THE CENOZOIC GEODYNAMIC EVOLUTION OF THE VALENCIA TROUGH (WESTERN MEDITERRANEAN)[1]

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ABSTRACT

The integration of subsurface data from the offshore Valencia trough areas and data obtained from geological studies carried out on its emerged margins permits recognition of two main structural domains in the València trough: *The Catalan Valencian domain,* along the Iberian coast, that is characterized by an extensional tectonics that persisted during the whole Neogene; and the *Betic-Balearic domain,* that represents a north-eastern prolongation of the external part of the Betic thrust and fold belt (emplaced in Early-Middle Miocene times). The Betic-Balearic domain, overthrusts the previous domain and has undergone a phase of extensional tectonics during Late Miocene times. In order to illustrate this structure three regional cross-sections based on interpreted seismic lines are presented.

The present day structural and morphological features of the Valencia trough, as well as the crustal thickness variations across them, can not be explained as the result of a simple rift event. These features resulted mainly from the development of i) a horst and graben system in the north-western area of the basin during the late Oligocene (?) - Early Miocene, and ii) a thrust system (the north-eastern prolongation of the Betics, active until Middle Miocene) and, superimposed on its internal zones, a phase of extensional tectonics (mainly Late Miocene in age). The Early Miocene rifting caused a generalized crustal thinning in the València trough area, whereas the stacking of the Balearic-Betic thrust-sheets led to a bending of the previously thinned crust and to a thickening of the crust in the Balearic promontory during the Lower and Middle Miocene (Burdigalian and Langhian). Therefore the València trough acted as a foreland basin in relation to the Betic-Balearic thrust and fold belt. During the rest of the Middle and Late Miocene the crustal thinning was caused by the opening of the Algerian basin, that affected to a considerable degree considerably the southeasternmost Balearic promontory areas but was weak in the València trough area.

Key words: Structure, Western Mediterranean, València trough, Cenozoic, Geodinamic evolution.

RESUMEN

La integración de datos del subsuelo de las áreas sumergidas del surco de València con datos procedentes del estudio geológico de sus márgenes emergidos ha permitido distinguir dos dominios estructurales: El *dominio Valenciano-catalán,* que se extiende a lo largo de la costa, se caracteriza por una tectónica extensiva que persistió durante todo el Neógeno; el *dominio Bético-balear,* que corresponde a la prolongación nororiental de las zonas externas de la cordillera Bética, cabalga al dominio previamente mencionado y sufrió una tectónica extensiva durante el Mioceno superior. Con el fin de ilustrar esta estructura se presentan tres secciones regionales basadas en interpretaciones de líneas sísmicas.

Así, tanto los rasgos estructurales y morfológicos actuales del surco de València, como las variaciones de grosor de la corteza a través del mismo no pueden explicarse como el resultado de un simple evento de rifting. Son el resultado, principalmente, del desarrollo de i) un sistema de horsts y grabens en el área NW de la cuenca durante el Oligoceno Superior (?)- Mioceno inferior, y ii) un sistema de cabalgamientos (la prolongación nororiental de la cordillera Bética, activo hasta el Mioceno medio) y, sobrepuesta a sus zonas internas, una tectónica extensiva de edad Mioceno superior. El rifting del Mioceno inferior causó un adelgazamiento cortical generalizado en el área del surco de València, mientras que el apilamiento de las láminas cabalgantes bético-baleáricas condujo, durante el Mioceno inferior y medio (Burdigaliense y Langhiense), a una flexión de la corteza previamente adelgazada y al engrosamiento de la misma en el promontorio balear. Por lo tanto, el surco de València tiene la condición de cuenca de antepaís respecto al cinturón de pliegues y cabalgamientos bético-balear. Durante el resto del Mioceno medio y el Mioceno superior, el adelgazamiento cortical relacionado con la apertura de la cuenca argelina afectó considerablemente las partes más sudorientales del promontorio balear, pero sólo de manera atenuada el área del surco de València.

Palabras clave: Estructura, Mediterráneo occidental, Surco de València, Cenozoico, Evolución geodinámica.

Fontboté,J.M., Guimerà,J., Roca,E., Sàbat,F., Santanach,P. and Fernández-Ortigosa,F. (1990): The Cenozoic geodynamic evolution of the València trough (Western Mediterranean). *Rev. Soc. Geol. España,* 3: 249-259.

Fontboté,J.M., Guimerà,J., Roca,E., Sàbat,F., Santanach,P. y Fernández-Ortigosa,F. (1990): La evolución geodinámica cenozoica del surco de València (Mediterráneo occidental). *Rev. Soc. Geol. España,* 3: 249-259.

(1) This paper integrates the papers S405c-20 and S405c-21 presented by the authors at the fifth meeting of the E.U.G. at Strasbourg (March 1989) as a contribution to ECRIS-Project (Sponsored by ICL-WG3 and EGS).

1. INTRODUCTION

The València trough is a NE-SW oriented basin located between the Iberian Peninsula and the Balearic islands. It is closed to the SW, but the València trough opens to the northeast and constitutes the southwestern prolongation of the Provençal basin (fig.1).

According to refraction seismic studies (Gobert *et al.*, 1972; Hinz, 1972; Banda *et al.*, 1980) and gravimetric data (Morelli *et al.*, 1975; Haxby, 1983; Torner, 1988) the València trough corresponds to an area with a thinned continental crust and an upper mantle characterized by low seismic velocities (7.7 km/s). These lithospheric features are not restricted to the València trough but are also the case on a widespread area of the eastern Iberian plate. Thus, the crustal thinning, that is greatest in the trough axis where the crust thickness is less than 15 km, also affects the easternmost parts of the Iberian Peninsula: including the Catalan Coastal Range, the SE Iberian Range and Eastern Betics (Zeyen *et al.*, 1985), as well as the Balearic promontory where the crust is about 20-25 km thick (Banda *et al.*, 1980).

