MESOZOIC PALAEOGEOGRAPHIC EVOLUTION OF THE EXTERNAL ZONES OF THE BETIC CORDILLERA[1]

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ABSTRACT

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The main events characterizing the Mesozoic palaeogeographic evolution of the External Zones of the Betic Cordillera are outlined. The Triassic sediments show a 'germanic' type facies over the entire region, ending with Late Triassic evaporites and variegated clays of Keuper facies. At the beginning of the Jurassic a transgression takes place, and a broad shallow-marine carbonate-platform environment appears.

During the Carixian (180 Ma) the carbonate platform breaks down leading to the differentiation of two large palaeogeographic units: the Prebetic Zone where shallow-water environments prevailed throughout the Mesozoic, and the Subbetic Zone where the sediments are clearly pelagic.

Within the Prebetic Zone, two palaeogeographic realms are differentiated: the External Prebetic showing important stratigraphic gaps in the Jurassic and Early Cretaceous sequence, and the Internal Prebetic with a thicker and more continuous stratigraphic sequence. Between the Prebetic and Subbetic Zones, a palaeogeographic realm is distinguished (Intermediate units) where turbiditic and pelagic materials were deposited. This zone corresponds approximately to a slope environment during most of Mesozoic times.

In the Subbetic Zone a marked differential subsidence occurs during the Jurassic, leading to trough (Median Subbetic) and swells (External and Internal Subbetic). In the Median Subbetic, the deposits consist mainly of marls, pelagic limestones, radiolarites and calcareous turbidites, with mafic volcanic and subvolcanic rocks. During the Cretaceous pelagic marls and marly limestones were laid down.

Mesozoic sedimentation took place along the southern margin of the European plate, in an Atlantic-type continental margin underlain by continental crust. Three-dimensional schemes, explaining the main palaeogeographic events are included.

INTRODUCTION

The Betic Cordillera forms the westernmost part of the alpine Mediterranean chains and occupies a belt in southern Spain about 600 km long and 200 km wide. Two main geological realms are distinguished: the *Internal* and the *External Zones*.

The Internal Zones consist mainly of overthrust units of Triassic and Palaeozoic materials; in some units, Mesozoic, Tertiary and probably Precambrian terraines can also be found.

The External Zones differ markedly from the Internal Zones. Palaeozoic materials are not exposed. They form the basement from which the Triassic to Lower Miocene cover was detached and thrust northwards along Triassic evaporites. The cover consists mainly of sediments with local submarine volcanic and subvolcanic mafic rocks of Jurassic and Early Cretaceous ages.

Sedimentation in the External Zones took place on a continental margin located along the southern border of the Spanish Meseta. During the Mesozoic the position of this marginal basin, in relation to the Internal Zones, was very different from that of the present. Most authors think that the Internal Zones occupied a position corresponding to the area of the present western Mediterranean, and that the juxtaposition of Internal and External Zones with the subsequent shortening and deformation of the cover of the External Zones, took place from the Eocene onwards, and especially during the Early Miocene.

As well as these two important zones it is possible to distinguish, within the Betic Cordillera, the *Campo de Gibraltar units* formed by allochthonous, largely turbiditic and olis-

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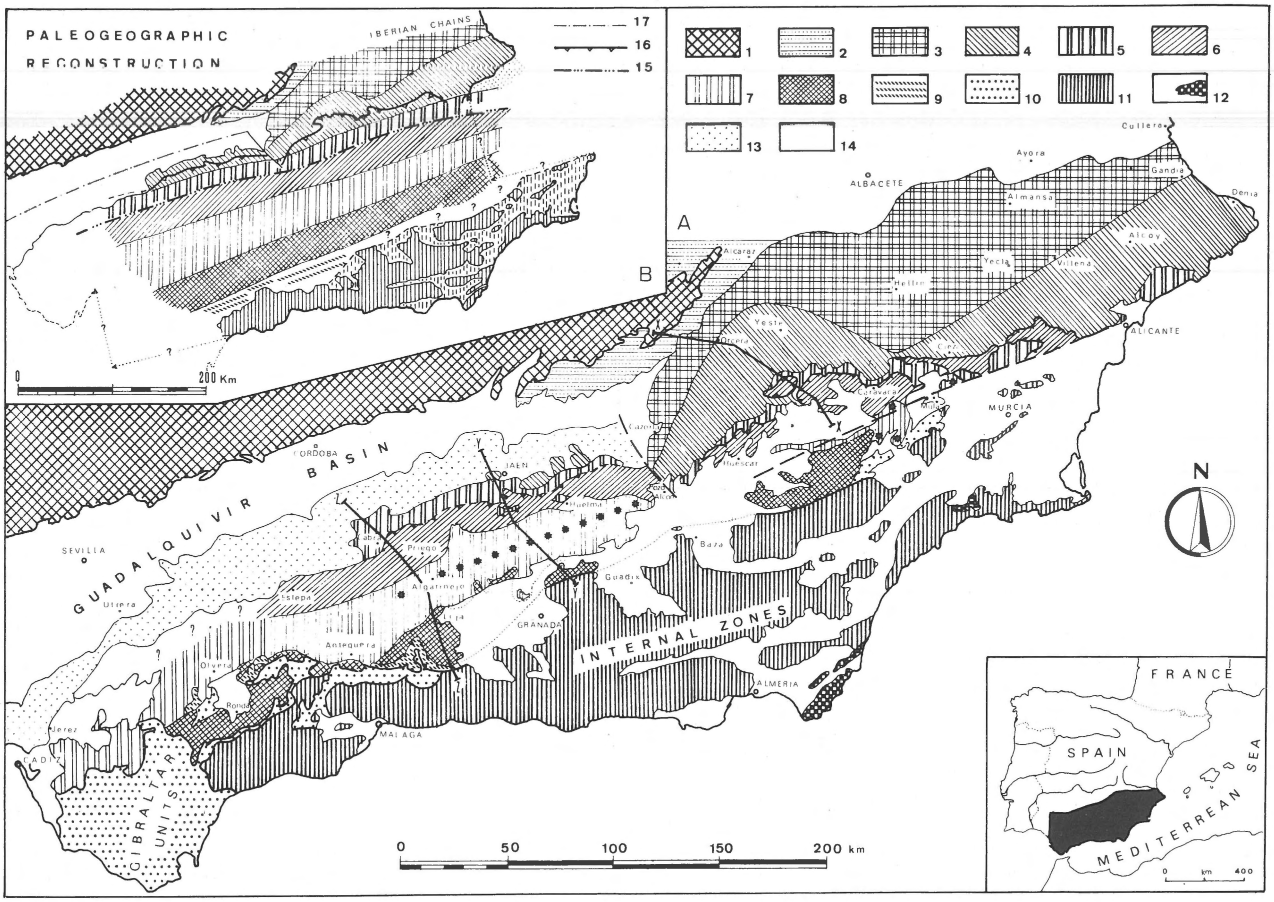

Fig. 1
Map showing the distribution of units in the External zones of the Betic Cordillera. Figure A displays the actual outcrops of the palaeogeographic units. In some areas (East of Cadiz and South of Caravaca) the interpretation is difficult because of tectonic complications and scarcity of Jurassic outcrops. On figure B the hypothetical palinspastic position of the palaeogeographic units during the Mesozoic is reconstructed. Shortening of the cover due to folding and overthrusting is estimated to about 2/3 of the original width. The Internal Zones have been separated from their actual position just enough to reconstruct the External Zones; their real position would have been much farther away during Mesozoic.

Legend. 1: Variscan massif of Meseta (Spanish plain); 2: Tabular cover of Meseta (Triassic and Jurassic); 3: External Prebetic; 4: Internal Prebetic; 5: Intermediate units between Prebetic and Subbetic; 6: External Subbetic; 7: Median Subbetic (the asterisks mark the main outcrops of submarine volcanic rocks intercalated in Jurassic formations); 8: Internal Subbetic; 9: Ultra-internal Subbetic; 10: 'Campo de Gibraltar' units (Numidian flysch and other turbiditic formations forming several nappes); 11: Internal Zones of Betic Cordillera (units are not separated); 12: Neogene-Quaternary volcanic rocks; 13: Guadalquivir basin areas, with subbetic nappes and olisthostromes (Guadalquivir units and Carmona nappe); 14: Neogene-Quaternary outcrops mainly in postorogenic basins; 15: Northern limit of Subbetic during the Mesozoic; 16: Actual position of Subbetic overthrust; 17: Northern limit of the Guadalquivir units olisthostromes.
x: cross-section of figure 2; y: cross-section of figure 3; Z: cross-section of figure 4.

thostromal formations, which range from Cretaceous to Early Miocene.

After the general alpine folding, postorogenic basins were filled by Neogene and Quaternary materials. Two types of basins exist; one marginal and with foredeep characteristics *(Guadalquivir Basin)* and others intramontaneous (Granada, Guadix-Baza, etc.). During the early Miocene, the Guadalquivir Basin constituted an important submergent trough where, by gravity gliding, some material of subbetic origin was inserted between formations of Miocene age, forming olisthostromes and nappes.

