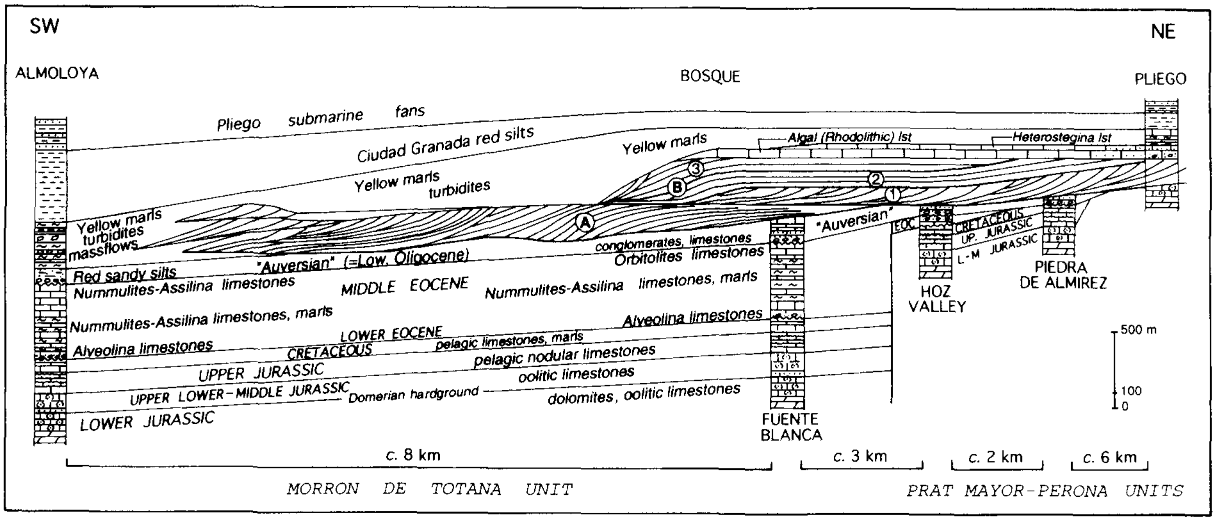

Fig. 5.—Reconstruction of Mesozoic to Palaeogene stratigraphy of the northwestern Sierra Espuña. Main differentiation between Morron de Totana and Prat Mayor-Perona units during Middle Eocene. «Auversian» (= Lower Oligocene) transgression unifies different units. Middle Oligocene conglomeratic fan deltas prograde southwestward (lower fan delta A, a lowstand prograding wedge; upper fan delta B, a shelf margin wedge). Upper Oligocene red silts (Ciudad Granada formation) are uniformly deposited over the entire area (note the differences in horizontal scale).

pseudograinstones (recrystallized packstones) with variable amounts of *Clypeina jurassica, Cayeuxia, Solenopora,* large *Trocholina, Pseudocyclammina,* miliolids, gastropods, pellets, micrite clasts, oncolites and ooids. All transitions between oolitic *Clypeina* or *Trocholina* limestones and oncolitic *Clypeina-Trocholina* limestones are found. Several clasts show incipient dolomitization, some are partly dolomitized. A few clasts of sponge-coral boundstones encasing large *Trocholina* and ooids were found in the massflows on top of delta A. From these data it can be concluded that the clasts of group b are the erosional products of an Upper Jurassic shallow platform, predominantly from the interior part.

c) *Lime mudstones.* Macroscopically creme coloured. Though found in all sample stations, they are always subordinate to the dolomites and *Clypeina-Trocholina* limestones. Microscopically, the micrites may contain some ostracods, miliolids, algal spores, calcified needle-like organisms and oncolites. They may show incipient dolomitization. The lime mudstones are related to the *Clypeina-Trocholina* limestones since clasts of that group may show partly the microfacies of the lime mudstones.

d) *Pellet-echinodermal packstones.* Macroscopically, creme coloured fine calcarenites. This type of rock is either absent or present in minor amounts in fan system A. Near Pliego, at the base of system B, they form one third of the examined limeclasts. Microscopically, they are largely made up of echinodermal remains and pellets with subordinate amounts of miliolids, algal spores, glauconite, phosphate and a very small amount of angular quartz grains. These clasts are likewise derived from a very shallow platform of which the age, however, is uncertain. Echinodermal-pellet packstones are known from the Upper Liassic of the Malaguides. However, they are characterized by a large percentage of quartz and a dissimilar microfauna (see Geel, 1973).

e) *Cretaceous clasts.* Near Pliego at the base of delta B, a few clasts of pellet packstones and grainstones are found with *Orbitolina* sp. and miliolids (very shallow platform, Aptian to early Cenomanian in age). They show incipient dolomitization. One of the massflows overlying the massive conglomerates of fan delta A, yielded a clast with *Pithonella, Globotruncana, Heterohelix* and *Inoceramus* fragments (pelagic facies, Turonian to Senonian in age).

f) *Eocene clasts* are only found, in minor amounts, in the top of the massive conglomerates of fan delta A and in isolated massflows atop of the conglomerates. The majority of the clasts is formed by coralgal boundstones with e.g. *Nummulites* and *Fabiania* (Late Eocene). Further occur silty packstones with *Nummulites, Assilina, Discocyclina, Asterocyclina, Aktinocyclina* (Lower to Middle Eocene platform); sandy packstones with *Discorbis,* ostracods, miliolids, *Solenomeris* and small *Pithonella*-limestone clasts (Eocene platform interior); fine conglomerate with *Nummulites, Discocyclina,* detritic dolomite rhombs, broken rounded quartz, quartzite, phyllite and volcanic rock (Upper Eocene transgressive platform).

Though some rock types (e.g. *Pithonella-Globotruncana* limestone, silty *Nummulites-Assilina* limestone) could have been derived from the Malaguide realm, they form but a minority among the examined clasts. It is more logical to assume that they came from the same source land that produced the other components, e.g. the *Clypeina-Trocholina* limestones and dolomites, and *Orbitolina* limestones, the facies of which has never been found within the realm of the Malaguide Complex, nor in its African and Sicilian equivalents (Alboran microplate or south Sardinian block). Here, in the Malaguide realm, the Late Jurassic and Early to Middle Cretaceous are represented by a deep, pelagic facies (*Saccocoma*- and *Calpionella* limestones, *Nannoconus*- and planktonic foraminiferal limestones) (Azéma, 1961; Paquet e.g. 1969; Geel, 1973; Roep, 1980; Wildi, 1983). Moreover, this kind of clasts have never been found in Tertiary deposits with unquestionable Malaguide detritus (see below, under Discussion).