Several different hypotheses have been proposed to explain the genesis and evolution of the València trough. Two main kind of models can be differentiated: those that considered the València trough, together with the Provençal basin and the Sardinian graben, as the southernmost segments of the Cenozoic rift system of Western Europe (Julivert *et al.*, 1974; Mauffret, 1976; Vegas *et al.*, 1980); and the ones that linked the genesis of the València trough to back-arc processes generated by the Cenozoic subduction of Africa beneath Europe (Boccaletti and Guazzone, 1974; Bocca-

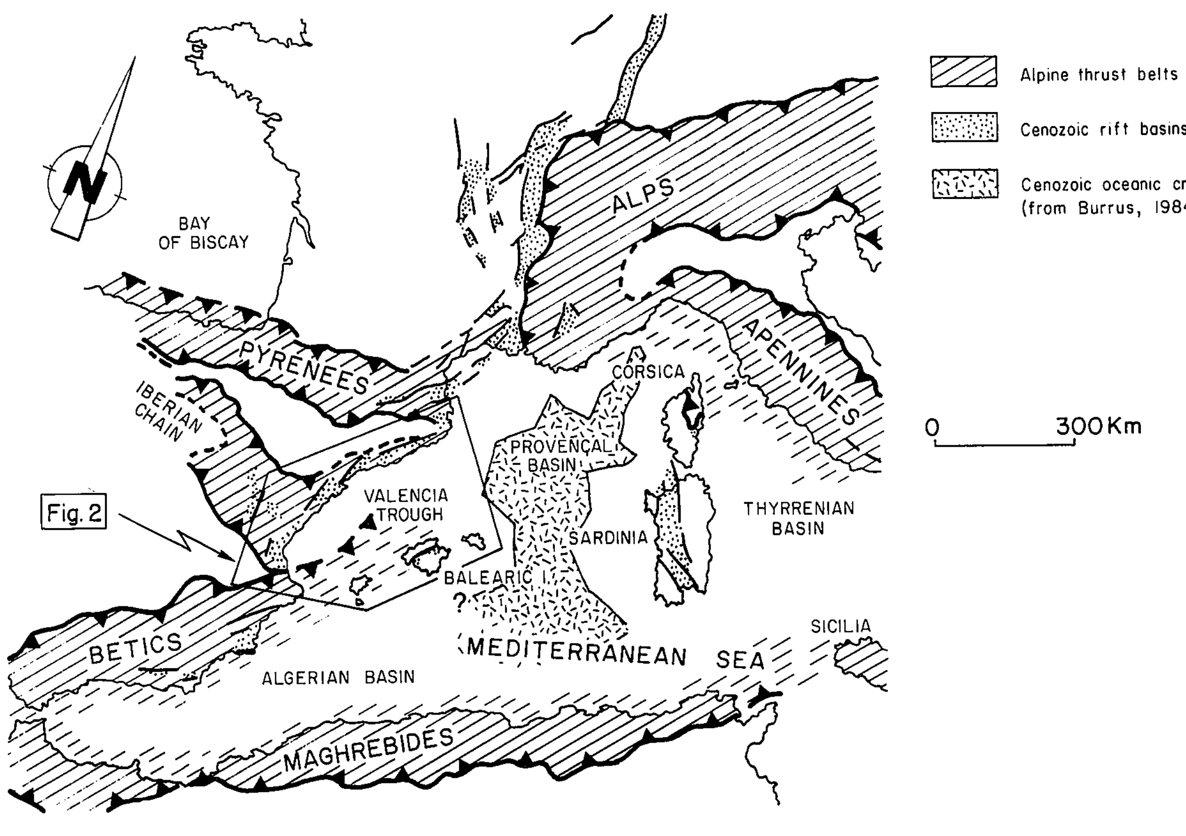


Fig. 1.-Location map of the València trough showing the major Cenozoic structural trends of the western Mediterranean.
Fig. 1.-Mapa de situación del surco de València con los principales rasgos estructurales cenozoicos del Mediterráneo occidental.

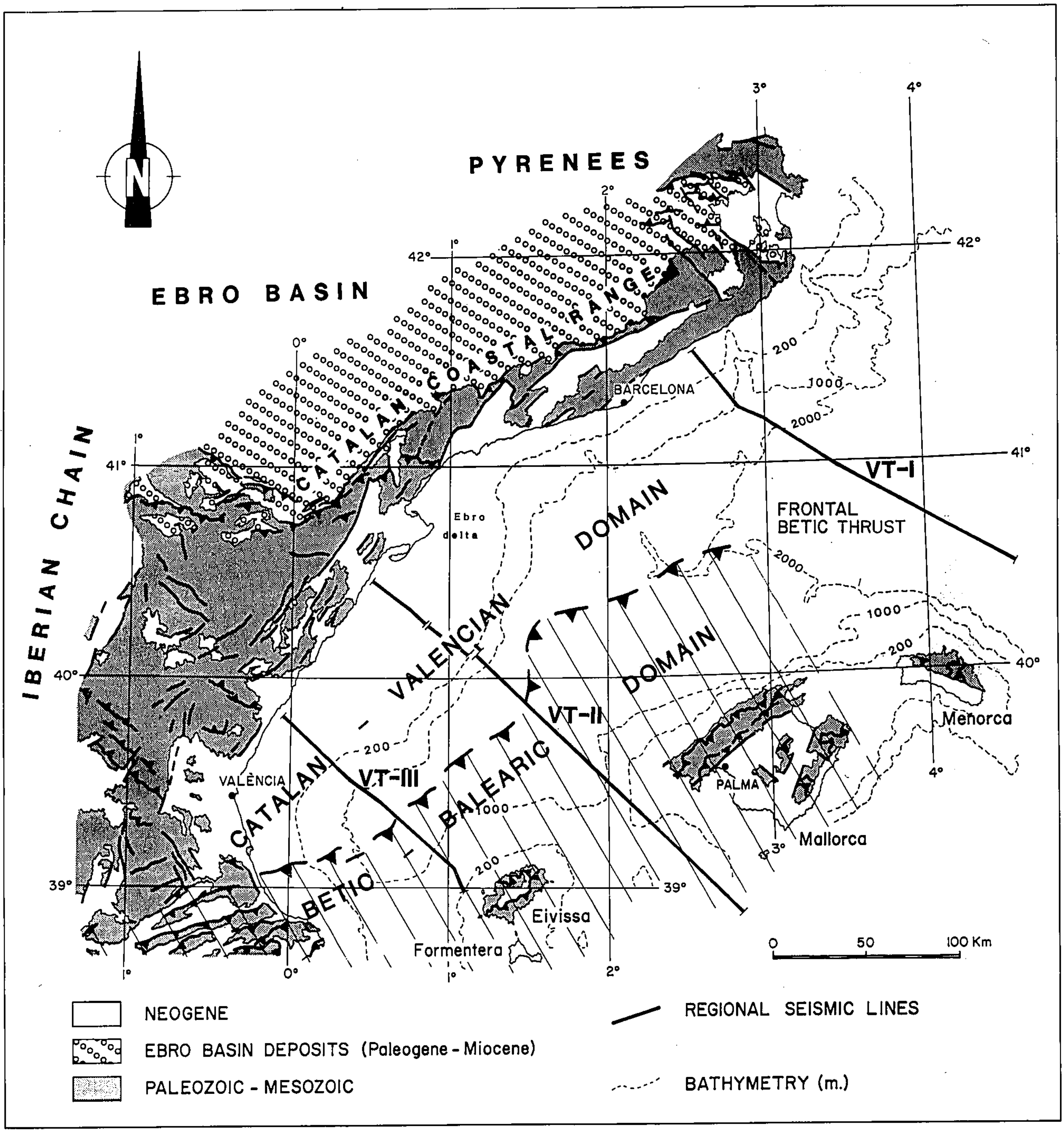


Fig. 2.-Geological map of the València trough emerged areas. The map includes: a) the areal distribution of the catalan-valencian and betic-balearic structural domains (bounded by the Frontal Betic Thrust), and b) the situation of the studied regional profiles shown in fig. 4. The bathymetry, after Canals *et al.* (1982).