For the reconstruction of the palaeogeographic evolution of the External Zones we compiled the stratigraphic and tectonic data of the whole area, especially those of more recent works. Our main sources are included in the list of references. In these references we find the description of approximately 800 stratigraphic sequences of the Mesozoic formations. Palaeogeographic syntheses are found in: GONZALEZ-DONOSO ET AL. (1970), AZEMA ET AL. (1970, 1973, 1979) and HERMES (1978).

The first important subdivision of the External Zones of the Betic Cordillera was given by BLUMENTHAL (1927) and FALLOT (1948) both distinguishing the *Prebetic Zone* to the north of the *Subbetic Zone*. The first is characterized by shallow-water facies as opposed to the second where pelagic facies prevails.

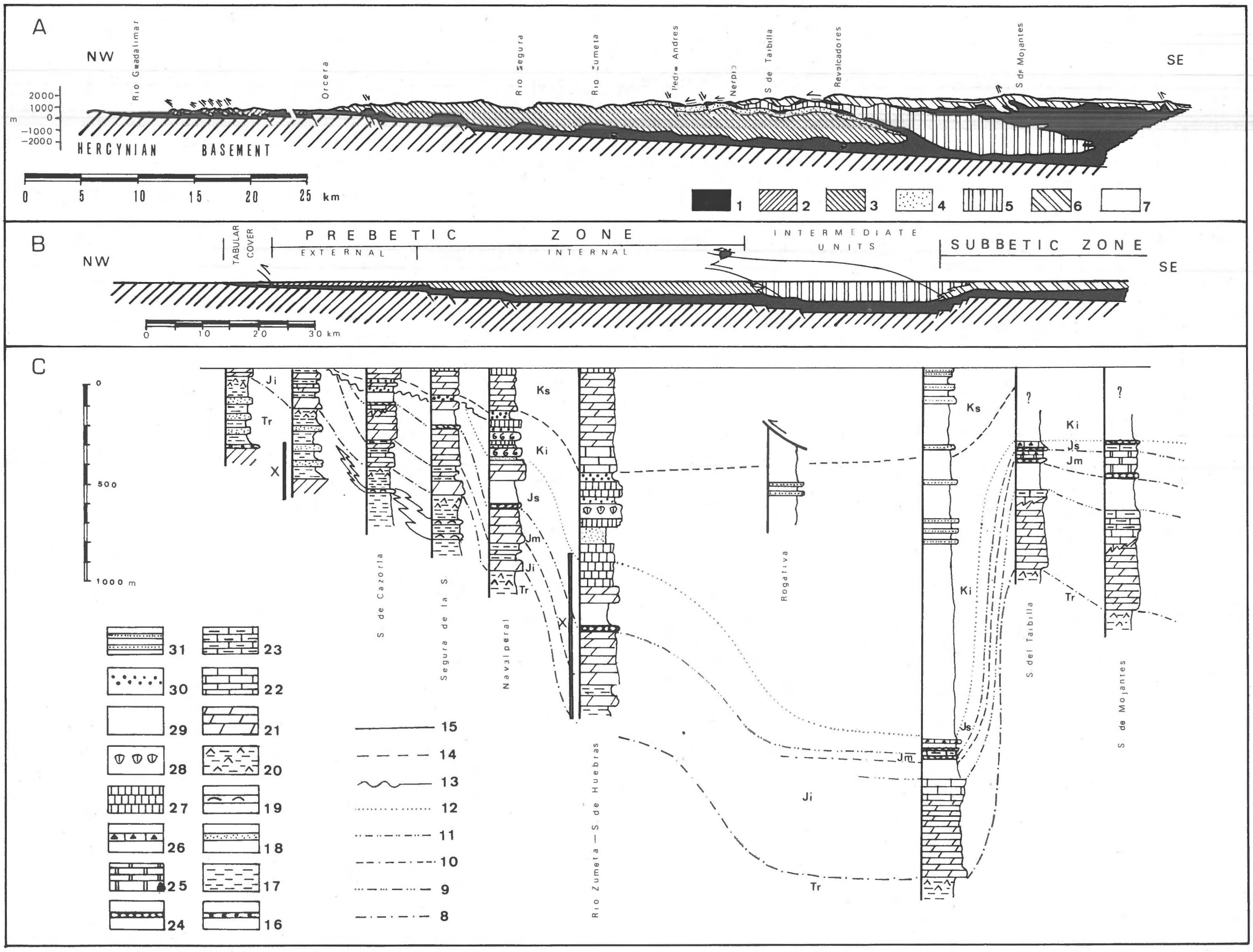

Fig. 2

Section across the External Zones in the Orcera-Nerpio region.

A: Structural cross-section; B: Palinspastic reconstruction (at a minor scale) at end of the Mesozoic; C: Correlation of the Mesozoic stratigraphic sequences located according to palinspastic interpretation.

Tr. = Triassic; Ji. = Lower Jurassic; JM. = Middle Jurassic; Js. = Upper Jurassic; Ki. = Lower Cretaceous; Ks. = Upper Cretaceous (Stratigraphic sequences marked by 'X' are interpreted by extrapolation).

Legend of figure A and B. 1: Triassic; 2: External Prebetic (Sierra Cazorla unit); 3: Internal Prebetic (Sierra Segura unit); 4: Tertiary sediments of Prebetic zone; 5: Intermediate units between Subbetic and Prebetic; 6: External Subbetic; 7: Neogene and Quaternary.

Legend of figure C. 8: Triassic-Liassic boundary; 9: Lower limit boundary of Domerian; 10: Liassic-Middle Jurassic boundary; 11: Middle-Upper Jurassic boundary; 12: Jurassic-Cretaceous boundary; 13: Base of Utrillas Formation; 14: Lower-Upper Cretaceous boundary; 15: Palaeogen-Cretaceous boundary; 16: Triassic basal conglomerate; 17: Green and red marls and clays; 18: Sands and sandstones; 19: Muschelkalk facies; 20: Keuper facies; 21: Dolomites; 22: Marine platform carbonates; 23: Cherty limestones and micritic levels; 24: Nodular limestones; 25: Filament and radiolarian limestones; 26: Calcareous breccias and turbidites; 27: Tidal flat and lagoonal limestones; 28: Reef limestones; 29: Pelagic facies (marls, marly limestones, micritic limestones with pelagic fauna); 30: Utrillas Formation; 31: Terrigenous turbidites interbedded in pelagic facies.

The contact between Prebetic and Subbetic Zones correspond to an important thrust. On the palinspastic map of figure 1B the present-day position of this contact and its position prior to the thrusting are marked.

In the Prebetic Zone, the *External* and *Internal Prebetic* are differentiated. Between the Prebetic and Subbetic Zones are the so-called *'Intermediate units'* with mixed stratigraphic features; they are overthrusted on the Prebetic and underlay the Subbetic tectonically. In the Subbetic, three main realms are distinguished mainly by their Mesozoic sequences: the *External,* the *Median* and the *Internal Subbetic.* The *Ultra-internal Subbetic* unit is locally differentiated along the southernmost areas. In the palaeogeographic reconstructions we do not consider this unit because of its local character and more southern origin.

A series of cross-sections, palinspastic reconstructions and stratigraphic correlations through the External Zones situated in the central region of the cordillera is presented in figures 2, 3 and 4.