From the above data one can tentatively reconstruct the stratigraphy and facies of the platform that formed the source area of the limestone conglomerates. During the Late Jurassic, the source area was covered by a sheltered carbonate platform, that was partly dolomitized (*Clypeina-Trocholina* limestones and dolomites). This environment persisted into the Middle Cretaceous (*Orbitolina* limestones). The source area became deeper, open marine during the Late Cretaceous (*Pithonella-Globotruncana* limestones). Transgressive upon the latter follows in the Eocene a lagoonal facies (sandy *Discorbis*-miliolid-*Solenomeris* limestones with *Pithonella*-limestone clasts), succeeded by the instalment of an open marine platform (*Nummulites-Assilina-Discocyclina* limestones). After an important erosive event, the Late Eocene is represented by immature marine conglomerates (age assignment on the presence of *Nummulites* and *Discocyclina,* absence of *Assilina*), and coralgal (reefal) limestones. Uncertainty exists about the stratigraphic position of the pellet-echinodermal packstones (sheltered platform) since their age could not be ascertained.

With respect to the age of the Espuña conglomerates, it is shown above that the underlying «Auversian» is of Early Oligocene age (P20 or younger). The turbidites, massflows and marls on top of the conglomerates of delta A contain a mixture of Eocene and Early Oligocene planktonic foraminifera and, besides reworked Eocene larger foraminifera also *Nephrolepidina* and *Eulepidina*. Lepidocyclinids have also been found in the algal limestones on top of the conglomerates of delta B. Given the absence of *Miogypsinoides,* this indicates a Middle Oligocene (P21, late Rupelian to early Chattian) age for the conglomerates.

Ciudad Granada and Pliego formations

Paquet (e.g., 1966, 1969; Magné and Paquet, 1967) lumped the yellow marls associated with the Espuña conglomerates together with overlying red silts into one lithostratigraphic unit and assigned a Late Oligocene age to the red levels on the presence of *Almaena escornebovensis* and *Miogypsinoides.* Jerez Mir (1981) and Martín Algarra (1987) assembled the above red silts with an overlying varicoloured (but predominantly red) silt-sandstone-conglomerate unit into, respectively, the Red Pliego formation and Ciudad Granada Group, and assigned an Oligocene to Aquitanian age to the whole. Lonergan *et al.* (1994) followed these latter authors in the lumping and age assignment, but used the name of Amalaya Formation. Red pelites with *Almaena* have been found everywhere in the Malaguides (Vélez Rubio Corridor, Western Betics; e.g. Roep and MacGillavry, 1962; Martín Algarra, 1987) and in their equivalents in Northern Africa (Ghomarides, Kabylids; e.g. Gélard *et al.,* 1973; Wildi, 1983). The varicoloured silt-sand-conglomerate unit, however, is restricted to the Espuña. Furthermore, it will be shown that the two lithologies are partly coeval but deposited under different environmental conditions. Therefore, it is proposed to make a distinction between the red *Almaena* silts and varicoloured coarser clastics. In the present paper, the former will be referred to as Ciudad Granada formation, after the original type area southwest of Vélez Rubio, the latter as Pliego formation.

a) Ciudad Granada formation

In the Espuña area, the Ciudad Granada formation consists of red silts containing only silt to very fine sand-sized non-calcareous detritus. The upper boundary is always of tectonic nature, the lower boundary often. In the southwest of the Espuña (Almoloya section), the lower boundary is stratigraphic and marked by an abrupt change in colour (grey and yellow to red), and decrease in grain size. Benthonic foraminifera indicate a sudden increase in waterdepth from *c.* 100 m towards more than 200 m across the boundary. The planktonic foraminiferal fauna indicates a late Chattian (P22) age (e.g. *Globorotalia kugleri, Globigerinita glutinata, Globoquadrina tripartita, Neogloboquadrina mayeri*).

In the Vélez Rubio Corridor, the Ciudad Granada formation consists of deeper water red *Almaena* silts underlain by yellow-brown, shallow-water *Lepidocyclina*-bearing calcarenites and sandstones. The latter rest transgressively, with a basal conglomerate, upon a palaeorelief of Triassic dolomites and sandstones (locally upon Liassic limestones). Though there is certainly an erosional unconformity, nowhere (over a distance of 36 km along strike) an angular unconformity could be ascertained. The basal beds are of late Chattian age, the red silts of late Chattian-earliest Aquitanian age. The facies change from calcarenites to silts records a rapid subsidence to more than 200 m in waterdepth during the Late Oligocene (Roep and MacGillavry, 1962; Geel, 1967, 1973; Soediono, 1971; Gelati and Steininger, 1984). The basal conglomerates, sandstones and calcarenites contain exclusively Malaguide detritus. The red silts may contain some intercalations of coarse, clast-supported massflows containing well-rounded pebbles of Malaguide provenance (mainly non-metamorphic Carboniferous greywackes). In one locality near Chirivel, southwest of Vélez Rubio, the conglomerates contain besides Malaguide Palaeozoic, also clasts of Eocene limestones, white quartzite pebbles and light coloured gneissic rock with a radiometric age of 323 ± 60, 332 ± 60 and 350 ± 60 m.y. (Soediono, 1971). Carboniferous gneisses are unknown in the Malaguides of Spain but do occur in the basement of their Kabylian equivalent in Northern Africa (e.g. Bourrouilh *et al.*, 1979; Boissière and Peucat, 1985; Monié *et al.*, 1988).

b) Pliego formation

Whereas in the Vélez Rubio Corridor the red silt facies persists till the early Aquitanian, this facies is replaced during the Late Oligocene by submarine fans in the Espuña area (Pliego formation). The Pliego formation, up to 800 m in thickness, consists of green, brown, yellow, white and red micaceous silts, calcareous sandstones, clast-supported conglomerates, pebbly mudstones and red, fine grained ferruginous siltstone beds. Large-scale slumping, normal and inverse grading, and chanelling indicate deposition by turbidites and massflows in a submarine fan complex. Midfan, outer fan and basin plain subfacies can be distinguished. Transport direction in channels is towards the north and northwest. The Pliego formation carries detritus derived from all levels of the Malaguide Complex (Palaeozoic greywackes, Triassic sandstones, Jurassic oolitic limestones, Eocene *Alveolina* limestones, Middle Oligocene *Eulepidina* limestones). The formation also contains a fair amount of phyllite and quartzite fragments, supposedly derived from the Alpujarride Complex (Rivière *et al.*, 1980; Lonergan and Mange-Rajetzky, 1994). Since the Pliego formation is mainly of Late Oligocene age (the top reaches into the Aquitanian, first occurrence of *Globoquadrina dehiscens*), this poses a problem, for it is generally assumed that Alpujarride metamorphism is of Aquitanian age (e.g. Zeck *et al.*, 1989; De Jong, 1991). However, not all phyllites and quartzites in the world need to belong to the Alpujarride Complex. They are known to occur in deeper levels of the Malaguide Palaeozoic and in the Kabylian basement. Besides, the phyllite fragments in the Pliego formation are dull grey and do not show the typical high lustre and blue colours of Alpujarride phyllites. Furthermore, if all phyllite- and quartzite fragments in the Pliego were indeed sourced in the Alpujarride Complex, the negligeable amount of heavy minerals that would be indicative for exhumation of metamorphosed Alpujarrides (Lonergan and Mange-Rajetzky, 1994) is surprisingly low. In the Burdigalian, when the first few fragments of undeniable Alpujarride fragments show up, the amount of indicative heavy minerals jumps to the significant percentage of more than 50 % of the heavy minerals *(op. cit.)*.