Fig. 2.-Mapa geológico de las áreas emergidas del surco de València. El mapa incluye: a) la distribución de los dominios estructurales catalano-valenciano y bético-balear (limitados por la traza del cabalgamiento bético frontal), y b) la situación de los cortes regionales de la figura 4. El mapa de isobatas del fondo marino, según Canals *et al.* (1982).

letti *et al.*, 1976; Biju-Duval *et al.*, 1978; Banda and Channell, 1979; Burrus, 1984). These two different kind of models also have been included in some composite hypotheses (Rehault *et al.*, 1985; Burrus *et al.*, 1987) that considered the genesis of these Neogene basins as a result of the superposition of both processes.

These hypotheses are based mainly on offshore geophysical data and come as a result of comparison with the known evolution of the adjacent Neogene basins (Provençal, Algerian and Thyrrenian basins). They consider the València trough as a basin generated only by extensional processes. However, structural studies carried out in the emerged margins of the València trough (see Fontboté *et al.*, 1989, for references) shows that its genesis and evolution can not be related to a simple extensional model. Because of this, the Neogene structure of the basin shows a conspicuous asymmetry between the Iberian and Betic-Balearic mar-

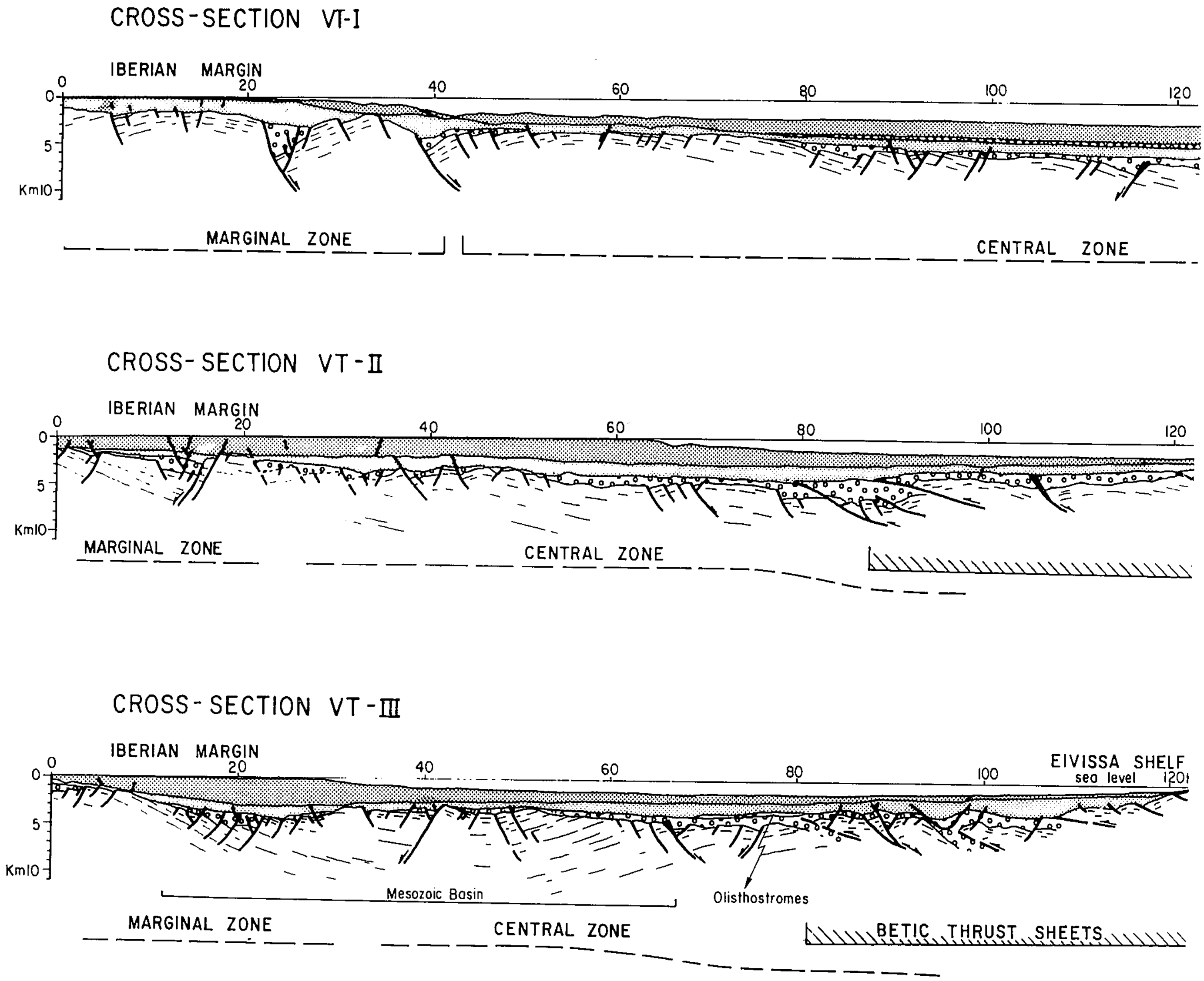


Fig. 3.-Regional cross-sections across the València trough (VT-I, VT-II, VT-III) drawn from reflection seismic profiles provided by REPSOL and SHELL. A summary picture of the main stratigraphic units of the València trough basin infilling (modified from Anadón *et al.*, 1989) is included.

