Geodynamics of Eastern Betic late Neogene Basins. A Review

Revisión de la geodinámica de las cuencas del Neogeno Superior en las Béticas Orientales

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ABSTRACT

Eastern Betic late Neogene basins evolveld in a compressional transcurrent regime. The dynamics of these basins is discussed from the example of three interconnected basins (Sorbas, Nijar and Vera), displaying various orientations, geometries, sedimentary and magmatic characters. Palynspastic sketch-maps illustrate the importance of lateral displacements in the paleogeographic evolution.

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The numerous studies dedicated to the Eastern Betic late Neogene basins have been synthesized recently (Montenat coord., 1990). This volume, accompanied the publication of geological maps of the basins, from Alicante to Almeria (scale 1/100.000e) (fig. 1). It points out the great diversity of sedimentary, tectonic and magmatic events interacting in the basin development. The basins located in the eastern part of the province of Almeria (Sorbas, Nijar-Carboneras and Vera basins; fig. 1 and 2) give a relevant picture of these dynamics. Notably, by means of palynspastic sketch-maps, it is possible to illustrate the part played by transcurrent movements in the paleogeographic evolution (fig. 3 to 9).

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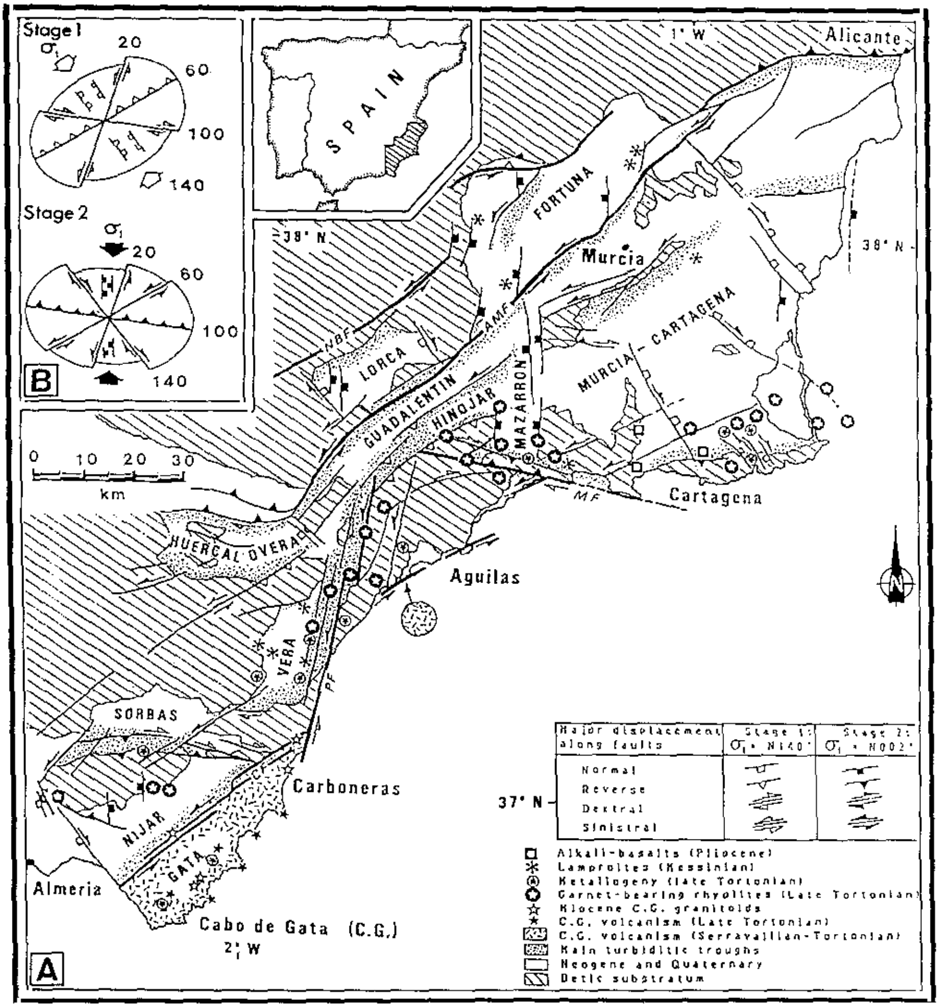

Figure 1.—Neogene structural framework of the Eastern Betic domain. A. Fault pattern of the Neogene basins and magmatism. B. Late Neogene stress field variations.