Discussion

Provenance of Espuña limestone conglomerates

As pointed out above, the source area of the hundreds of meters thick Middle Oligocene limestone conglomerates of the Espuña possessed a stratigraphic succession unknown in either the Spanish Malaguides or their African and Sicilian equivalents. Most important is the difference in facies during the Late Jurassic to Early Cretaceous. Given the large amount of Upper Jurassic sheltered platform clasts (*Clypeina-Trocholina* limestones and dolomites), during the Late Jurassic the source area must have been attached to the large circum-Mediterranean platforms. Though Upper Jurassic platforms do occur in Northern Africa, an African origin for the clasts is ruled out by the fact that a deep flysch trough separated this continent from the West Mediterranean continental fragments (Alboran microplate or South Sardinian block) in the Oligocene (Wildi, 1983; Dercourt *et al.*, 1986). On figure 7A the distribution of Upper Jurassic sheltered platform facies and pelagic facies in the Western Mediterranean is shown. Figure 3 presents the Jurassic to Oligocene stratigraphic successions of the Spanish Prebetic, the nearby Subbetic, Mallorca, the Malaguides of Vélez Rubio and Espuña, and Sardinia. From maps and columns it can be deduced that likely source areas are either the Spanish Prebetic or Sardinia. A Prebetic provenance of the conglomerates would imply that during the Middle Oligocene the Espuña was situated at least 200 km to the east of its present position, given the fact that the fan deltas are very proximal to their source and the clasts cannot have passed through the deep Subbetic basin in between. The southwestward transport and occurrence of clasts of Upper Jurassic and Lower Cretaceous sheltered platform, Upper Cretaceous pelagic limestones and transgressive Eocene would be explained if the Espuña once formed the southeastern prolongation of the Prebetic of Alicante. However, the facies and history of both platform and slope of the Prebetic of Alicante during the Oligocene are well-known and completely different from the development in the Espuña: the slope fans of Alicante contain exclusively Palaeogene platform clasts, Jurassic and Lower Cretaceous being deeply buried at this time (Geel, 1995). The inevitable conclusion from the above discussion is, that during the Middle Oligocene the Espuña was situated in the neighbourhood of Sardinia. That is, more than 500 km to the northeast of its present position.

This would explain:

— the huge amount of clasts of *Clypeina-Trocholina* limestones and dolomitized Upper Jurassic platform limestones,
— the absence of Liassic clasts, since in Sardinia the Lower Jurassic is either absent or thin,
— the occurrence of clasts of Lower Cretaceous platform and Upper Cretaceous pelagic facies,
— the presence of clasts of transgressive Eocene.

A Sardinian proximity would also afford an explanation for the reworked *Orbitolina* in the Middle Eocene of the Espuña and for the mature gravels at the base of the «Auversian» (= Lower Oligocene), since exactly the same gravels are found in Sardinia at the base of transgressive Middle Jurassic (Fourcade *et al.,* 1977), and again in the continental Eocene-Oligocene (Larangot, 1985). With respect to the Lower to Middle Eocene succession of the Espuña, Sardinia forms the logical, more landward prolongation. There are other similarities between Sardinia and Espuña: absence of Paleocene and an erosional unconformity at the base of the Lower Eocene; a tectonic phase inducing emersion and erosion during the Late Eocene to Middle Oligocene; rapid subsidence and drowning during the Late Oligocene (for more details and palaeogeographic consequences, see below).

Timing of kinematics in the Espuña

Paquet (1966, 1968, 1969, 1974) expressed the view, that the post-Lutetian of the Sierra Espuña was deposited after the main orogeny responsible for the superposition of the Malaguide imbricated units and their emplacement next to the Subbetic. His main argument for this important conclusion was, that in one locality in the Espuña (north of Fuente Blanca; figs. 1, 4), the «Auversian» would overstep the tectonic contact between imbricated units. Hermes and Kuhry (1969) and Hermes (1978) argued that the post-Lutetian of the Espuña belonged to the original Malaguide sequence. Their arguments were:

a) There is a gradual transition between sediments below and above the «Auversian» transgression.
b) The supermature character of the «Auversian» conglomerates is hardly compatible with major-tectonic-phase sediments.
c) The post-Lutetian of the Espuña and post-Lutetian of the Subbetic are quite dissimilar qua facies and lithology, transitions have not been found.
d) At several localities in the Espuña, wedges of Triassic rocks have been found along the alleged transgressive «Auversian» contact.

Lonergan (1993) followed on the one hand Paquet in his interpretation of the highly tectonized situation near Fuente Blanca as a normal transgressive overstep of «Auversian»-Oligocene conglomerates upon imbricated units of Jurassic carbonates and Lower to Middle Eocene limestones, and on the other hand Hermes and Kuhry in their interpretation of a conformable contact between Middle Eocene and «Auversian» elsewhere. Lonergan (1993) reconciled this apparent controversy in a model depicting a thrust front with active thrusting, piggyback wise propagating into a shallow carbonate shelf of a foreland basin, fossilized by detritus shed off uplifted thrust slices. Thrusting would start in the Late Eocene and propagate north-northwestward during the Oligocene into the foreland basin. In her view, all important deformation was compressional throughout the Eocene to Oligocene.

If the models of Paquet and Lonergan are valid, the following requirements must be met:

1. The contact at the base of the «Auversian» near Fuente Blanca must be of stratigraphic nature.
2. The highest imbricated thrust units of the Espuña should show comparable stratigraphic successions up to and including the Middle Eocene.
3. Between Espuña and External Zone, a fore-

land basin would form with continuous sedimentation from the Late Eocene through to the Burdigalian.