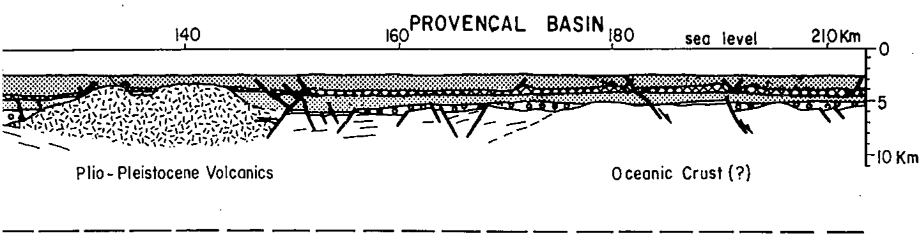
Fig. 3.-Cortes regionales transversales al surco de València (VT-I, VT-II, VT-III) dibujados a partir de perfiles de sísmica de reflexión cedidos por REPSOL y SHELL. Se adjunta un cuadro resumen de las principales unidades estratigráficas del relleno del surco de València (modificado de Anadón *et al.*, 1989).

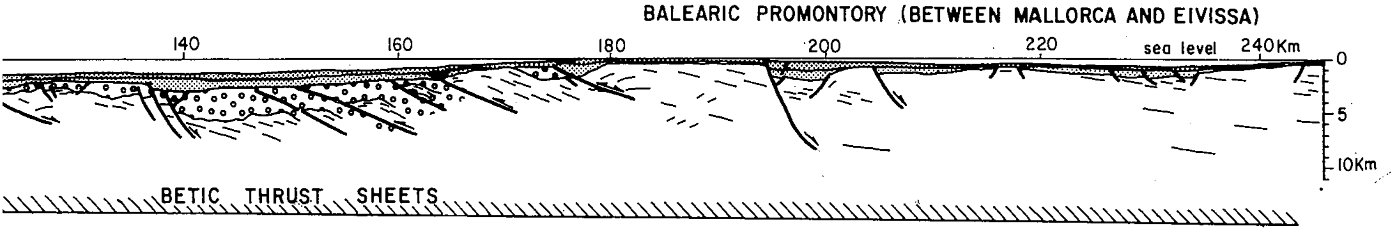
gins (Soler y José *et al.*, 1983). While the Iberian margin is characterized by extensional tectonics with ENE-WSW to N-S normal-trending faults, the Betic-Balearic margin is structured in a NW-directed thrust system (fig.2).

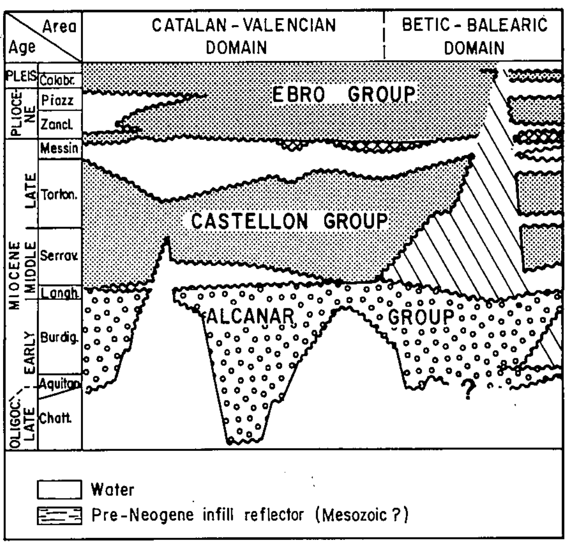
In order to study the geometric relationships of these different structural elements and the resulting complex Neogene evolution of the València trough, we have carried out an analysis of the available subsurface data of the offshore basin areas. In this way, we have utilized the excellent grid of reflection seismic lines and oil wells that is available because the València trough is an oil and gas producing area. From these data, three regional cross-sections (fig. 3) and a structural sketch of the València trough have been made up (fig.4).

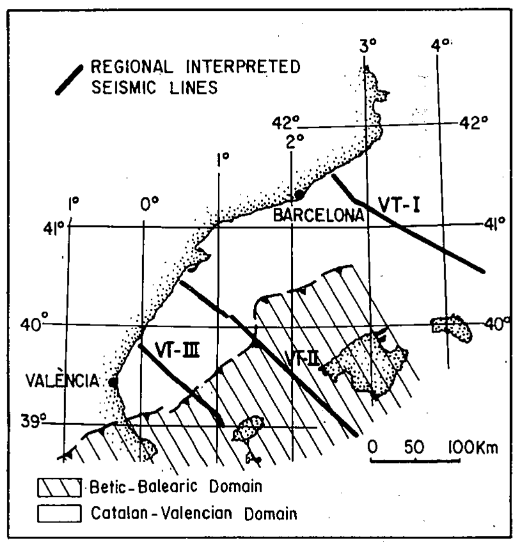
The combination of the analysis of these subsurface data with the geological structural studies carried out onshore permits two main domains to be distinguished in the València trough: a) a Catalan-Valèncian domain, characterized by extensional tectonics that persisted during the whole Neogene, and b) a Betic-Balearic domain which corresponds to the northeastern prolongation of the external part of the Betic thrust and fold belt (emplaced in Early-Middle Miocene times), that overthrusts the previous domain and has undergone an extensional tectonics during Late Miocene times. The boundary between both domains is the Frontal Betic Thrust which is clearly visible on the VT-II and VT-III offshore cross-sections (fig. 2).

The aim of this paper is to present a synthesis of the main structural features of these two domains and









to delineate their role in the genesis and evolution of the València trough. Finally, a model for the Cenozoic evolution of the València trough will be proposed.

2. CATALAN-VALÈNCIAN DOMAIN

With this name we designate the area of the basin located to the west and northwest of the Frontal Betic Thrust (fig. 2). It includes the southeastern areas of the Iberian Range, the Catalan Coastal Range and the adjacent offshore basin areas.

The present structure of this domain corresponds to a Neogene system of horsts and grabens bounded by extensional faults having an orientation that ranges from ENE-WSW (northern areas, Catalan Coastal Range) to N-S (southern areas, south eastern Iberian Range areas). Two main zones can be recognized in the Catalan-Valèncian domain having different structure (fig. 3: cross-section VT-I), both being roughly parallel to the Iberian coast: a) a Marginal Zone developed along the present Iberian margin and characterized by a prominent horst and graben structure. b) a Central Zone, located further to the south-east, slightly structured that coincides with the area where the crust thickness is minimum. This zone is well developed in the north-eastern offshore areas of the basin (fig.3, cross-section VT-I), but to the southwest (where the Betics are developed) it is flexed and overthrust by the Betic system (fig. 3: cross-sections VT-II and VT-III).