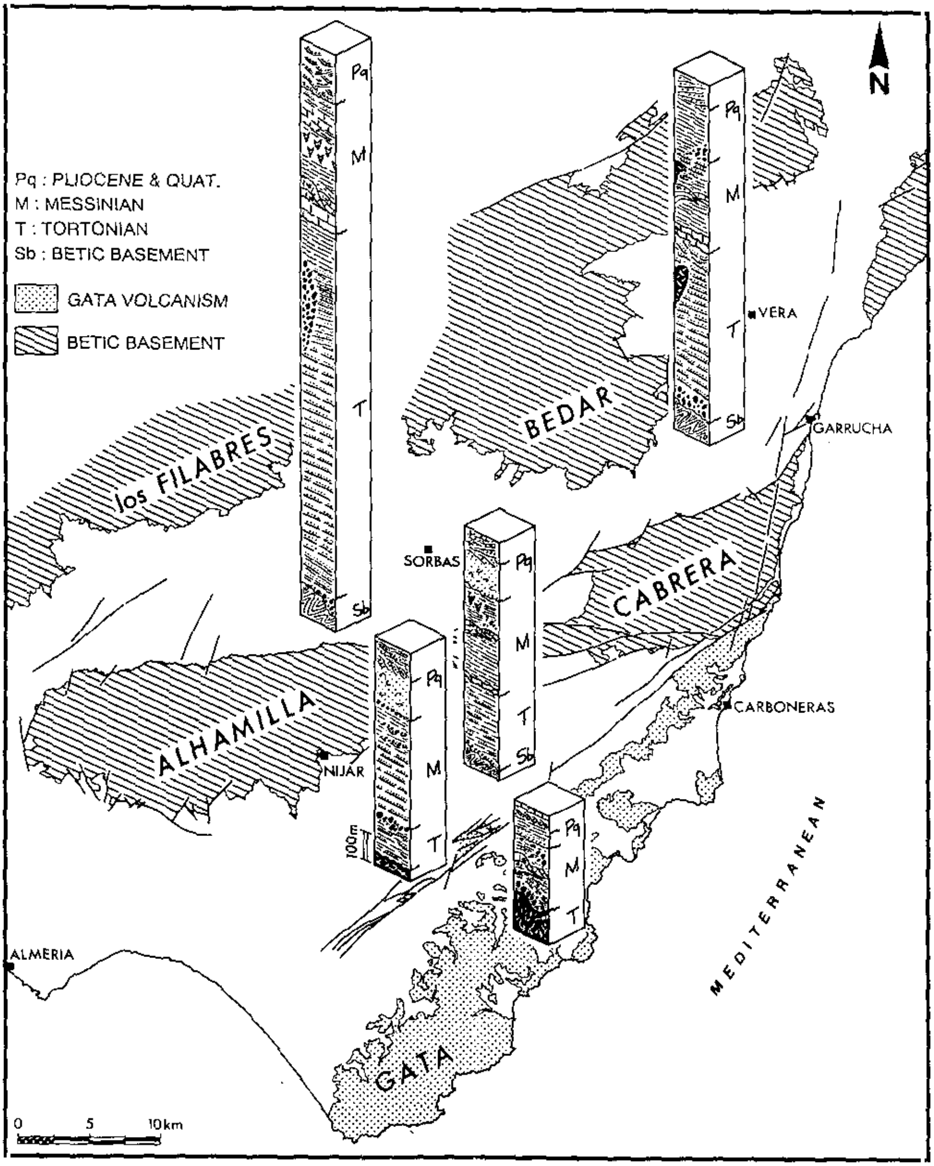

Figure 2.—Location of the studied area and synthetic Neogene sequences corresponding to the Sorbas, Nijar-Carboneras and Vera basins.