4. This foreland basin would be filled, from the Late Eocene upwards, with immature erosional products from the Malaguides on the southeastern side. Some erosional products of the External Zone would be expected on the northwestern side.

5. Fan propagation would be north-northwestward, away from the Malaguide thrust front.

6. The oldest fans should contain mainly erosional products of the lowermost thrust slice (Morron de Totana), thus a large amount of Eocene clasts. The youngest fans should contain predominant clasts of the uppermost unit (Perona), thus a large amount of Liassic limestones and dolomites.

Ad. 1. *Basal contact of the «Auversian» north of Fuente Blanca*

Besides the fact that the «Auversian» is Early Oligocene in age, it is highly improbable that the contact near Fuente Blanca represents a syn-sedimentary thrust front:

— The models of both Paquet and Lonergan are based on the present situation and do not take into account that since the Late Miocene tons of carbonates have been removed from the Sierra and deposited in surrounding basins. The horizontal tectonic contacts between the imbricated thrusts, therefore, extended before erosion further to the southwest. If thrusting happened during the «Auversian», tectonic slices of Jurassic to Eocene rocks would be expected to occur in the section immediately southwest of the so-called stratigraphic overstep.

— If one pushes hundreds of meters thick slabs of hard rock upwards through a soft, shallow sea bottom, one would expect large-scale soft-sediment deformation, and massflows and fault breccias of the imbricated rocks throughout the section, and not neatly parallel-bedded or mega-crossbedded calcarenites and well-rounded supermature clasts supposedly from deep below. One cannot deposit soft sediments upon a smooth, rather steep dipping surface other than in steep onlap, and not with the beds parallel to that surface.

— If successive slabs are pushed upwards through a shallow sea bottom, this would create a palaeorelief, not a smooth surface as if cut-off by a razor. The highs of hard rock amidst soft bottom sediments would be settled upon immediately by hard-bottom organisms, the hollows filled in by fault breccias. Differences in waterdepth would be up to several hundreds of meters. None of these features, expected during an eventual «Auversian» tectonic phase, have been observed.

Our conclusion is, that the rectilinear contact north of Fuente Blanca is of tectonic nature, which is in accordance with field observations of Roep and Bodenhausen (pers. com.) and with the general geologic setting. Figure 4 shows that north of Fuente Blanca, contrary to the impression given by the maps of both Paquet (1966) and Lonergan (1993), the «Auversian» is not found undisturbed in a continuous strip, but has been tectonically squeezed between Lutetian imbricated units and Espuña conglomerates. Strike-parallel faults truncating the sedimentary structures in the Espuña conglomerates and the «Auversian» stratigraphy can be traced southwestward (somewhat offset by younger transverse faults). Elsewhere, e.g. west of Fuente Blanca and in the Perona area (figs. 1, 4), the «Auversian» is overthrusted by either Middle Eocene or Liassic rocks (Lonergan, 1993; Lonergan and Mange-Rajetzky, 1994). The general conclusion therefore is, that main thrusting in the Espuña is post-«Auversian» (post-Early Oligocene).

Ad. 2. *Lower to Middle Eocene sediments of Morron de Totana-Prat Mayor-Perona units*

The Lower to Middle Eocene of the Morron de Totana unit is up to more than 500 m in thickness and shows an overall, gradual facies transition from open marine in the southwest to more sheltered marine in the northeast. In the Prat Mayor unit, the Eocene is very reduced and sheltered marine to continental. In the Perona, the Eocene is absent. This contrast either means that these units originally were at a distance on the order of tens of kilometers or that the sediments were deposited upon differentially subsiding fault blocks. Whatever the case, the differences cannot be explained by simple post-Lutetian piggy-back wise thrusting in a coherent, uniform carbonate slab.

Ad. 3. *Continuous sedimentation in the foreland basin*

Lonergan (1993) rejected the idea of Mäkel (1985) that thrusting and emplacement in the Espuña was Early Miocene in age. Her main argument was that there is no evidence for a major break in sedimentation in the Lower Miocene, which was proven in Lonergan *et al.* (1994). This is a rather astonishing statement, for our own observations in the Vélez Rubio Corridor (e.g. Geel, 1967) and in the Espuña area show otherwise. Northwest of

Lonergan, 1993 Lonergan et al., 1994			Allerton et al., 1993		This paper		
CHRON. STRAT.	NANNOPL. ZONES	FORMATIONS	PALAEOMAGN. SAMPLES	CLOCKWISE ROTATION	FORMATIONS	PLANKT. FORAM ZONES	CHRON. STRAT.
LANGHIAN	NN 4	Bernabeles			Grey marls calcarenites	N 7/8	*UP. BURD. – LANGH.*
BURDIGAL.							
							Hiatus
AQUITAN.	NN 1 NN 1	- - - - - - - -	Aqu 3 Aqu 2		Pliego	N 4/5	*LOW. AQUITAN.*
UP.OLIGOC.	NP 25	Amalaya		140°		P 22	*UP.OLIGOC*
			Aqu 1		Ciudad Granada	P 22	*UP.OLIGOC.*
LOW. OLIGOC.		Bosque	Oli 1	201°	Yellow marls, turbidites, massflows	P 21	*MID.OLIGOC.*
					Espuña limestone conglomerates	P 21	*MID.OLIGOC.*
UP. EOC.		"Auversian"			"Auversian"	P 20	*LOW. OLIGOC.*

Fig. 6.—Table showing stratigraphic schemes and age data for Oligocene to Middle Miocene sediments of the northwestern Sierra Espuña according to Lonergan, 1993, and Lonergan *et al.*, 1994 (to the left) and this paper (to the right). In the centre, the strati graphic position of palaeomagnetic samples discussed in Allerton *et al.* (1993). Explanation in the text.