The structure of the **Marginal Zone** is strongly controlled by the inherited Paleogene structures related to the N-S compression that affected the Iberian Peninsula and gave rise to the Pyrenees, the Catalan Coastal Range and the Iberian Range.

In this way, the Catalan Coastal Range displays a contractive Paleogene structure characterized by a set of sinistral ENE-WSW to NE-SW faults (Guimerà, 1984; Anadón *et al.*, 1985). These faults probably originated as Late Hercinian strike-slip faults (Arthaud and Matte, 1975) and had a normal motion during Mesozoic times (Salas, 1987). Later, close to the beginning of the Neogene a negative tectonic inversion took place. During the Neogene, these large faults became extensional and gave rise to a northwest tilted block-structures in this area.

Further to the south, the pre-Neogene structure of the SE Iberian Range displays a different arrangement. This area is characterized by E-W to NW-SE oriented, thick Mesozoic basins that have been shortened in a N- and S-directed thrust system. This thrust system became detached on the Triassic evaporites during the N-S Paleogene compression (Viallard, 1983; Guimerà and Alvaro, 1990). Since these Paleogene structures are parallel to the direction of the Neogene extension (approximately E-W: Guimerà, 1988), during the Neogene new normal faults oriented NNE-SSW and NNW-SSE were generated, cutting through the Paleogene structures. Two kinds of normal faults can be distinguished: a) long east-dipping basement involving faults, which bound the Neogene extensional areas (València trough) to the west, and b) antithetic west-dipping listric normal faults (related to the previous faults) that affect only the Mesozoic cover. The greater development of this second kind of normal faults resulted in the structural development of this area in a system of blocks tilted mainly to the east-southeast to east. In the area surrounding València areas (SE Iberian chain) this extensional structure is complicated by the presence of thick Triassic evaporites, which gave rise to the development of a complex set of diapires and growth faults in the Mesozoic cover, during the Neogene extension.

By contrast, the **Central Zone** of the Catalan-Valencian domain, developed parallel to the Iberian coast in the northeast and central offshore basin areas, displays an uniform structure all along the basin. This structure consists on a more or less flat-lying pre-Neogene unconformity affected by some sets of normal faults generally dipping to the west-southwest or to northwest. Thesefaults have a comparatively small slip.

This complex extensional structure of the Catalan-Valencian domain took place mainly since the Paleogene-Neogene transition and resulted, to a greatextent, from the gradual negative tectonic inversion of previous northeast-southwest transpressional structures (Guimerà, 1984; Guimerà, 1988).

Two main extensional stages can be distinguishedin the Neogene kinematic evolution of this domain: a) a first synrift stage characterized by the extensionalstructuration of the Catalan-Valencian domain and the correlative deposition of the Lower Alcanar Group (Ne-O and Ne-1 after Soler y José *et al.*, 1983), during the Late Oligocene and the Burdigalian. b) A second stage initiated during the Burdigalian in which the tectonic activity has been restricted to the master faults of the Marginal Zone (for instance the Vallès, Penedès, El Camp, Ebre and Teruel faults). This fact is reflected by the onlap of the Upper Alcanar (Ne-2 after Soler y José *et al.*, 1983), Castellón and Ebro Groups sediments (Burdigalian up to Recent) on almost all the antithetic faults and the main offshore Neogene extensional structures (fig. 3).

These features suggest that the rift system of the Catalan Valencian domain corresponds to the margin of an extensional basin whose thinned central part would be partially involved in the Betic thrust system. This extensional basin, due to its similar orientation (NE-SW) and geological features (age Late Oligocene?-Early Miocene, structure, etc.), would correspond to the SW continuation of the Provençal basin.

3. BETIC-BALEARIC DOMAIN

The Betic-Balearic domain includes the islands and adjacent submerged areas of the Balearic promontory, the onshore Eastern Betics, and the east and southeast areas of the Valencia trough. The present structure of this domainis different from those in the Catalan-Valencian domain. It consists on a stack of west-northwest directed thrust sheets, which is affected by a system of east-northeast - west-southwest listric, extensional faults. These faults are well developed in the eastermost areas (Balearic promontory). The structure of the Betic-Balearic domain is the result of two different tectonic processes which developed during the Neogene in the westernmost Mediterranean: the contractional building up of the Betic thrust system (mainly Late Oligocene-Middle Miocene) and the opening of the Algerian basin (mainly Middle-Late Miocene in age).

From the study of the emerged areas of this domain (Mallorca, Cabrera and Eivissa) it has been established that this thrust system consists of several east-northeast - west-southwest oriented thrusts involving the Mesozoic cover as well as Lower-Middle Miocene syncompressional deposits, the Sant Elm and Banyalbufar Formations (Fallot, 1922; Rangheard, 1972; Sàbat and Santanach, 1985; Alvaro, 1987; Sàbat *et al.*, 1988). The small outcrops of Paleozoic basement rocks described by Ramos and Rodríguez-Perea (1985) suggest that the basement also could be involved in the lower thrust sheets.

The development of this thrust system began in the Late Oligocene (Sàbat, 1986; Ramos-Guerrero *et al.*, 1989) and lasted till the Langhian (Middle Miocene). The system propagated mainly in a piggy-back sequence (Álvaro, 1987; Ramos- Guerrero *et al.* , 1989) toward the west-northwest. The propagation towards the north-northwest of the Betic system had two consequences: a) The reduction of the area covered by the initial Catalan-Valencian Rift Basin, as a result of the incor-