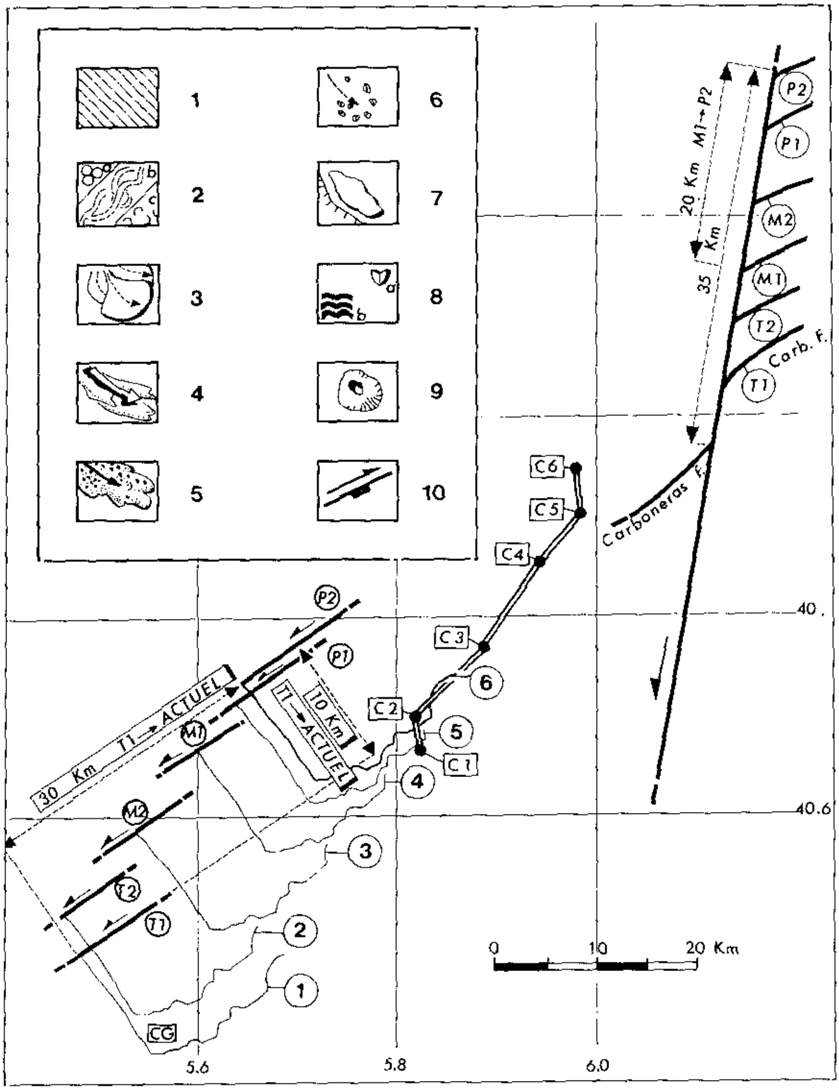

Figure 3.—Movements of blocks related to wrench faulting during late Neogene times. Numbers 1 to 6, situations illustrated by Figure 4 to 9, from early Tortonian (T1) to late Pliocene (P2). Captions for Figure 3 to 9: 1, emerged relief; 2, sedimentation areas, a. open marine, b. alluvial, c. littoral; 3, alluvial or submarine fan; 4, turbiditic flow with indication of the direction of transit; 5, «Brèche rouge» olistostrome; 6, olistolite; 7, reef and reefal platform; 8, a. evaporite; b. stromatolitic carbonates; 9, volcanoes; 10, faults with indication of horizontal or vertical displacement. A. Almeria; C. Carboneras; CG. Cape of Gata; G. Garrucha; N. Nijar; S. Sorbas, V. Vera. C1 to C6: successive position of Carboneras.