Casas Nuevas (Bernabeles area; fig. 2), the top of the mainly Upper Oligocene (P22) red siliciclastic-calcareous Pliego formation is bleached and contains *Globoquadrina dehiscens,* indicating that siliciclastic sedimentation continued into the basal Aquitanian. The Pliego formation is overlain with an angular unconformity by a grey marly-calcareous formation of late Burdigalian to Langhian age (N7/8, N8). Southwest of Casas Nuevas (Almoloya area; fig. 2), the Upper Oligocene to Aquitanian Pliego formation is overlain by lower Burdigalian (N5/6) grey-green marls, conglomerates and silexites of the Espejos formation, not to be confused with the mentioned upper Burdigalian to Langhian grey marly-calcareous formation in the Bernabeles area. Here, the section is truncated by a Subbetic thrust. Thus, in the Bernabeles area the larger part of the Aquitanian and the lower and middle Burdigalian are missing (some 5 Ma), in the Almoloya area the middle and upper Aquitanian (some 3 Ma). If one examines the palaeontological data of Lonergan *et al.* (1994, figs. 3, 5) one cannot but wonder how they could conclude to continuous sedimentation. Lower in their Amalaya (our Pliego) formation their samples yielded nannoplankton of Late Oligocene age (NP25). They sampled further across the boundary between «red, yellow and grey marls and sandstones» of the Amalaya and «grey marls and sandstones» of the Bernabeles formation (they lumped the grey formations of the Almoloya and Bernabeles areas). In one locality in the Bernabeles area they observed a transitional contact between red and grey sandstones without a break. They gathered all across-boundary samples into the cathegory «Amalaya-Bernabeles boundary» labeled «Late Oligocene/Early Miocene». However, the samples of the Almoloya area indicate NP25, those of the Bernabeles area all NN1. In other words, their boundary lies within the Late Oligocene in one area, within the Aquitanian in the other. The suspicion arises, that they incorporated also the grey, bleached top of the Pliego formation into their Bernabeles formation and sampled the boundary between unbleached and bleached sediments. Exactly in the Bernabeles area, the real contrast between the two formations is rather striking, the base of the grey marly-calcarenitic Bernabeles formation being formed by even-bedded planktonic foraminiferal packstones and laminated siliceous beds. The samples within the Bernabeles formation all yielded nannoplankton flora of a which the concurrent ranges indicate the late Burdigalian (NN4). It is evident that instead of proving continuous sedimentation from the Oligocene up into the Langhian, the data of Lonergan *et al.* (1994) prove nothing in the section of the Almoloya area, the youngest sample being Late Oligocene in age. With respect to the Bernabeles area, the nannoplankton data indicate the existence of a stratigraphic gap comprising late Aquitanian and early to middle Burdigalian, which is exactly what we concluded from the planktonic foraminiferal fauna (see also fig. 7).

Ad. 4, 5, 6. *Fan progradation and detritus*

As is pointed out above, during the «Auversian» (= Early Oligocene) the facies distribution in the Espuña varies from shallow platform in the northeast to deep, outer shelf in the southwest. The transgressive basal conglomerates contain but a minor amount of locally derived, subjacent Malaguide limeclasts. Conspicuous is the presence and predominance of supermature gravels, the clasts of which are certainly not the erosional products of an active Malaguide thrust front. Stratigraphically upwards, the amount of non-calcareous detritus decreases to nil. This can only be interpreted as an Early Oligocene northeastward transgression over a flat, eroded surface followed by the formation of a carbonate platform in the Espuña.

In the Middle Oligocene, we observe the onset of shedding of huge volumes of carbonate clasts and the build-up of fan deltas at the margin of a carbonate platform. Since the Espuña Malaguides are largely made up of Lower Jurassic dolomites and Lower to Middle Jurassic oolitic limestones, and the conglomerates consist macroscopically largely of clasts of oolitic limestones and dolomites, both Paquet (e.g. 1966) and Lonergan (e.g. 1993) assumed that the clasts were reworked from the Malaguides. However, as is pointed out in the present paper, these clasts are of Late Jurassic age and not derived from the Espuña Malaguides, nor from other Malaguide successions. Furthermore, foresetting in the fans is towards the southwest, thus not perpendicular to the alleged thrust front and southern margin of a supposed foreland basin. These observations are hardly compatible with an «imbricate thrust stack of Malaguide rocks formed as a result of north-northwest directed motion fossilized beneath a thick sequence of erosional products of uplifted Malaguide thrust slices followed by further north-northwest directed deformation into a foreland basin» (Lonergan, 1993).

During the Late Oligocene, the Espuña at first underwent rapid subsidence (deposition of deep-water red silts of the Ciudad Granada formation over the entire area) and supply of coarse extra-Malaguide detritus stopped. The overlying turbiditic submarine fans (Pliego formation, Late Oligocene to early Aquitanian) carry detritus exclusively of Malaguide provenance, with a predominance of deeper Malaguide, Palaeozoic basement which is practically absent in the Espuña thrust stack. The drastic change in source area of the detritus, from extra-Malaguide to predominantly Malaguide basement, cannot be explained by simple further north-northwest propagation of thrusting into one and the same foreland basin.

Conclusions

The conclusion from the above discussion is, that none of the arguments of Lonergan (e.g. 1993) for the timing of the kinematics in the Espuña can bear the scrutiny of criticism. As has been pointed out above, main thrusting is not syn- but post- «Auversian» (= Early Oligocene). However, the fact remains that the transgressive «Auversian» sits upon units with comparable Mesozoic stratigraphies but differing in their Eocene development (see above; see also fig. 5). Consequently, these units were juxtaposed before sedimentation of the «Auversian». On figure 2 it is shown that the units with marine Eocene extend from the Vélez Rubio Corridor up to Fuente Blanca (Morron de Totana). From Fuente Blanca northeastward, units are found with reduced and incomplete, continental Eocene or with the Eocene altogether lacking (Prat Mayor and Perona). If the model of Paquet (1966) is valid, to wit stacking of units with different stratigraphies, one would expect occurrences of Morron de Totana type units southeast and northeast of the Prat Mayor-Perona units. However, the distribution of the units suggests that the differences between the Morron de Totana on the one hand and the Prat Mayor-Perona on the other, are initially due to differential subsidence of blocks during the Middle Eocene. It is to be expected that during thrusting the former block boundary was the locus of severe tectonization which would explain the extreme complex tectonics in the Fuente Blanca area.

It is generally assumed by most previous workers in the Espuña that at least the Espuña conglomerates are entirely post main thrusting. However, to the north of Fuente Blanca, the basal contact of the conglomerates is of tectonic nature (see above). More to the northeast, in the Perona area (fig. 4), the northwestward thrusting of Jurassic dolomites and limestones upon «Auversian» is not sealed by the Espuña conglomerates as suggested by the map in Lonergan and Mange-Rajetzky (1994), but the thrust fault can be followed southwestward within the conglomerates. Nor is the contact between «Auversian» and conglomerates normal stratigraphic since the contact truncates the stratigraphy of the latter. Jurassic dolomites are even thrusted upon the algal limestones on top of the conglomerates. Still further east, one of the main tectonic boundaries of Paquet (1966), to wit Perona upon Prat Mayor, can be followed northward into the Pliego formation (see map, fig. 1). So, main thrusting in the Espuña not only is post-«Auversian» but even post-Pliego (post-early Aquitanian), which is in accordance with observations made elsewhere independently by Dutch and Spanish workers (see Introduction).