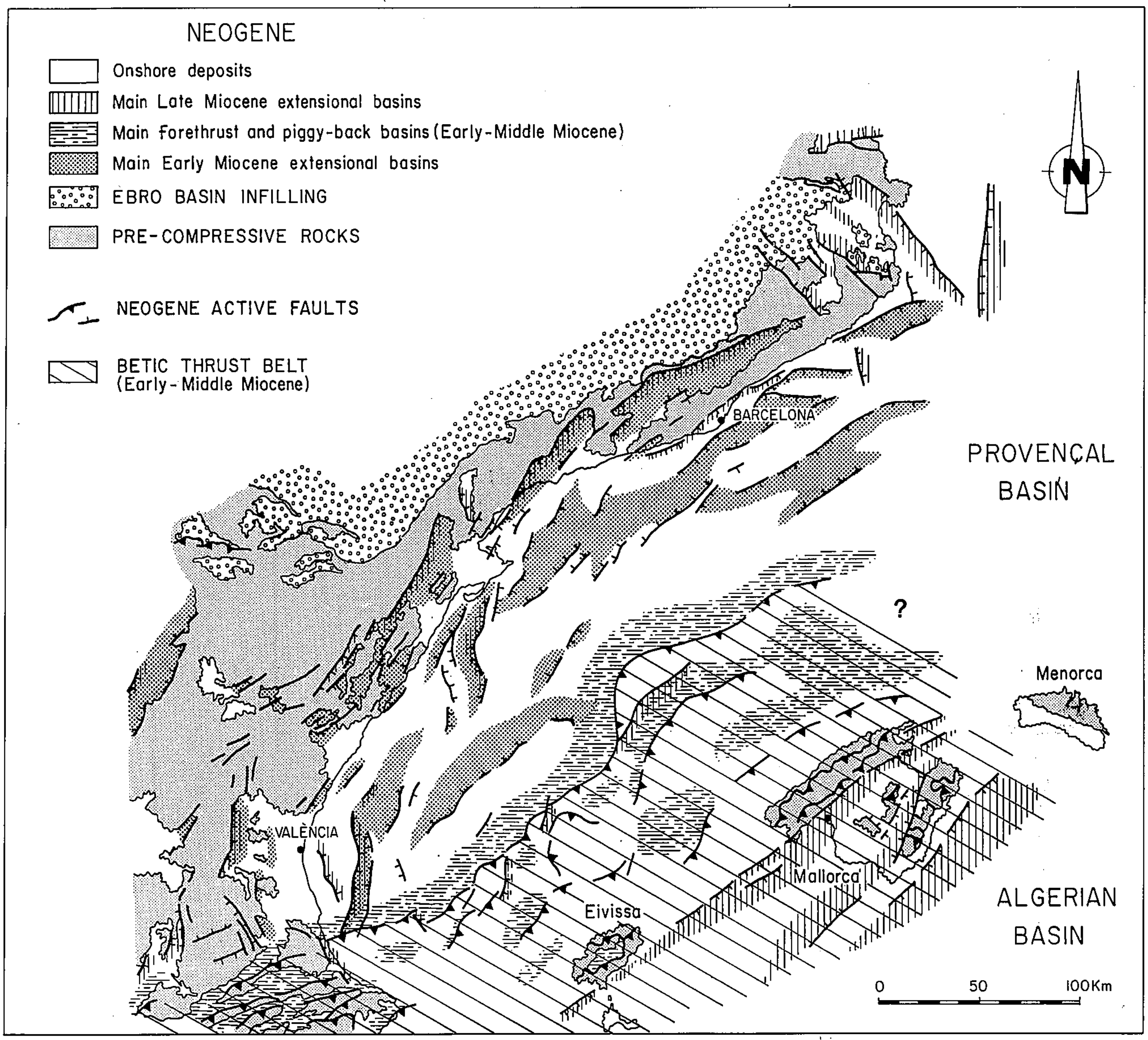


Fig. 4.-Late Oligocene (?) - Neogene structural sketch map of the València trough. The structure of the València trough results mainly from the coeval development of a) a horst and graben system along the Iberian margin during the Late Oligocene (?) - Early Miocene, and b) the NE- prolongation of the Betic thrust system during the Early-Middle Miocene. Later, a Middle-Late Miocene extensional tectonics is superimposed to this structure.

Fig. 4.-Mapa esquemático de la estructura oligocena sup. (?) neógena del surco de València. La estructura del surco de València resulta del desarrollo más o menos sincrónico de a) un sistema de horsts y grabens a lo largo del margen ibérico durante el Oligoceno sup. (?) - Mioceno inferior, y b) la prolongación NE del sistema de cabalgamientos béticos desarrollados principalmente en el Mioceno inferior y medio. Más tarde, durante el Mioceno medio y superior, a esta estructura se le superpone una tectónica de carácter extensivo.

poration of its southeasternmost parts in the Betic-Balearic thrust system. b) The bending of the lithosphere due to the loading effect of the Betic Balearic thrust-sheets. The resulting lithospheric bend contributed to the València trough formation which partially behaved as a Betic foreland basin.

In the Langhian-Serravallian transition -Middle Miocene (Álvaro *et al.*, 1984; Pomar *et al.*, 1983) the Betic-Balearic thrust system underwent regional extension. As a result, a SE dipping listric fault system originated which divided the area into a set of tilted horsts and grabens mainly dipping toward the northwest (fig. 5). These extensional structures are well developed where the stacking of thrust sheets is greatest (Balearic promontory) and they probably reactivated several thrusts as normal faults.

4. BASIN EVOLUTION

The following stages of Cenozoic evolution have been distinguished for the València trough based on the integration of onshore and offshore data (fig. 6):

Late Cretaceous - Oligocene.- During this period the Iberian Peninsula was under compression because of the convergence between the Eurasian and the Afri-