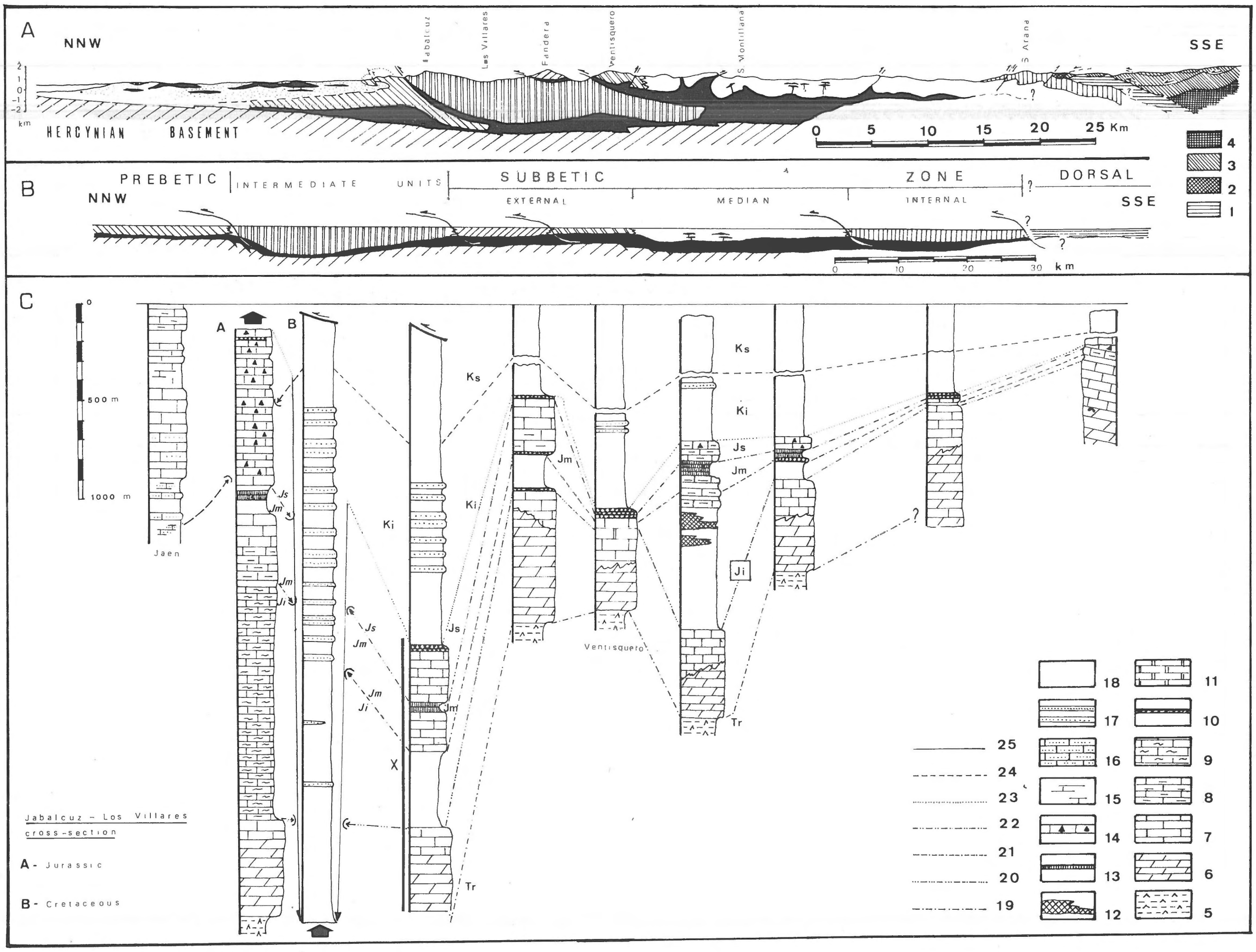

Fig. 3
Section across the External Zones in the Granada-Jaén region modified and completed. (after Rivas et al., 1979)
Tr. = Triassic; Ji. = Lower Jurassic; Jm. = Middle Jurrasic; Js. = Upper Jurassic. Ki. = Lower Cretaceous; Ks. = Upper Cretaceous. Stratigraphic sequences marked by 'x' are deduced by extrapolation.
A: structural cross-section; B: palinspastic reconstruction (minor scale) at end of the Mesozoic; C: Stratigraphic sequences correlated and located according to palinspastic reconstruction.
Legend of figures A and B. 1: 'Dorsale betique'; 2: Malaguide complex; 3: Alpujarride complex; 4: Nevado-Filabride complex; Other signs as in figure 4.
Legend of figure C. 5: Keuper facies; 6: Dolomites; 7: Marine platform limestones; 8: Cherty limestones and micritic levels; 9: Marls, marly limestones and limestones in general; 10: Nodular limestones; 11: Limestones with filaments and radiolarians, locally radiolarites; 12: Volcanic and subvolcanic mafic rocks; 13: Radiolarites and marls with cherty interbeds; 14: Calcareous turbidites and breccias; 15: Limestones and marly limestones laterally passing into marls; 16: Detritic limestones; 17: Terrigenous turbidites, interbedded in pelagic facies; 18: Pelagic facies (marls, marly limestones, micritic limestones with planktonic and pelagic fauna); 19: Triassic-Liassic boundary; 20: Lower boundary of Domerian; 21: Liassic-Middle Jurassic boundary; 22: Middle-Upper Jurassic boundary; 23: Jurassic-Cretaceous boundary; 24: Lower-Upper Cretaceous boundary; 25: Cretaceous-Palaeogene boundary.

STRUCTURE OF THE EXTERNAL ZONES

The External Zones of the Betic Cordillera show a tectonic style typical of sheared-off sedimentary cover. The main décollement is situated in the Triassic terraines; locally, there are other décollement levels at a stratigraphically higher position.

Although the structure of the External Zones differs along different traverses (compare Figs. 2, 3 and 4), the allochthonous character of the Subbetic Zone, with internal nappe structure, appears as a consistent feature contrasting with the relatively autochthonous character of the Prebetic.

The Prebetic zone shows an important shortening of the cover, in some sectors, estimated at 15 km (DABRIO & LOPEZ-GARRIDO, 1970). The general structure of the Prebetic is shown in figure 2A. The tabular cover of the Variscan Meseta at the external side of the Prebetic Zone is not affected by Alpine deformation (LOPEZ-GARRIDO, 1971-b). The northern margin of