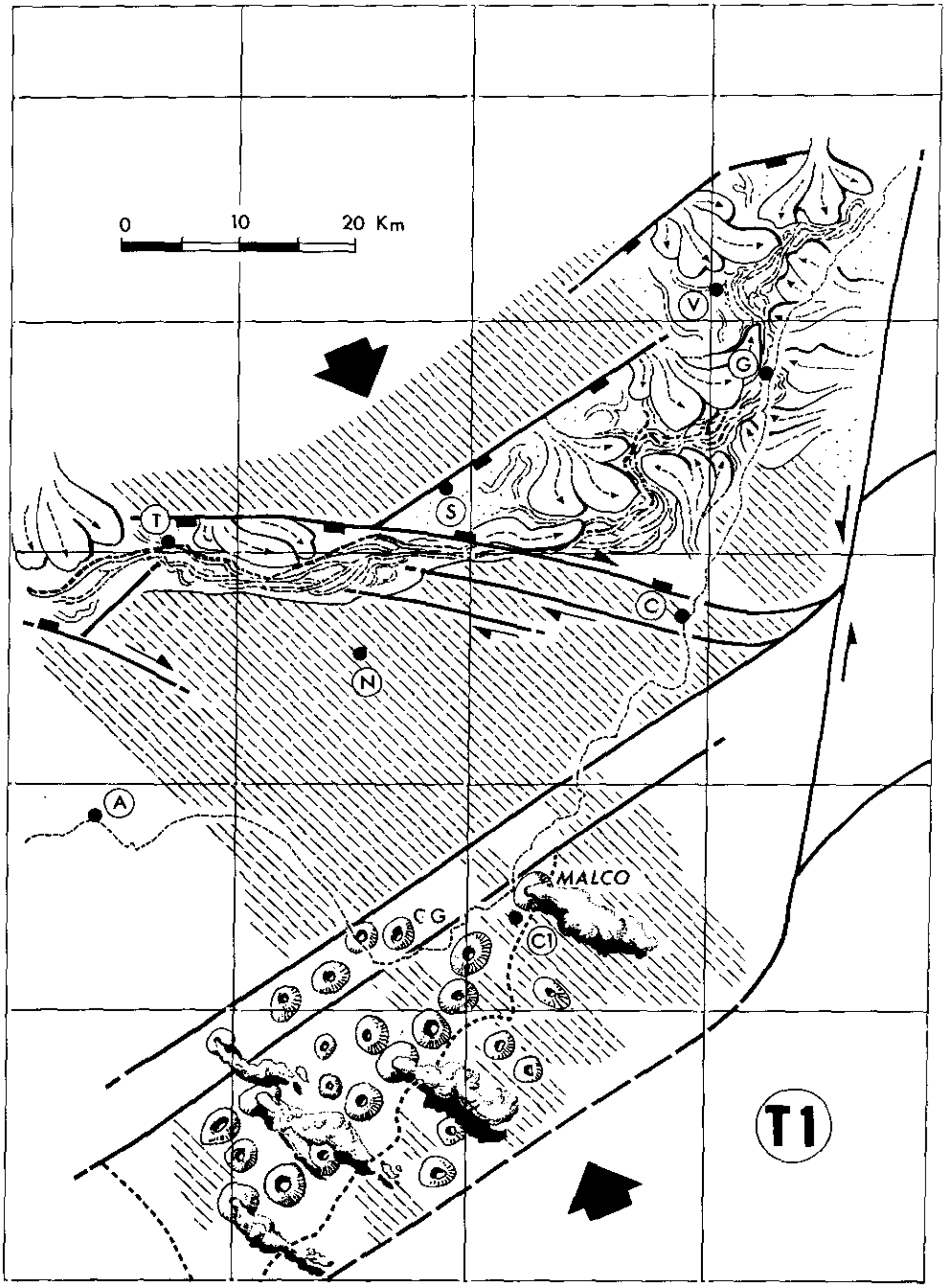

Figure 4.—Paleogeographic sketch-map: early Tortonian (T1).