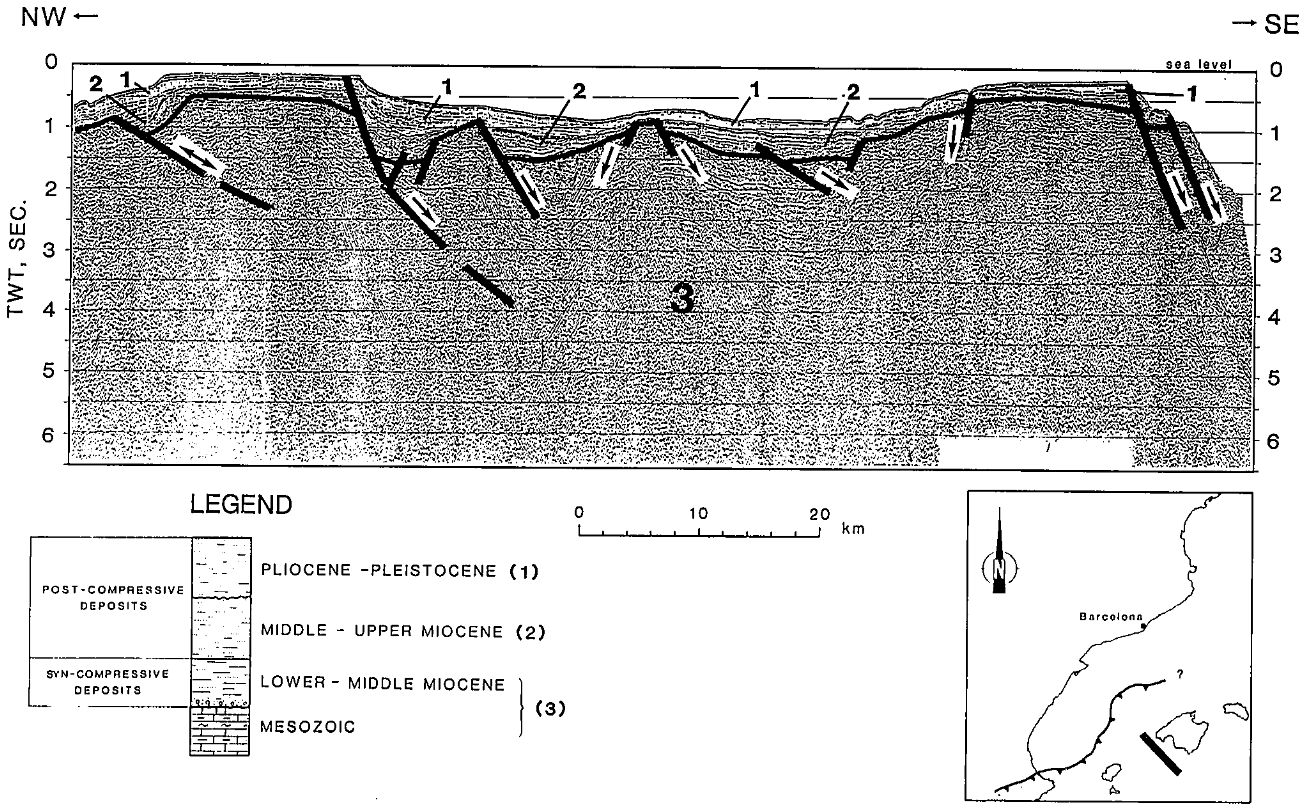


Fig. 5.-Unmigrated seismic reflection profile across the Balearic promontory between Mallorca and Eivissa islands (SE part of the regional cross-section VT-II, see fig. 3) showing the major structural features of the Middle-Late Miocene extensional tectonics.

Fig. 5.-Perfil de sísmica de reflexión no migrado a través del promontorio balear, según una transversal situada entre las islas de Mallorca y Eivissa (este perfil corresponde a la parte más SE del corte regional VT-II, ver fig. 3), en el que se muestran los principales rasgos estructurales de la tectónica extensional de edad mioceno medio-superior.

can plates. This situation lead to the compressive structural development of the Catalan Coastal Range in the eastern part of the microplate with a sinistral NE-SW strike-slip fault system and the development of the Iberian Range in a complex system of NW-SE to E-W striking thrusts and dextral strike-slip faults. In the Valencia trough area, the Paleogene compression was reflected by uplift and variably deep erosion of the Mesozoic sediments in this area.

Late Oligocene (?) - Early Miocene.- Synchronously with the Corso-Sardinian block rotation a negative tectonic inversion took place in the València trough area. This situation caused the sinking of the previously uplifted areas and the development of a horst and graben system along the Catalan-Valencian domain. At the same time, further to the southeast of the Balearic promontory, the emplacement of the Betic thrust units began.

Burdigalian (Early Miocene) - Late Langhian (Middle Miocene).- While in the Catalan-Valencian domain the extensional tectonics weakened, in the Betic-Balearic domain the progressive stacking of the Betic-Balearic thrust sheets took place, the lithosphere was bent and a foreland basin originated. Due to the displacement towards the west-northwest and to the piggy-back propagation of the Betic thrust sheets a great part of this foreland basin is included in the Betic thrust sheet system.

Serravallian (Middle Miocene) - Recent.- In the Betic-Balearic domain the Betic compression was replaced by a phase of extension. This tectonic inversion, that can be related to the rifting and opening of the Algerian basin, gave rise to the collapse of the inner parts of the Betic thrust system. In this way a widespread horst and graben system developed in the Balearic promontory, whereas this period is only characterized by weakened extensional tectonics in the València trough area (Catalan-Valèncian domain and westernmost zones of the Betic-Balearic domain) and the tectonic activity is restricted to the normal motion of the main basin bounding faults.

5. CONCLUSIONS

The present day structural and morphological features of the València trough can by no means be explained by a simple aborted rift process (fig. 4). They have resulted mainly from the coeval development of a) a horst and graben system in the northwestern area of the basin during the Late Oligocene (?) - Early Miocene, and b) a thrust system, the northeastern prolongation of the Betics (developed till Middle Miocene) and, superimposed on its internal zones, a phase of extensional tectonics (Late Miocene in age). So, the present trough axis does not correspond to a true rift axis,