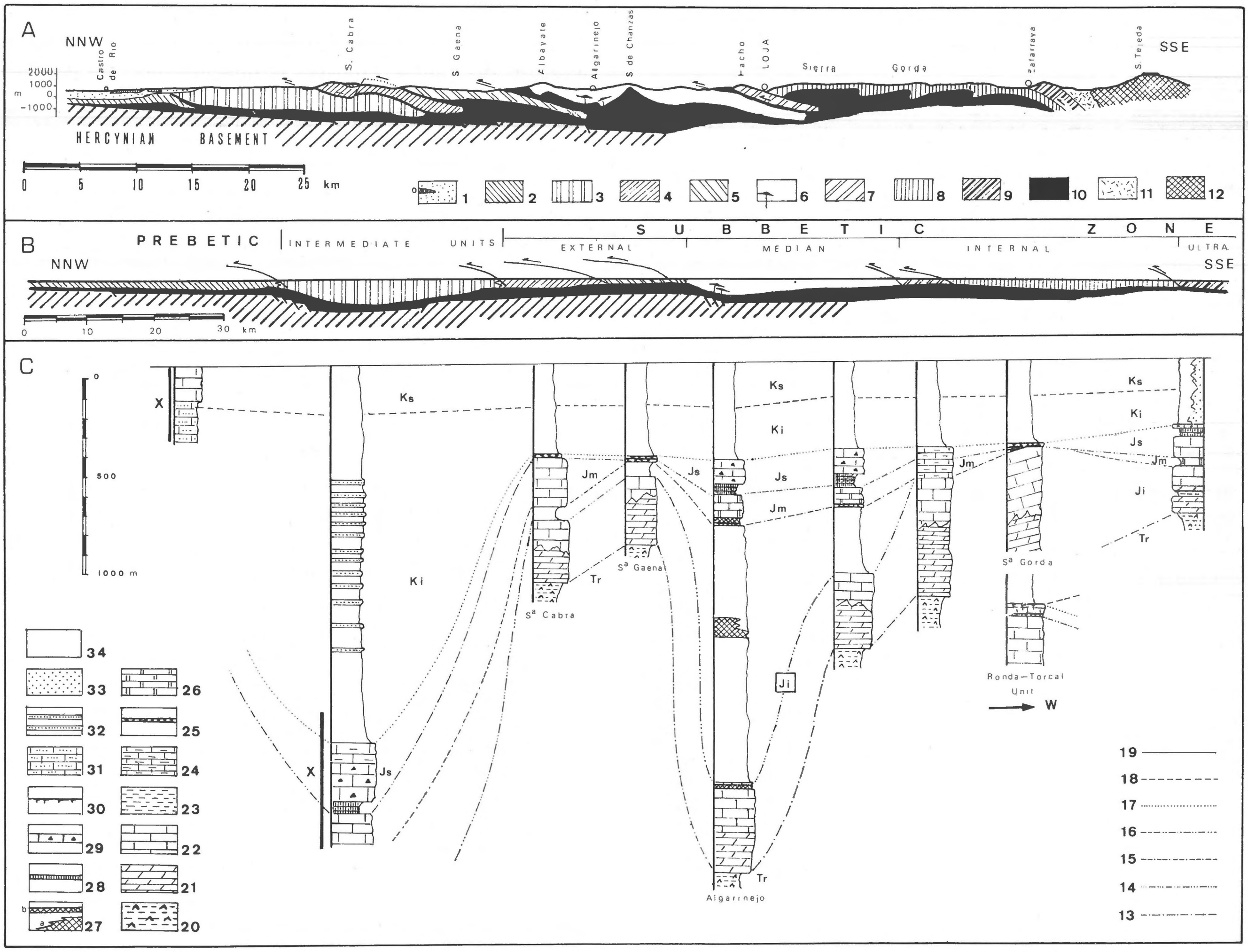

Fig. 4
Section across the External Zones in the Loja-Cabra region. (After RIVAS et al., 1979; modified and completed).
Tr. = Triassic; Ji. = Lower Jurassic; Jm. = Middle Jurassic; Js. = Upper Jurassic; Ki. = Lower Cretaceous; Ks. = Upper Cretaceous
Stratigraphic sequences marked by 'X' are deduced by extrapolation.
A: Structural cross-section; B: Palinspastic reconstruction (at a minor scale) at the end of the Mesozoic; C: Correlation of the Mesozoic stratigraphic sequences located according to palinspastic reconstruction.
Legend of figures A and B. 1: Miocene of Guadalquivir basin (o: olisthostromes of Subbetic origin); 2: Prebetic zone; 3: Intermediate units between Prebetic and Subbetic; 4: Northern External Subbetic (Sierra de Cabra unit); 5: Southern External Subbetic (Sierra de Gaena unit); 6: Median Subbetic, with submarine volcanism; 7: Internal Subbetic (Parapanda-Moclin unit); 8: Internal Subbetic (Sierra Gorda unit); 9: Ultra-internal Subbetic (Zafarraya and Gallo-Vilo units); 10: Triassic terraines; 11: 'Campo de Gibraltar' units; 12: Internal zones (Alpujarride complex).
Legend of figure C. 13: Triassic-Liassic boundary; 14: Lower boundary of Domerian; 15: Liassic-Middle Jurassic boundary; 16: Middle-Upper Jurassic boundary; 17: Jurassic-Cretaceous boundary; 18: Lower-Upper Cretaceous boundary; 19: Cretaceous-Palaeocene boundary; 20: Keuper facies; 21: Dolomites; 22: Marine platform limestones; 23: Red marls; 24: Cherty limestones and micrite levels; 25: Nodular limestones; 26: Limestones with filaments and radiolarians, locally radiolarites; 27: Mafic volcanic and subvolcanic rocks; 28: Radiolarites and marls with cherts; 29: Calcareous turbidites and breccias; 30: Erosion surfaces with sedimentary infills; 31: Detrital limestones; 32: Terrigenous turbidites interbedded in pelagic facies; 33: Detrital, partially turbiditic facies; 34: Pelagic facies (marls, marly limestones, micritic limestones with planktonic and pelagic fauna).

the Prebetic zone (External Prebetic) shows a reverse-fault imbricated structure also with narrow overturned folds, both up dipping toward the Meseta. The Internal Prebetic shows a gentler fold and fault structure. The southern margin of the Prebetic Zone is overthrusted by the Intermediate units, which in their turn are overthrusted by Subbetic nappes (Figs. 3 and 4).

Towards the East (provinces of Murcia and Alicante, Fig. 1) the structure of the Prebetic Zone is simpler with folds and normal faults and, occasionally, overthrusts and mushroom folds, which in many cases are linked to diapiric structures (RODRIGUEZ-ESTRELLA, 1977).

An important feature which is not displayed by the cross-sections, but that is common to the entire Prebetic is the occurrence of major transcurrent faults, that cut across preexisting structures and presently have a conspicuous seismic activity.

The cross-sections of figures 3 and 4 terminate northwards in the Internal Prebetic and the Intermediate units; the more external units are covered by Neogene sediments of the Guadalquivir Basin. Klippes of Subbetic origin and Prebetic tectonic windows are common.

The structure of the Subbetic zone is illustrated in figures 3 and 4. Every tectonic unit has been overthrusted to the north and covered to the south by the next higher tectonic unit. The boundaries of the tectonic units in general coincide with those of the Mesozoic palaeogeographic units; in some regions (Fig. 3) a transition between two palaeogeographical realms takes place along continuous outcrops in a single tectonic unit.

During the latest Oligocene and Early Miocene the main overthrusts of the Subbetic Zone were thrust over the deepest portions of the submergent trough of the innermost part of the realm of the Prebetic and Intermediate units. West of Cazorla some of the Subbetic units extend beyond this limit across the Prebetic into the Guadalquivir basin where they form olisthostromes and gravitational nappes intercalated in Burdigalian sediments. This ensemble is called the *Guadalquivir allochthonous units* (GARCIA-ROSSELL, 1973). The present outcrop position of the olisthostromes is shown in figure 1A, whereas their northern extension as inferred from borehole data is indicated in figure 1B (PERCONING & MARTINEZ, 1977).

PALAEOGEOGRAPHIC REALMS

In the map of figure 1 the units of the External Zone are outlined. Each of the units is defined by its Mesozoic stratigraphic sequence and palaeogeographic evolution.

Prebetic zone

The External Prebetic is characterized by the thinness of the Mesozoic cover, important Jurassic outcrops and a general stratigraphic gap from the Portlandian[4] to the Neocomian. We here refer to the characteristics in the sector situated between the meridians of Cazorla and Cieza.

The Triassic, near the margin of the Meseta, is formed exclusively by classic sediments, but towards the interior of the basin carbonate of Muschelkalk facies appears (Fig. 2C). In the Lower Jurassic dolomite predominates with some marl and clay interbeds of increasing frequency upwards. The Middle Jurassic also consists of dolomites with local limestones at the top; the Upper Jurassic presents nodular limestones in the Middle-Upper Oxfordian and marls and marly limestone in the Lower Kimmeridgian, both with abundant ammonite fauna. The uppermost Jurassic has only very local outcrops, in Purbeck facies. The Upper Cretaceous is thin and consists of Cenomanian dolomites and of lagoonal deposits of the Senonian. During the Palaeogene the External Prebetic emerged; the Lower Miocene is transgressive and directly overlies the Mesozoic rocks.

The Mesozoic cover of the Internal Prebetic is thicker than that of the External Prebetic, with fewer stratigraphic gaps, which are located along the marginal areas of the zone or associated with diapiric structures of Triassic rocks.

The Early and Middle Jurassic sediments appear only in small outcrops and have characters similar to those of the External Prebetic; on the other hand the Upper Jurassic (Upper Kimmeridgian and Portlandian) is well developed and mainly in Purbeck facies. The Early Cretaceous sediments show a variety of facies becoming increasingly pelagic basin inwards. The Urgonian facies is developed in the Aptian-Albian (GARCIA-HERNANDEZ, 1979) and is overlain by sands and clays with strong continental influence, belonging to the Utrillas Formation. Below this there occur stratigraphical gaps with different and increasing range increasing towards the external border of the Prebetic basin. The Upper Cretaceous, mainly carbonates (dolomites and limestones), is clearly pelagic. The Palaeogene is well developed in the southernmost areas of this realm. It is mainly of shallow-marine facies with continental and coastal episodes. The Lower Miocene is represented by calcarenites and marls with *Globigerina*.

Intermediate units

Between the Subbetic and Prebetic Zones a palaeogeographical realm with peculiar features is individualized (see Figs. 2, 3 and 4). During the Mesozoic and Tertiary it formed a subsiding trough, in which a sequence was deposited with characteristics 'intermediate' between the Subbetic and the Prebetic. In the South of Jaen (Jabalcuz-Los Villares unit) the Mesozoic cover is exceptionally thick (Fig. 3).

The Jurassic sequence is thick and presents similar features to those of the more subsident parts of the Subbetic zone, with radiolaritic levels at the boundary Middle/Upper Jurassic, and turbidites in the Upper Jurassic.

The very thick Lower Cretaceous presents turbiditic levels of Barremian-Albian ages. The upper Cretaceous and Palaeogene are pelagic, with gravitational slumps, olisthostromes and turbidites (HOEDEMAEKER, 1973) that reach their greatest development during the Early Miocene.

Subbetic zone

In the central sector of the Betic Cordillera, three sedimentary realms have been distinguished based on facies and thickness of the Jurassic. They are: *External Subbetic, Median Subbetic* and *Internal Subbetic* (GARCIA-DUEÑAS, 1967; FONTBOTÉ, 1970). The Cretaceous is very uniformly developed. The Lower Cretaceous is formed by light-coloured marls and marly limestones with abundant ammonites. The Upper Cretaceous is present in 'couches rouges' facies with planktonic foraminif-

[4] Portlandian is used instead of Tithonian because of the occurrence of shallow-water facies.

era similar to that of other Alpine Mediterranean regions (e.g. 'Scaglia rossa' in the Apennines). The Palaeogene presents very scarce outcrops of pelagic facies with interbedded turbidites and olisthostromes (HOEDEMAEKER, 1973; COMAS, 1978).

The sequence of the External Subbetic (Figs. 2, 3 and 4C) is characterized in the Upper Jurassic by nodular limestones of limited thickness and by the absence of radiolaritic facies in the Jurassic. In the region between the transversals of Granada-Jaen (Fig. 3) and Loja-Cabra (Fig. 4) two palaeographic realms can be distinguished, according to the facies of the Middle Jurassic; the northern one is thick and formed by oolithic limestones, the southern one consists of thin nodular limestones (Fig. 5C). This differentiation is of local character since eastwards (Fig. 2) and westwards the facies are the same all over the region, consisting mainly of nodular limestones in the Upper and of varying lithologies in the Middle Jurassic (marls, limestones, etc).