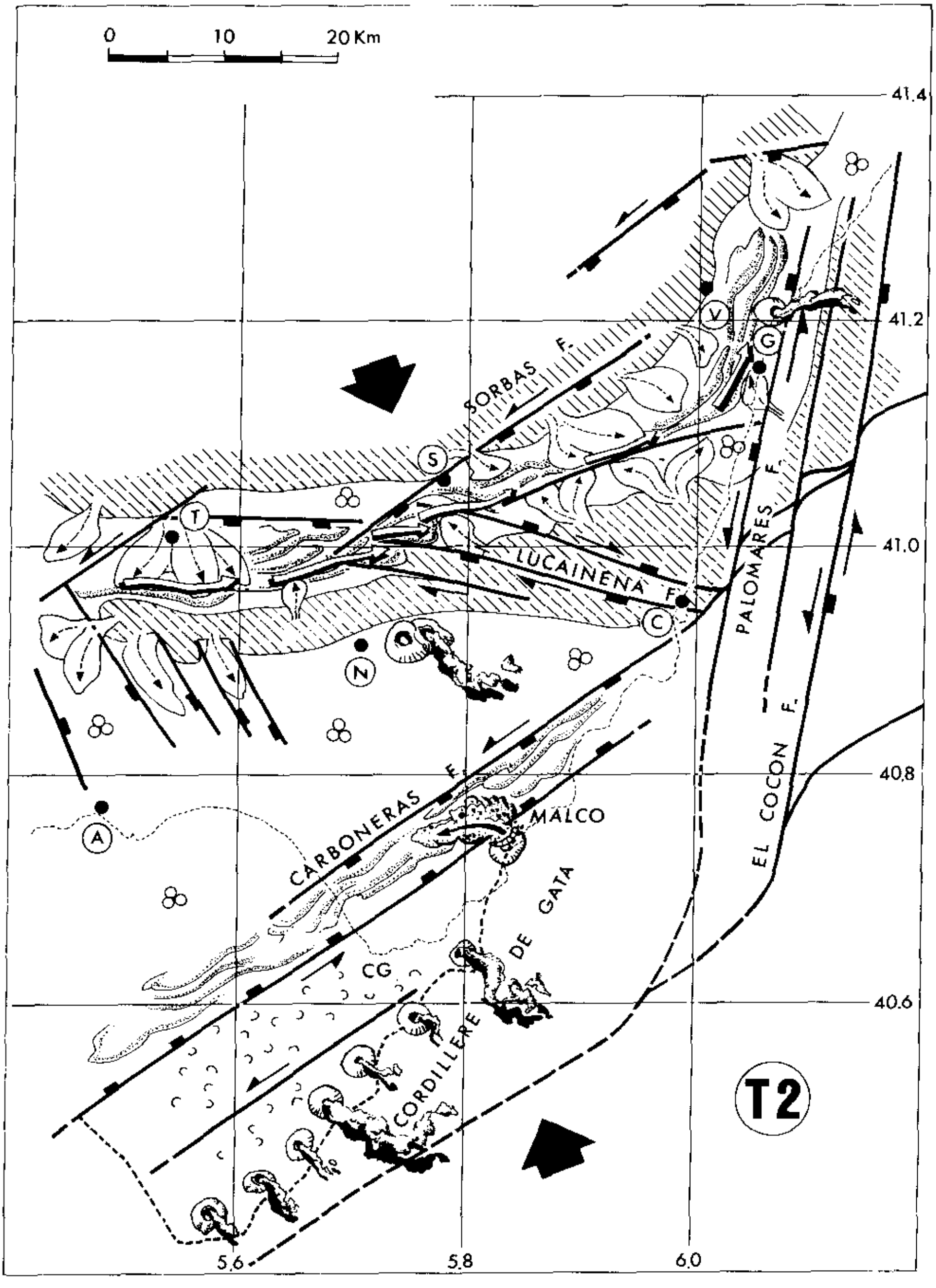

Figure 5.—Paleogeographic sketch-map: late Tortonian (T2).