Rotation of the Espuña

It is recently suggested, that the Sierra Espuña rotated clockwise as a coherent block over 200° during the Early to Middle Miocene (Allerton *et al.*, 1993). This statement is based upon palaeomagnetic measurements at three sites in Permo-Triassic red beds (PT-1, 2, 3) situated in lower Espuña thrusted units, one site in Upper Jurassic pelagic limestones (Jur-1) located in the Prat Mayor thrusted unit, one site in Oligocene marls (Oli-1) of the Morron de Totana unit, and three sites in Upper Oligocene to Lower Miocene red marls (Aqu-1, 2, 3; fig. 6). According to the above cited authors, the results of the measurements in the Permo-Triassic are ambiguous, they indicate either zero or 180° rotation. The Jurassic site rotated either 150° anticlockwise or 210° clockwise. Site Oli-1 rotated 201° clockwise, the samples coming from «marls of the Oligocene Bosque formation at a site across a minor anticline» (*op. cit.*, p. 237). However, sample station Oli-1 is situated in a far more complex tectonic locality at the southwestern spur of the northern outcrop of the Espuña limestone conglomerates (at the site of our sample stations 1, 2, 3; fig. 1). The «small anticline» is in fact part of a bent tectonic slice of Middle Oligocene yellow marls, turbidites and massflows disconnected from their original base, the Espuña conglomerates. The tectonic slice is squeezed between, in the northwest, a large vertical fault with a strike-slip component separating the Espuña succession from a separate Malaguide tectonic unit, the Palomeque unit, and, in the southeast, a steep fault separating the above slice from imbricated Upper Oligocene Ciudad Granada silts and Middle Oligocene marls. Here, deformation is clearly post-Ciudad Granada. According to Allerton *et al.* (1993) the site was rotated over 201° clockwise after deformation. Aqu-1, 2, 3 were sampled from the Amalaya formation *sensu* Lonergan (1993) (see fig. 6). In fact, sample station Aqu-1 is situated in the Upper Oligocene Ciudad Granada silts, southwest of Oli-1. Sample stations Aqu-2 and Aqu-3 are located near the top of the Pliego formation in uppermost Oligocene or lowermost Aquitanian sediments. The mean site declination of Aqu-1, 2, 3, would indicate a 140° clockwise rotation predating Miocene deformation. So, contrary to the statement of Allerton *et al.* (1993) that older rocks consistently show a 200° clockwise rotation and younger rocks a clockwise rotation over 140°, the Ciudad Granada silts participated in both, dependent on the locality (fig. 6). This suggests that the extra 60° rotation is a young rotation whereby only parts of the Espuña were involved. If the amount of 140° clockwise rotation is correct, the Espuña rotated as a coherent block after deposition of the Upper Oligocene to lowermost Aquitanian Pliego formation.

A 200° clockwise rotation of the entire Espuña during the Early to Middle Miocene in combination with Palaeogene thrusting as suggested by Lonergan (1993) would pose severe palaeogeographical and tectonic problems. Recent models for the Betic Cordilleras suggest northwestward nappe transport, the driving force being either the extensional opening of the Algerian-Provençal Basin (e.g. Sanz de Galdeano, 1990) or extensional collapse and opening of the Alboran Sea (Platt and Vissers, 1989) during oblique convergence of Iberia and Africa. During thrusting, a foreland basin would have formed, into which deformation north-northwestward propagated piggy-back wise during the Late Eocene to Langhian (e.g. Lonergan, 1993) or during the Burdigalian to Serravallian (e.g. Sanz de Galdeano and Vera, 1992). If the Espuña rotated over more than 180° during the Early to Middle Miocene, the alleged earlier main trusting and north-northwest directed nappe transport (Late Eocene to Oligocene according to Lonergan, 1993) was originally south-southeastward directed. This raises several questions: what was the driving mechanism during the Palaeogene south-southeast directed thrusting and nappe transport and where was the foreland basin located, a basin wherein the originally south-southeastward thrusting propagated and erosional products of Internal Zone unroofing accumulated from the Late Eocene onwards (Lonergan and Mange-Rajetzky, 1994). The combination of more than 180° Miocene rotation with early (Late Eocene to Oligocene) thrusting implies, that the Betic foreland basin was situated between the southern margin of the South Sardinian block and the northern margin of Africa. Thus, at the site of the Maghrebian flysch trough (see fig. 7B), the sedimentary history of which is completely different from that of the Betic foreland basin (cf. Wildi, 1983).

A new model for the Palaeogene to Early Miocene history of the Espuña; conclusions

The new sedimentological and palaeontological data presented in this paper, especially the unexpected outcome of the analysis of the Espuña conglomerates suggesting a juxtaposition of the Espuña to the north Sardinian block during the Oligocene, call for a complete change of view on the palaeogeography and amount and timing of movements in the Western Mediterranean. Correlation with other Malaguide outcrops and comparison with the Sardinian Palaeogene results in the following model for the sequence of events in the Malaguide realm.