The Median Subbetic is the most subsiding realm in the subbetic and shows pelagic marls and marly limestones in the upper Liassic, with intercalated volcanic and subvolcanic mafic rocks (VERA, 1966). During the Middle Jurassic marly limestones very rich in radiolarians and Bositra 'Filaments' were deposited. Within them abundant intercalations of volcanic and subvolcanic rocks occur (e.g. FONTBOTE & QUINTERO, 1960; GARCIA-YEBRA ET AL, 1972; PAQUET, 1967). In the lower part of the upper Jurassic, radiolarites (in part Middle Jurassic) and marls rich in radiolarians appear. The uppermost Jurassic presents breccias and carbonate turbidites interlayered with marly and micritic limestones. In the Upper Jurassic interbedded volcanic rocks are locally abundant (GARCIA-ROSSELL, 1973; COMAS, 1978).

The Jurassic sequences of the Internal Subbetic are entirely formed by carbonate sediments, with stratigraphic gaps that include the late Liassic and, more locally, the Middle Jurassic. The Malm, as the External Subbetic, consists of thin nodular limestones with abundant ammonites, that permit accurate dating (LINARES & VERA, 1965; SEQUEIROS, 1974; OLORIZ, 1976).

In the southern parts of the Subbetic, allochthonous terraines appear that are interpreted as of still more southerly origin than the Internal Subbetic. They correspond to several units that can be included in the *Ultra-internal Subbetic* (CRUZ-SANJULIAN, 1974) formed in a subsiding trough similar to that of the Median Subbetic which developed radiolaritic facies in the late Jurassic.

MESOZOIC PALAEOGEOGRAPHIC EVOLUTION

The palaeogeographical features of the External Zones during Jurassic and Cretaceous times are summarised in figure 5. Figures 6, 7 and 8 show a three-dimensional interpretation of three characteristic stages and the corresponding sedimentary environments, facies and thickness-distribution patterns. The reconstructions are valuable mainly for the central part of the Betic Cordillera, between the meridians of Caravaca and Antequera.

The Variscan craton of the Spanish Meseta was a continental area continuously eroded during the Mesozoic; at some periods the more external Prebetic areas emerged and were affected by erosion (Figs. 5D, E, F).

Triassic

In spite of the great extension of Triassic outcrops both 'autochthonous' and allochthonous sections for detailed stratigraphic analysis are rare.

The lithofacies are closely similar to those of the 'Germanic Triassic' and the term 'germanic-andalousian facies' is therefore used. Three main lithological units are recognized: Buntsandstein, Muschelkalk and Keuper.

In the tabular cover of the Meseta the Triassic is composed of red fluviatile clastic sediments covered by evaporitic levels (FERNANDEZ, 1975); to the South at the borders of the Prebetic zone, the marine Muschelkalk facies begins (LOPEZ-GARRIDO, 1971-b). Triassic sediments become gradually thicker, up to 2000 m in some areas of the Subbetic zone (SANZ DE GALDEANO, 1973) toward the interior of the External Zones.

The Buntsandstein facies has been dated by the bivalve fauna in only one place (BUSNARDO, 1975): as uppermost Werfenian. During the Early Triassic the sedimentation supposedly took place in lagoonal and fluvial environments.

The Muschelkalk facies consists of limestones, marly limestones and dolomites sedimented in marine or lagoonal environments. Its Middle Triassic age is established by ceratites, bivalves and conodont faunas from many places (LOPEZ-GARRIDO, 1971-b; BUSNARDO, 1975; HIRSCH & PARNES, 1977). The Muschelkalk facies disappears gradually towards the Meseta (Fig. 2C) by an irregular decrease in thickness. The maximum thickness including clastic intercalations is 200-300 m. This facies change is the main palaeogeographic feature recorded in the External Zones during Triassic times.

The Keuper facies basically consists of red and green variegated clays with subordinated interbedded sands, sandstones, and carbonate rocks of variable thickness and extension. Important amounts of gypsum up to 300 m thick in outcrop and salt more than 100 m in the subsurface are recorded. Fossils are rare, mainly because of the preservational conditions, and consist of Estheridae of the Late Triassic. The sedimentary environment is comparable to that of the Buntsandstein, however, with larger marine influence and with minor detrital influx.

An interesting feature is the presence of important doleritic and other mafic intrusions, specially in the Subbetic zone.

Pre-Domerian Liassic

The beginning of the Jurassic coincides with an important transgression which affects the entire area including the tabular cover of the Meseta. A shallow carbonate platform is

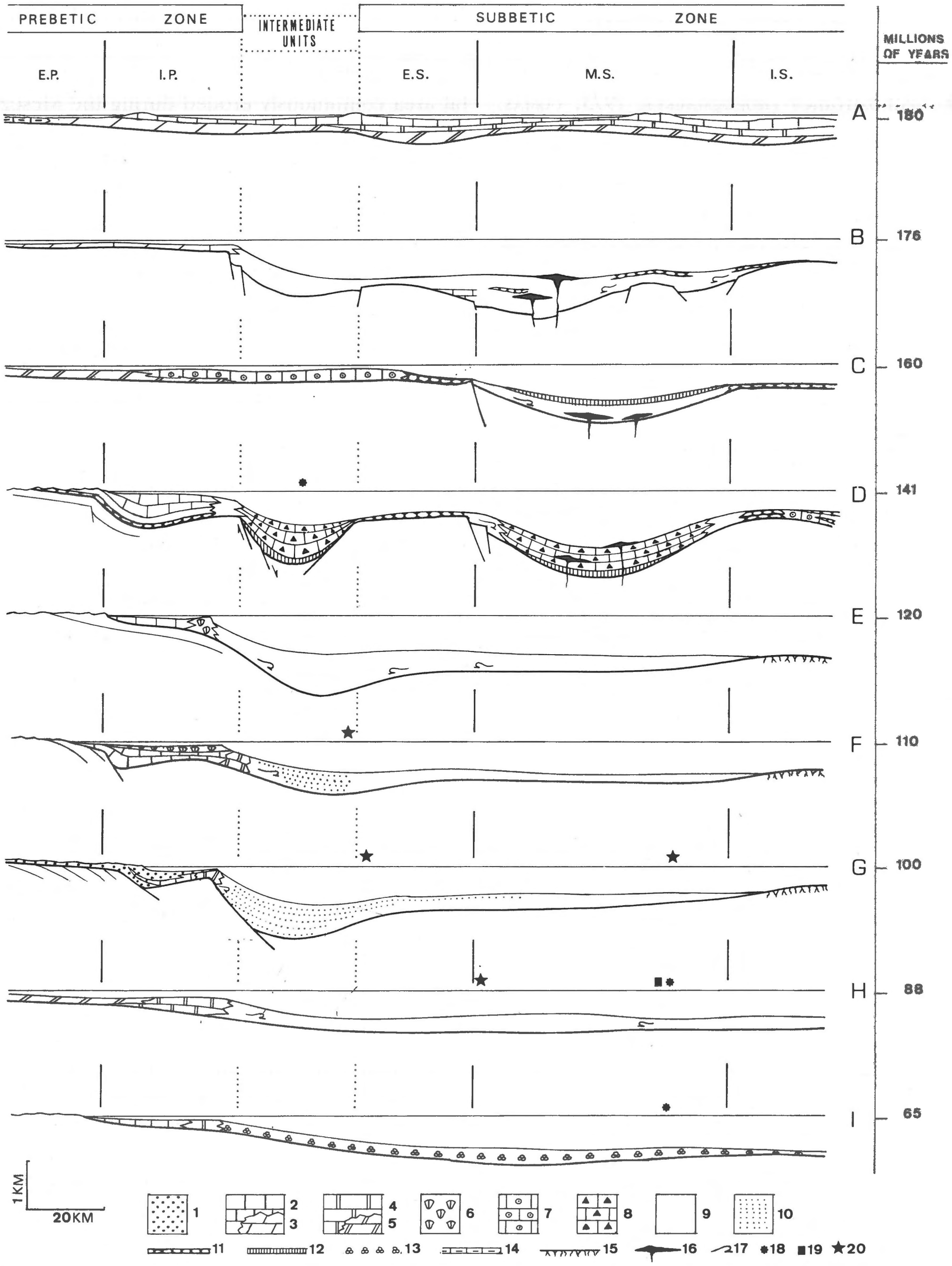

Fig. 5
Palaeogeographic evolution.