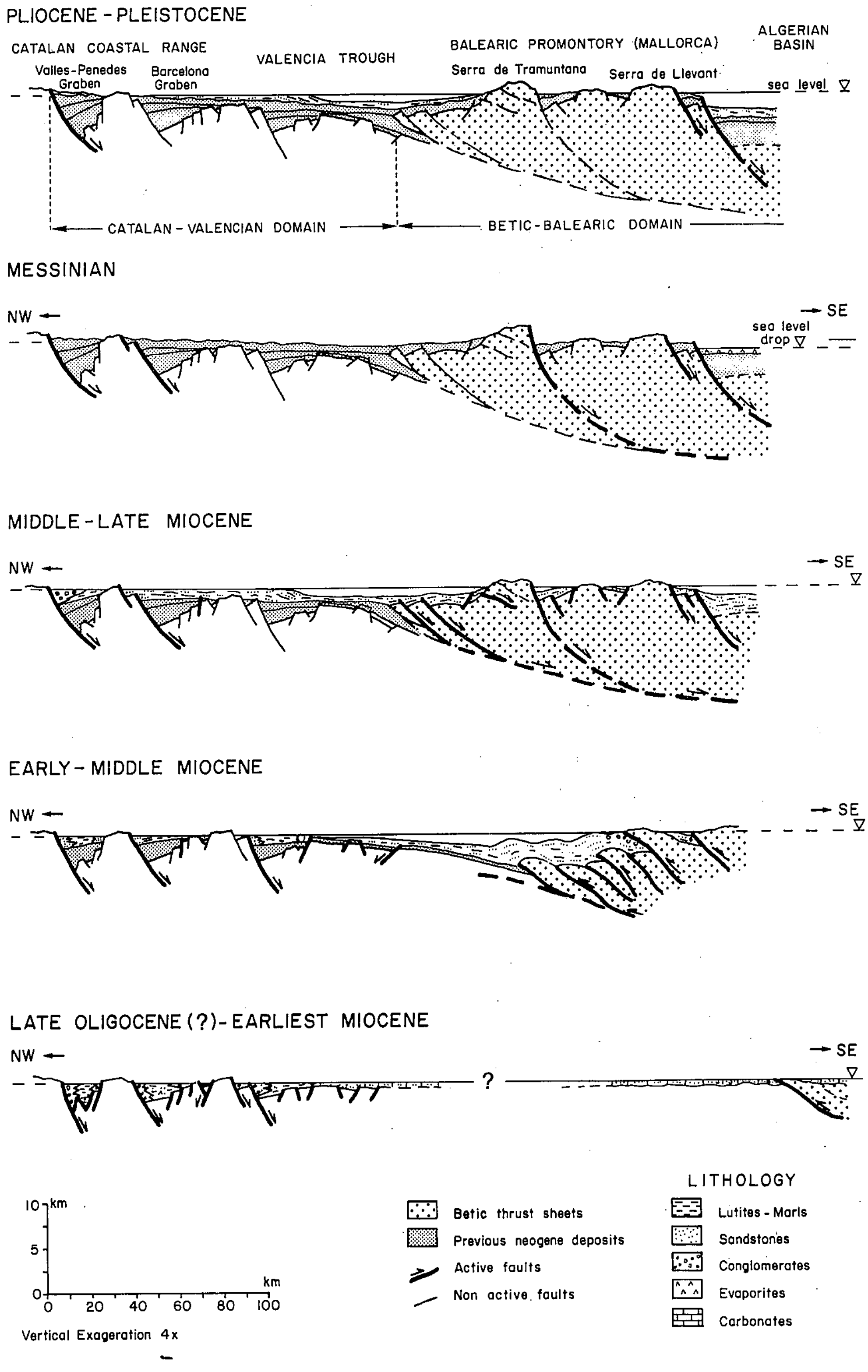


Fig. 6.-Synthetic scheme of the main evolutive stages of a hypothetical NW-SE cross-section, located between the Catalan Coastal Range (near Barcelona) and Mallorca island, from the Late Oligocene (?) up to present.

Fig. 6.-Esquema sintético de las principales etapas evolutivas de un perfil hipotético NW-SE, situado entre la Cadena Costera Catalana (alrededores de Barcelona) y la isla de Mallorca, durante el período comprendido entre el Oligoceno superior (?) y la actualidad.

but it coincides with the foredeep of the frontal Balearic Betic thrust sheets.

Therefore the crustal thickness variations across the València trough, should not be explained as the result of a simple rift event. The present structure of the crust is mainly the result of the superposition of the thinning caused by the Early Miocene rifting in the València trough area and the thickening of the crust in the Ba-

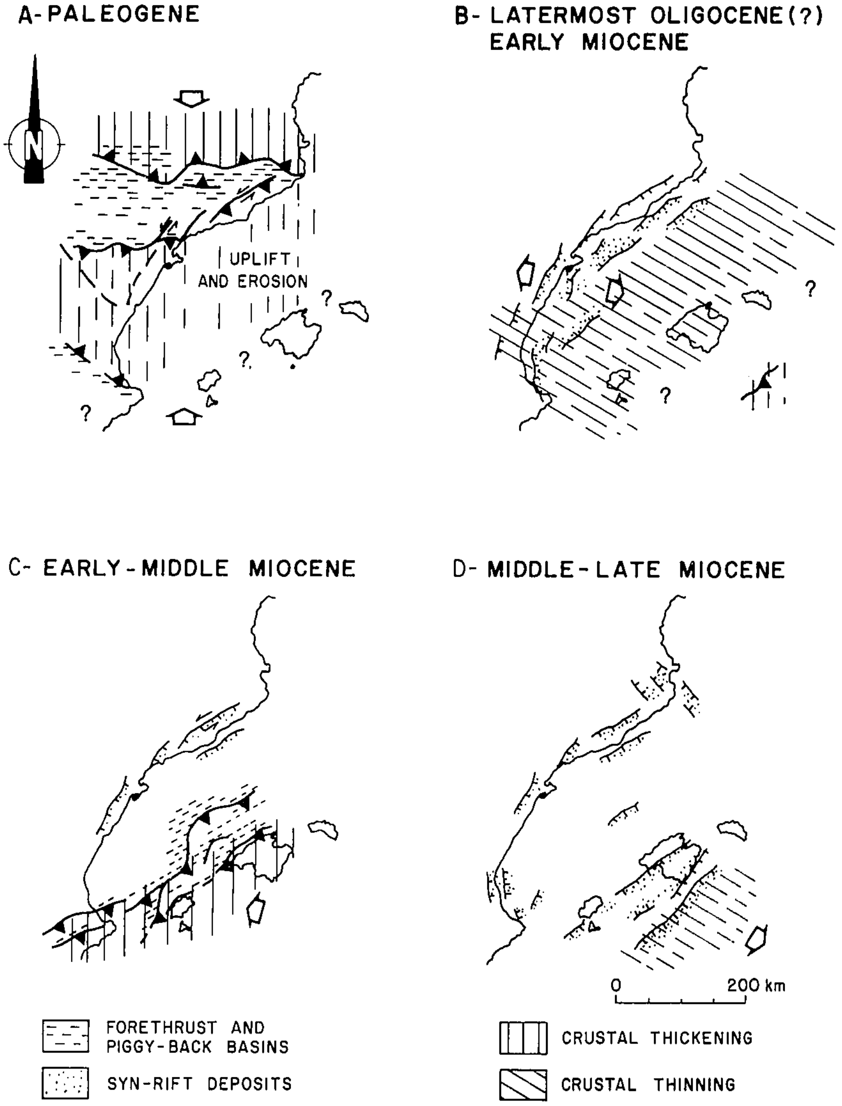


Fig. 7.-Lithospheric and kinematic evolution of the València trough and adjacent areas from the Paleogene up to Late Miocene.
Fig. 7.-Esquema de la evolución cinemática y litosférica del área del surco de València desde el Paleógeno hasta el Mioceno superior.

learic promontory originated by the piling up of the Balearic-Betic thrust sheets during the Middle Miocene fig.7). During Middle and Late Miocene the crustal thinning related to the opening of the Algerian basin considerably affected the southeasternmost Balearic promotory areas. The València trough area was scarcely extended.

ACKNOWLEDGEMENTS

We wish to thank REPSOL and SHELL ESPAÑA oil companies for their generous release of data, and the anonymous reviewers for their comments and suggestions.

This research was supported by two CIRIT grants ("Ajuts a projectes de recerca d'investigadors joves": summons 1987, 1988), and is a part of the CICYT projects GEO 89-831 and GEO 89-426-CO2

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Recibido el 19 de enero de 1990
Aceptado el 5 de abril de 1990