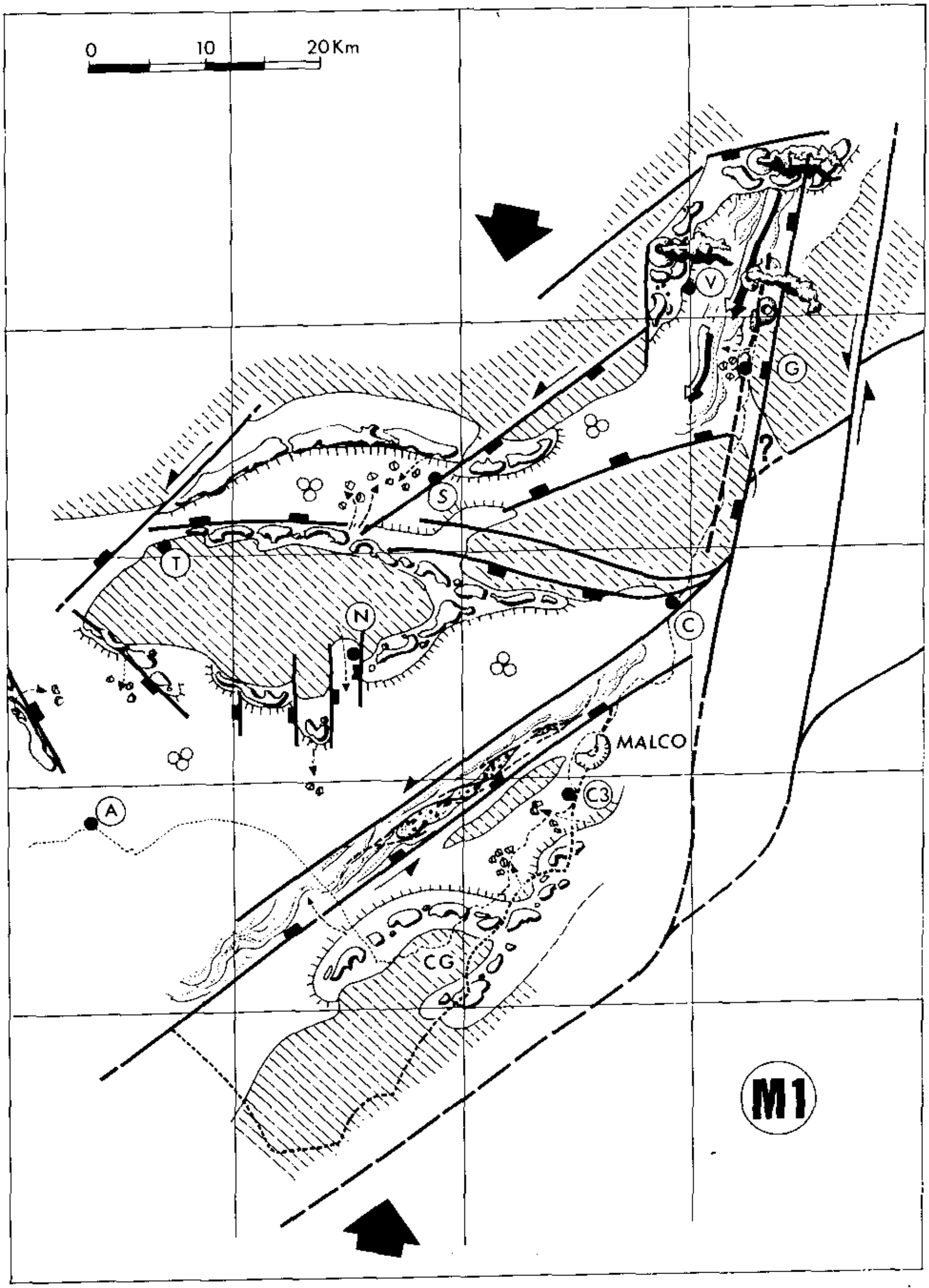

Figure 6.—Paleogeographic sketch-map: early Messinian (M1).