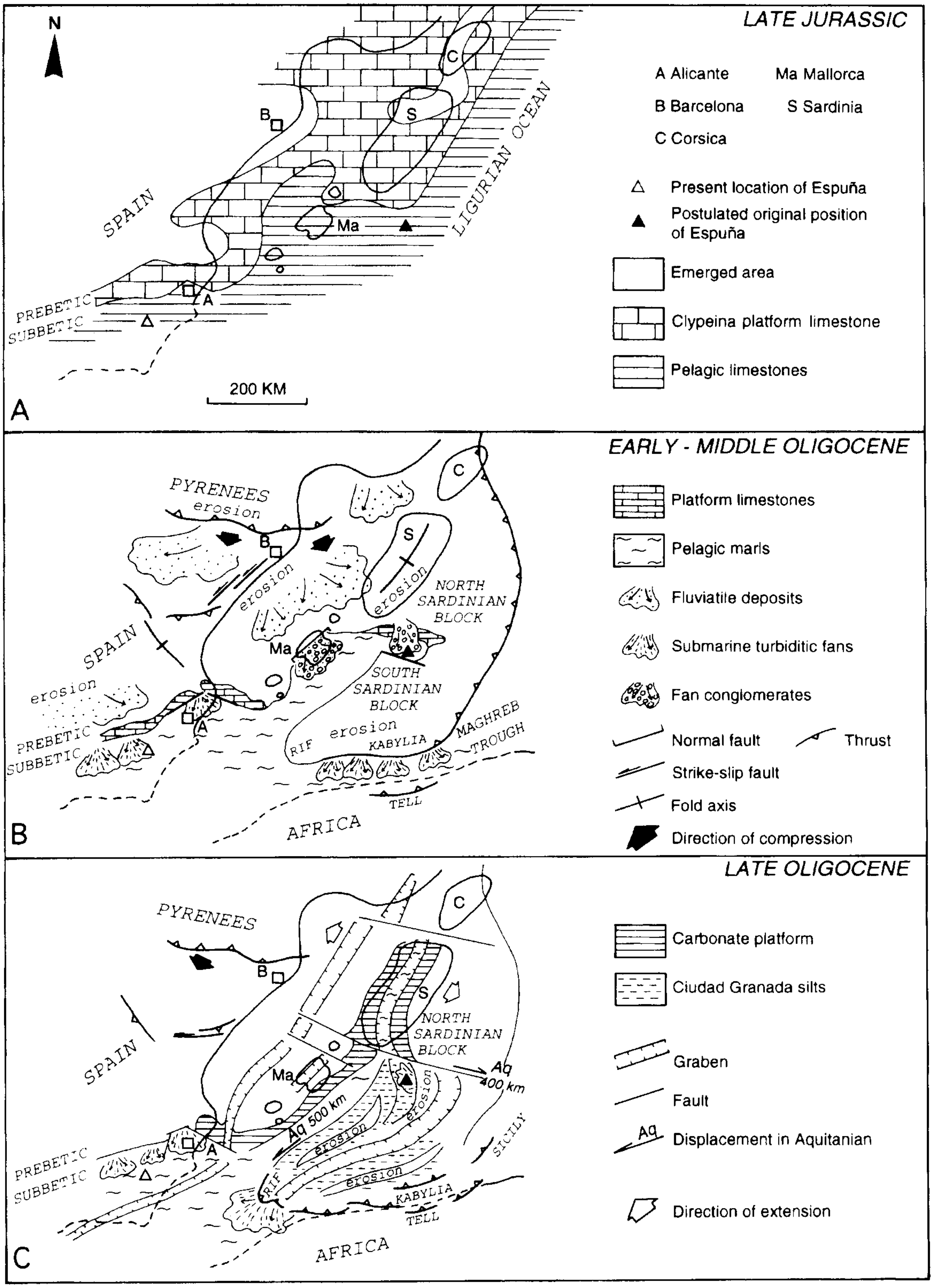

Fig. 7.—Palaeogeographic sketch maps of the Western Mediterranean for the Late Jurassic (fig. 7A), the Early to Middle Oligocene (fig. 7B) and the Late Oligocene (fig. 7C). Compiled after data from Alvaro *et al.* (1984), Azéma *et al.* (1979), Cherchi and Montadert (1982), De Jong (1991), Dercourt *et al.* (1986), Fourcade *et al.* (1977), Geel (1995; this paper), Guiméra (1984), Sanz de Galdeano (1990) and Wildi (1983).

During Early and Middle Eocene, the Espuña was part of a large carbonate platform covering a substantial area of the Malaguide realm, following a period of emersion and erosion during the Paleocene (Geel, 1973). In the Espuña, there is an overall facies distribution towards more sheltered marine and even continental deposition in the northeast. However, there are indications that the sediments were deposited upon differentially subsiding blocks given the major contrast in facies and thickness between tectonic units (Morron de Totana and Perona-Prat Mayor units). Previous folding during the Paleocene is unlikely, since the Lower Eocene rests everywhere in the Malaguides upon either the Cretaceous or on Upper Jurassic levels without a marked angular unconformity (Azéma, 1961; Paquet, 1969; Geel, 1973) carrying detritus derived from the Triassic, pelagic Upper Jurassic and Cretaceous. Whereas elsewhere in the Malaguides the detritus has its origin within the Malaguides, the presence of reworked *Orbitolina* in the Espuña points to the nearness of a shallow, middle Cretaceous platform unknown in the Malaguides proper. As a source, the north Sardinian block comes to mind of which the Eocene development forms the logical prolongation of the eastern Malaguides (absence of Paleocene, erosional unconformity down to the Triassic below a transgressive, marine Lower Eocene, fluviatile Middle and Upper Eocene; first Pyrenean phase in the late Middle Eocene (Chabrier, 1970; Cherchi and Montadert, 1982; Larangot, 1985).

Everywhere in the Malaguide realm, Upper Eocene and Lower to Middle Oligocene rocks are missing. Sedimentation started anew during the Late Oligocene (P22) (e.g. Soediono, 1971; Geel, 1973; Gelati and Steininger, 1984; Martín Algarra, 1987). The same holds for the Ghomarides of the Rif and the Kabylids (Wildi, 1983). In Spain, the Espuña always formed an exception, Upper Eocene (Auversian) would rest unconformably, but without a large hiatus upon the Lutetian. In the foregoing it is shown that also in the Espuña the Upper Eocene is missing, the «Auversian» of Paquet being Early Oligocene in age. Nevertheless, the Espuña section still is exceptional in comprising Lower to Middle Oligocene (P20-21) sediments. During the Early Oligocene (P20), the Espuña area was part of a shallow carbonate platform deepening southward. Compared with the underlying Middle Eocene rocks, there is a marked difference: during the Late Eocene to earliest Oligocene, the large Lower to Middle Eocene Malaguide carbonate platform that stretched from the Vélez Rubio Corridor to the Morron de Totana must have been broken, for the Vélez Rubio Corridor was uplifted and eroded, whereas the Espuña as a whole subsided and became the flooded margin of a northern platform (the former continental block of the Perona-Prat Mayor units included). The peculiar mature basal conglomerate and the reworking of Eocene fauna can be explained if we consider the north Sardinian block to be that northern platform.

The onset of shedding of huge volumes of extra-Malaguide carbonate clasts during the Middle Oligocene (P21) and the build-up of fan deltas at the southwestern margin of a platform under erosion, indicates a drastic change in detritus compared with the underlying strata. The source area was evidently suddenly uplifted, whereas the site of the Espuña shows increased subsidence. In our view, the source area must have been connected with the north Sardinian block, where large parts were emerged and eroded during the Middle Oligocene (fig. 7B). Whether the sudden onset of carbonate clast shedding is the result of a late phase of Pyrenean compression or to the onset of rifting (dated as 29.95 ± 1.5 Ma on Sardinia; Cherchi and Montadert, 1982) is not clear. Clast shedding terminated near the end of the Middle Oligocene. As is shown above, the Espuña limestone conglomerates represent a fan delta complex in an overall transgressive setting interrupted by two successive lowstands of relative sea level, the first producing fan delta A (a lowstand prograding wedge), the second one fan delta B (a shelf margin wedge topped by a shallow-water algal platform). Though onset and termination of carbonate clast shedding evidently is caused by tectonic processes, the presence of an eustatic component cannot be excluded (compare the Prebetic of Alicante, where coeval eustatic signals with local tectonic components have been observed during the Middle Oligocene, at 30 Ma and 29 Ma; Geel, 1995).