A: Palaeogeographic reconstruction (P.r.) for Carixian times and facies distribution (f.d.) of pre-domerian Liassic; B: P.r. for latest Liassic times and f.d. of Liassic; C: P.r. for Middle-Late Jurassic boundary and f.d. of Middle Jurassic; D: P.r. for Jurassic-Cretaceous boundary and f.d. of the Late Jurassic: E: P.r. for Hauterivian and f.d. of Neocomian; F: P.r. for early Aptian/late Aptian boundary and f.d. of Barremian-early Aptian; G: P.r. for late Albian and f.d. of late Aptian-Albian; H: P.r. for latest Turonian and f.d. of Cenomanian-Turonian; I: P.r. for Maestrichtian and f.d. of Senonian.

1: Fluviatile-influenced sands and lutites (Utrillas Formation); 2: Tidal-flat and lagoonal carbonate rocks; 3: Idem, dolomitized; 4: Open-marine carbonate-platform facies; 5: Idem, dolomitized; 6: Reefs; 7: Oolite bars; 8: Limestones with chert and pelagic marls with calcareous turbidite interbeds; 9: Marls and marly limestones of pelagic facies; 10: Terrigenous turbidites; 11: Nodular limestones; 12: Marly limestones with radiolarians, and radiolarites; 13: Pelagic marls with abundant planktonic Foraminifera; 14: Tidal-flat carbonated rocks with red clay interbeds; 15: Erosion surfaces; 16: Submarine volcanism; 17: Synsedimentary slumps and breccias; 18: Calcareous breccia; 19: Local olisthostromes; 20: Triassic diapirs rising from the sea floor.

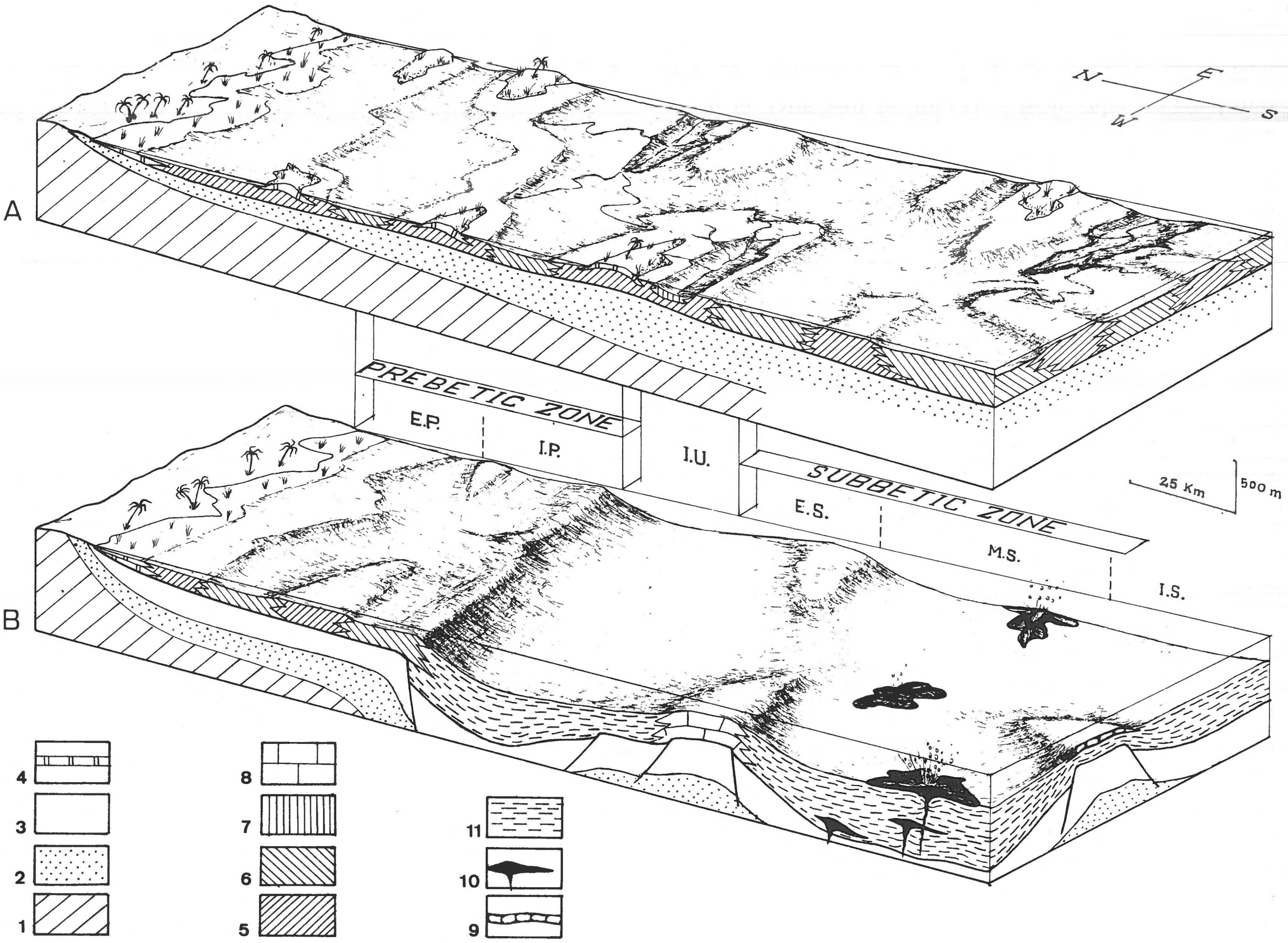

Fig. 6
A: Palaeogeographic reconstruction for pre-domerian Liassic.
B: Palaeogeographic reconstruction for late Liassic.
1: Palaeozoic basement; 2: Triassic; 3: Predomerian dolomites and limestones; 4: Supratidal environments; 5: Intertidal environments; 6: Subtidal environments; 7: Areas of pelagic sedimentation within platform; 8: Carbonate sand bars; 9: Rosso Ammonitico facies; 10: Volcanic and subvolcanic rocks; 11: Pelagic facies.

developed with episodes of tidal-flat deposition and locally with an open-sea-influenced facies, suggesting the presence of channels, gulfs and embayments (Figs. 5A and 6A).

The bulk of the sediments is a thick sequence of limestones of Hettangian-Sinemurian age, more or less dolomitized. This dolomitization usually affects only the lower part of the formation, but sometimes also the entire pile of shallow-water carbonates. The study of the microfacies reveals diverse textures: oosparites, biosparites, intrasparites and biomicrites with abundant algal debris (Codiaceae, Dasycladaceae, Cyanophythae, etc.) and with agglutinated Foraminifera (Lituolidae), other calcareous Formanifera and invertebrate remains (Bivalvia, Gastropoda, Ostracoda, Echinodermata, Brachiopoda, etc.). In the upper part of the sequence, *Lithiothis* and *Opisoma* limestones may occur. The environment is interpreted as a very shallow carbonate platform, with the different textures reflecting various energy regimes according to the relative position to the tidal level (GARCIA-HERNANDEZ, ET AL., 1976). The oolitic and intraclastic limestones with abundant algal remains reflect intertidal bars, while micritic sediments with larger Foraminifera *(Orbitopsella, Haurania)* are assumed to be from subtidal or lagoonal environments.

The Carixian is represented by a thin sequence of crinoidal and oncolitic limestones. Carixian (mostly middle Carixian) and, locally, lower Domerian ammonites are frequently found (RIVAS, 1972). The Lower part of this formation shows similar characteristics to those described from Sicily by JENKYNS (1971). However, the upper part of some sequences contains stratigraphic features (mud-cracks; herringbone crossbedding) indicative of a very shallow depositional environment (intertidal and even supratidal).

On top of these limestones a 'hard-ground' occurs, coinciding with a stratigraphical gap, preceeding partial break down of the carbonate platform.

Figure 6A shows a model for the environment and facies pattern for Pre-Domerian Liassic times. It comprises a shallow carbonate platform with intertidal and emerged (supratidal) areas, the latter mainly during Carixian times. Figure 6 B displays the equivalent model for the time after the breakdown of the carbonate platform.

Post-Domerian Jurassic

During the late Liassic (Figs. 5B and 6B) the Prebetic and Subbetic Zones were clearly differentiated. In the Prebetic Zone sedimentation of platform carbonates continued, whereas in the Subbetic pelagic conditions were established.

Within the Subbetic zone, pronounced changes occur in facies and thickness due to differential sinking of the basin floor. Thick marly basinal deposits with submarine volcanic rocks interbedded laterally changing to reduced and condensed sequences of deposits 'Rosso ammonítico' facies can be found. The extent of the area with little or no sedimentation varied in time (RIVAS, 1972; SEYFRIED, 1978).

During the Middle Jurassic, the southern border of the carbonate platform occupied a more southerly position than it did in the late Liassic (Fig. 5C.) In the Prebetic Zone, Intermediate units and part of the External Subbetic (Cabra and Pandera units) formed part of this platform (Figs. 4 and 3 respectively). The main deposits consist of oolitic limestones, locally passing into bioclastic or cherty micritic limestones, suggesting the existence of areas protected from waves and currents. In the rest of the Subbetic zone, troughs and swells were differentiated in the basin, as a consequence of differential subsidence. It caused frequent changes of facies and thickness. The volcanic activity still went on and reached its maximum in the Aalenian and Bajocian.