During the Late Oligocene (P22), the Espuña area underwent further subsidence (deposition of deep-water red silts over the entire area). Outside the Espuña, the Late Oligocene transgression of the Ciudad Granada formation spread over the Malaguide realm starting with the deposition of shallow-water sandstones and calcarenites showing rapid deepening upwards into red deep-water silts. This is the time of active rifting and rapid subsidence of the central graben on Sardinia (Cherchi and Montadert, 1982) and of rifting in the Prebetic of Alicante (Geel, 1995). It is also the time of extension followed by reheating observed in deeper Betic units (31-25 Ma; De Jong, 1991). In the Spanish Betic Cordilleras and their equivalents in the North African Rif, the Upper Oligocene Ciudad Granada transgressive sediments always rest upon higher, non-metamorphic levels of the Malaguides (predominantly the Triassic; Roep and MacGillavry, 1962;

Soediono, 1971; Geel, 1973; Martín Algarra, 1987), but in Kabylia upon their crystalline basement (Gélard *et al.,* 1973). In the Malaguides, nowhere an angular unconformity could be ascertained at the base of the Upper Oligocene, nor does the formation seal thrust contacts. It never has been found stratigraphically upon deeper Betic Complexes (Martín Algarra, 1987). The Ciudad Granada exclusively contains detritus from the Malaguide Complex and its crystalline basement. In the Espuña, the red silt facies is followed during the Late Oligocene to early Aquitanian by the build up of a submarine turbiditic fan complex carrying predominantly detritus derived from deeper Malaguide levels. From this we may conclude that the Late Oligocene drowning was accompanied by a change in source area of the detritus, from extra-Malaguide (Sardinian) to intra-Malaguide, down to the crystalline basement. The presence of clasts of crystalline basement in the Upper Oligocene sediments near Chirivel shows, that at this time the Spanish Malaguides were not yet detached from their crystalline basement (their Kabylian counterpart still shows this connection). This suggests that the Algerian Basin had not yet opened.

All above data combined lead to the conclusion that the Upper Oligocene to lowermost Aquitanian sediments of the Espuña (and the Malaguides elsewhere) were deposited during an extensional tectonic regime (fig. 7C). In this time, the Espuña was separated from the north Sardinian block by a deep basin wherein the Pliego submarine fans were deposited. Westward movement, thrusting, uplift and exhumation of deeper Betic complexes started after the deposition of the Ciudad Granada and Pliego formations (after the early Aquitanian) coeval with Sardinian rotation and opening of the Algerian Basin (cf. Cherchi and Montadert, 1982; Sanz de Galdeano, 1990). The oldest sediments that overlie both Malaguide and Alpujarride units, sealing the contacts and containing detritus from both complexes and the External Zone are of early Burdigalian age, to wit Espejos formation (Soediono, 1971; Geel, 1973), Las Millanas formation (Bourgois *et al.,* 1972), and Viñuela formation (Boulin *et al.,* 1973). Consequently, westward movement and emplacement of the Malaguides was completed by this time (cf. Sanz de Galdeano, 1990).

The above scenario differs considerably from the general accepted views on the palaeogeography of the Betic Internal Zone. In the sixties and seventies, the general thought became established that, since nappe movement is towards the north, the uppermost non-metamorphic nappe complex (Malaguide realm) had the most southern, that is «African» provenance. Consequently, the palaeogeographic order was thought to be (from north to south): Nevado-Filabride realm (the deepest metamorphic structural elements) - Alpujarride realm - Malaguide realm (references in Mäkel, 1985). This implies the thrusting of Europe underneath elements of the African plate in a south-dipping subduction zone, represented by the Nevado-Filabrides (e.g. Torres-Roldán, 1979). This view was challenged by Bourrouilh and Gorsline (1979, 1980), who pointed out that the Palaeozoic sediments of the Malaguide Complex, the Rif, the Kabylies, Minorca and Sardinia must have been deposited in one and the same basin and hence, were once all part of the Iberian block. De Jong (1993) argued that the northward directed nappe movements occurred as the last major thrusting phase during the Early Miocene and thus can not be used for palaeogeographic reconstructions. Recently it has been suggested that the metamorphic nappes of the Betic Internal Zone represent the deep structure of an unroofed Cretaceous subduction complex, where elements of the African plate have been thrusted underneath the overlying Iberian plate along a westnorthwestward dipping subduction zone (Bakker *et al.,* 1989; De Jong, 1991; Biermann, 1995). This implies a reversal of the previously accepted palaeogeographic order of Betic units and consequently, an «Iberian» provenance of the Malaguide Complex. The data presented in this paper support the latter view.

The model proposed in the present paper differs also considerably from the models of Paquet (e.g. 1966, 1974) and Lonergan (1993) for the Betic Cordilleras in general and the Espuña in particular. The main points of disagreement can be summarized as follows:

1. The «Auversian» (= Lower Oligocene) cannot considered to be a syn-deformational formation.
2. The Middle Oligocene limestone conglomerates are not the erosional products of Malaguide imbricated thrust slices but derived from an extra-Malaguide, Sardinian-type, eroded Upper Jurassic sheltered platform.
3. «Auversian» (= Lower Oligocene), Middle Oligocene and Upper Oligocene to lowermost Aquitanian sediments were not deposited into one and the same foreland basin.
4. In the Espuña, the Upper Eocene is missing and there is no continuous sedimentation from the Late Oligocene through to the Langhian. In the Vélez Rubio Corridor there are stratigraphic gaps comprising the Upper Eocene to Middle Oligocene and the major part of the Aquitanian.
5. There is no gradual deepening throughout the Palaeogene.
6. There is no continuous unroofing history of the Internal Zone orogenic edifice recorded in the

Palaeogene to Lower Miocene sediments of the Espuña.

7. Main thrusting in the Espuña is post- early Aquitanian in age.

8. With respect to the more than 200° clockwise rotation of the Espuña during the Early to Middle Miocene, suggested by Allerton *et al.* (1993): if the emplacement of the Malaguides is Oligocene in age, such a large rotation is quite impossible.

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