The differentiation into troughs and swells of the basin persisted throughout the Late Jurassic, resulting in a most characteristic constant palaeogeographic pattern.

In the Prebetic zone, after the Oxfordian, a sedimentation began of more or less pelagic type almost to the shoreline. This led to the deposition of nodular limestones during the middle and late Oxfordian and of marls and marly limestones during the Kimmeridgian. Thick Portlandian formations form their cover, composed of carbonates laid down in a tidal-flat. The limit between the External and the Internal Prebetic corresponds to the northern shore-line during this time.

In the Intermediate units, a strongly subsiding trough is developed in which radiolaritic sediments overlain by calcareous turbidites are deposited with a maximum thickness to the south of Jaen.

The differential sinking in the Subbetic zone led to different sedimentary areas by which the External, Median and Internal Subbetic realms are defined (Fig. 7A). The thicker sequence corresponds to the Median Subbetic and contains radiolarites as well as calcareous turbidite facies with submarine volcanic rocks. To the North and South (External and Internal Subbetic), the Late Jurassic formations consist of nodular limestones ('Rosso Ammonítico' facies) of much more reduced thickness.

Lower Cretaceous

The Lower Cretaceous in the Prebetic zone is continuous with the uppermost Jurassic and consists, in the Berriasian, of limestones with marls, deposited in a fluctuating environment, which repeatedly evolves from supratidal (laminated limestones with mudcracks) to subtidal limestones and marls with *Clypeina jurassica* FAVRE. Eastwards, the presence of some calpionellids denotes an open marine influence. Nodular limestones with ammonites and calpionellids in the basal Berriasian and white marly limestones throughout the rest of the Lower Cretaceous are the predominant lithologies in the Intermediate units and the Subbetic zone. In the latter, these facies persist in the entire Lower Cretaceous. while in the former they only extend up to the Hauterivian. In some regions of the Internal Subbetic (Ronda-Torcal unit) the Lower Cretaceous is absent (Fig. 7B) due to a submarine erosion documented by a non-depositional surface between the Upper Jurassic and the Upper Cretaceous (HOPPE, 1968; PEYRE, 1974; BOURGOIS, 1978).

In the Prebetic zone the shore-line kept approximately to its uppermost Jurassic position, with emersion and erosion in the External Prebetic. The Internal Prebetic now presents very diverse facies. The Lower Valanginian facies, for instance, change from West to East from tidal-flat, to lagoonal, reef and even to pelagic (Fig. 5E). In the eastern region the Valanginian-Hauterivian boundary is characterized by sandy marls with ammonites and *Exogyra* remains, while in the west unfossiliferous lutites and sands denote a strong fluviatile influence (Weald facies).

An important palaeogeographic change took place in the Barremian; the Internal and part of the External Prebetic were occupied by marshes and lagoons where rich organic materials, intraclastic limestones and limestones with abundant Charophyte, were deposited (FOURCADE, 1970; JEREZ, 1973; AZEMA, 1977; GARCIA-HERNANDEZ, 1978; RODRIGUEZ-ESTRELLA, 1978). These sediments record the beginning of a cycle that becomes gradually more marine during the Early Aptian (Bedoulian) ending with subtidal facies at the Bedoulian-Gargasian boundary (GARCIA-HERNANDEZ, 1978, 1979). The maximum transgression occurred in the late Bedulian with coral reef facies and sandy calcarenite bars with *Palorbitolina*.

By Gargasian times the Prebetic zone was almost completely invaded by continental terrigenous materials. In the External Prebetic these sediments rest unconformably on different Jurassic formations (FOURCADE, 1970; AZEMA 1977; GARCIA-HERNANDEZ, 1978; RODRIGUEZ-ESTRELLA, 1978). Later, predominantly in the Internal Prebetic, marine environments are recorded, mostly of restricted marine, but also of open marine character (limestones with *Mesorbitolina* and *Pseudotoucasia*). Renewed fluviatile sedimentation occurred in the late Albian with the deposition of clays and sands rich in

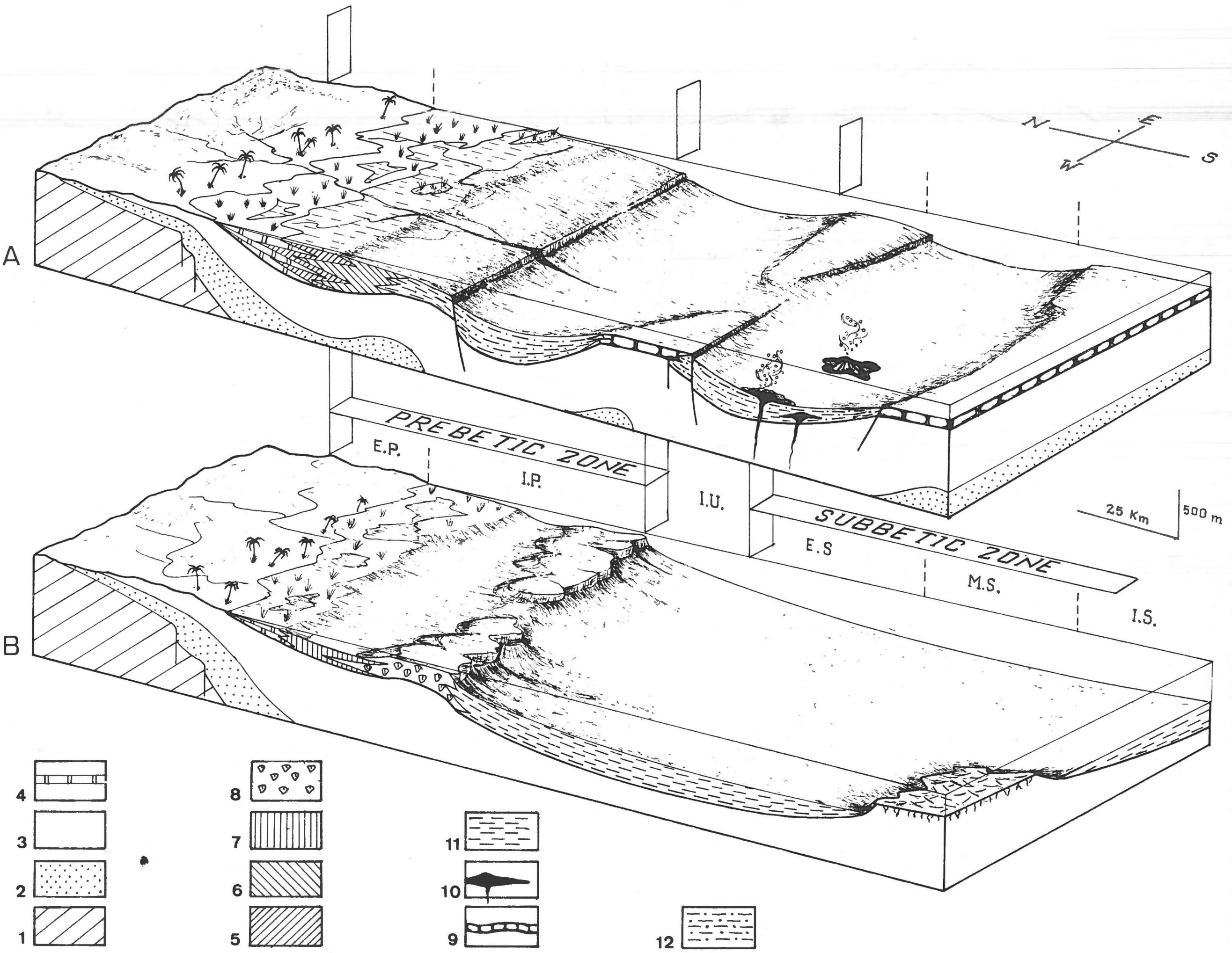

Fig. 7
A: Palaeogeographic reconstruction for the Jurassic-Cretaceous boundary.
B: Palaeogeographic reconstruction for the early Valanginian.
1: Palaeozoic basement; 2: Triassic; 3: Jurassic; 4: Supratidal environment; 5: Intertidal environment; 6: Subtidal environment; 7: Restricted platform environment (lagoon); 8: Reefs; 9: Rosso Ammonitico facies; 10: Volcanic and subvolcanic rocks; 11: Pelagic facies; 12: Calcareous turbidites.

quartzite pebbles (Utrillas facies). Another unconformity lies at the base of this formation (LOPEZ-GARRIDO, 1971-a).

Throughout Barremian, Aptian and Albian times, turbiditic terrigenous sediments were deposited in the basin of the Intermediate units where they became interbedded with pelagic material (Fig. 8A). These turbiditic levels contain wood debris and displaced *Orbitolina,* suggesting that their sources received sediments from rivers in the north. Sometimes during Aptian-Albian times the submarine fans moved to the South, causing the arrival of detritic sediments in the Median Subbetic (SANZ DE GALDEANO, 1973; GONZALEZ-DONOSO et al, 1974). In several areas of the Intermediate units, diapirically rising Triassic material became intercalated in the sequence (FOUCAULT, 1971; GARCIA-HERNANDEZ ET AL. 1973; SANZ DE GALDEANO, 1973).

Upper Cretaceous

Figure 8B displays a reconstruction of the sedimentary basin at the beginning of the Late Cretaceous. It shows very uniform conditions in contrast to those reconstructed for the Albian (Fig. 8A).

The northward extension of the Cenomanian is rather similar to that of the Albian; however, dolomitized open-marine platform carbonates extend over nearly the entire Prebetic zone. The subsiding trough of the Intermediate units is filled up during this time and marls and marly limestones with planktonic Foraminifera cover the submarine topography from the Intermediate units to the Subbetic. Also in the Cenomanian some Triassic masses were emplaced as olisthostromes (COMAS, 1978).

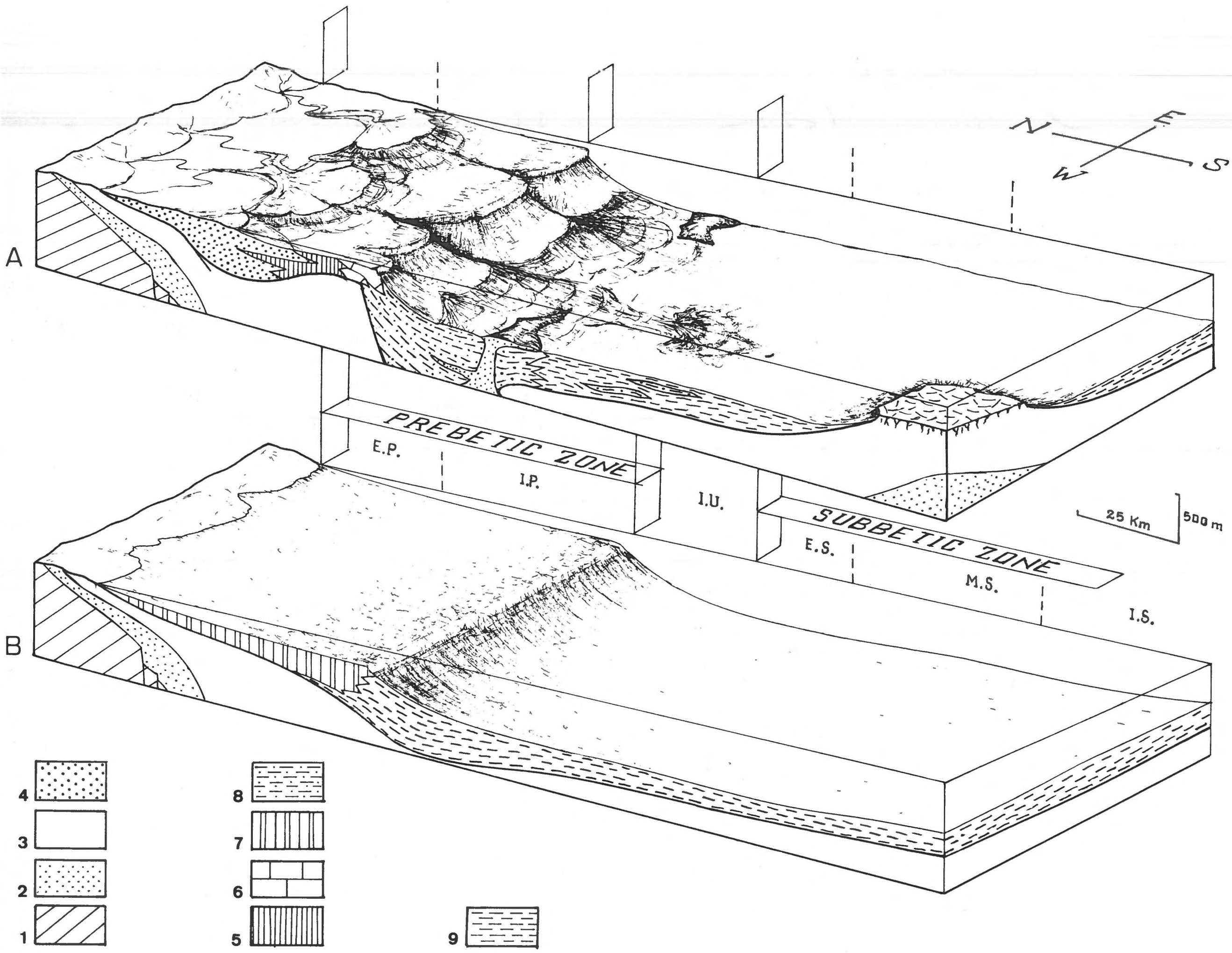

Fig. 8
A: Palaeogeographic reconstruction for late Aptian-Albian.
B: Palaeogeographic reconstruction for Cenomanian.
1: Palaeozoic basement; 2: Triassic; 3: Jurassic and Cretaceous (up to early Aptian); 4: Sands and lutites (Utrillas Formation); 5: Restricted platform environment (lagoon); 6: Carbonate sand bars; 7: Carbonate platform; 8: Turbiditic facies; 9: Pelagic facies.

An important palaeogeographic change in the Prebetic Zone during the Senonian is the eastwards retreat of the shore-line. The lower Senonian limestones with Charophyte remains and with laminated intercalations are deposited on tidal flats and swamp regions. From the West to the East there exist facies of *Discorbis* limestones, rudist limestones (both of them of lagoonal environment), reefal calcarenites, and pelagic marls with planktonic Foraminifera.

In the late Senonian the facies changes seawards from lacustrine and lagoonal, to marine carbonate platform.

Throughout the Intermediate units and the Subbetic, pelagic sedimentation prevailed with pink and white marls and marly limestones containing abundant *Globotruncana* and nannofossils.

CONCLUSIONS

The palaeogeographic evolution of the External Zones of the Betic Cordillera is closely parallelled by that of other Alpine Mediterranean Mesozoic basins. BERNOULLI & JENKYNS (1974) described the Mesozoic facies of these basins with brief reference to the Betic Cordillera, emphasizing the palaeogeographical events noticed in this paper.

The beginning of the Jurassic is accompanied by the installation of a carbonate platform over the germanic-andalousian Triassic; GARCIA-HERNANDEZ ET AL. (1976) compared these sediments to analogous ones found in N. Africa, the Apennines, Sicily, the Alps, the Carpathians, and the Jonian zone of the Hellenides; the sedimentation rate is equivalent to those of the recent Bahamas. The prevailing facies are of shallow-marine carbonate platform with episodes of tidal-flat and supratidal deposition as described from the Calcare Massiccio formation of the Apennines (BERNOULLI & WAGNER 1971; COLACCICHI ET AL., 1975).

In the Subbetic zone the uppermost levels of this calcareous sequence are composed of Carixian crinoidal limestones which are also present, with similar age and facies, in other alpine basins (i.e. Sicily, JENKYNS, 1971; CATALANO & D'ARGENIO, 1978).

Between the middle Carixian and early Domerian ages (180 Ma) the change from shallow water to pelagic facies occurred, an event which coincides with a breakdown of the main carbonate platform all over the Mediterranean domain and with early stages of opening of the Central Atlantic (BERNOULLI & JENKYNS, 1974; SCANDONE, 1975; BIJU-DUVAL ET AL. 1976; TAPPONIER, 1977).

After this event in the External Zones of the Betic Cordillera two main realms are differentiated: the Prebetic and Subbetic Zones.

The Prebetic Zone constitutes, throughout Mesozoic times, a border zone of a geosynclinal area, linked to the NW to emerged areas, and characterized by marginal facies comprising tidal-flats, lagoonal and open-marine platform carbonate, with frequent clastic episodes of fluvial or coastal sedimentation; many facies associations are in fact similar in lithology to coeval ones described from elsewhere not only in the Mediterranean area but also in the North of Europe. The Purberck facies, Weald facies and Urgon facies have been recognized.

In the Subbetic zone, sedimentation was pelagic from the middle Liassic onwards. Troughs and swells are related to differential subsidence of a fractured and thinned continental crust. In some of the troughs, interbedded with pelagic sediments, subvolcanic and submarine volcanic rocks appear. Overall, Mesozoic sedimentation occurred in a continental margin of the Atlantic type, analogous to other alpine regions, e.g. the Apennines (D'ARGENIO, 1976).

The main pelagic facies, which have their equivalents in other Alpine regions are: (1) Grey limestone-marls interbeds (biomicrites); (2) Rosso Ammonítico and red nodular limestones; (3) Radiolarites and marl with radiolarians; (4) Calcareous turbidites; and (5) red to white biomicrites containing planktonic foraminifera.

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