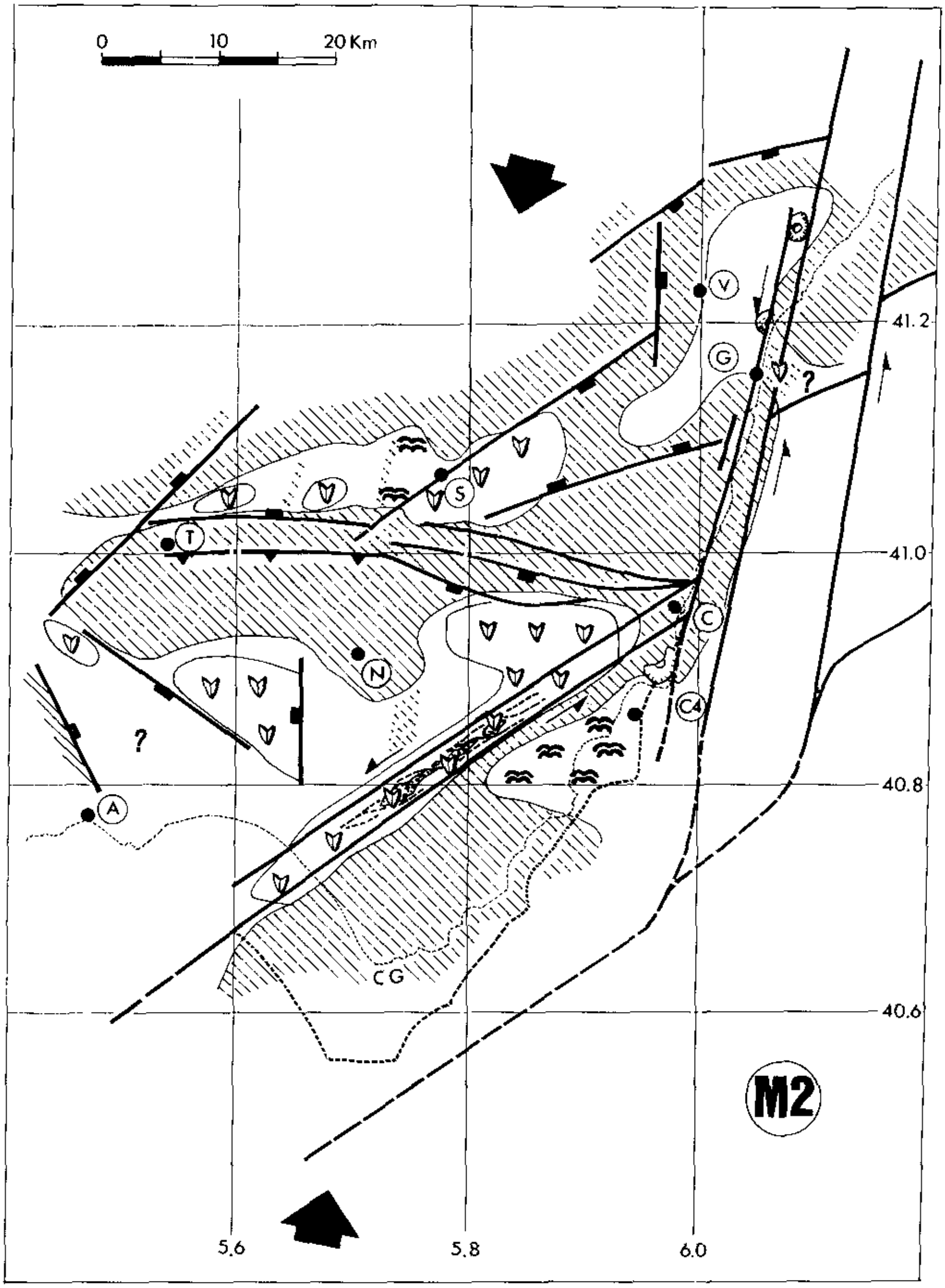

Figure 7.—Paleogeographic sketch-map: late Messinian (M2).

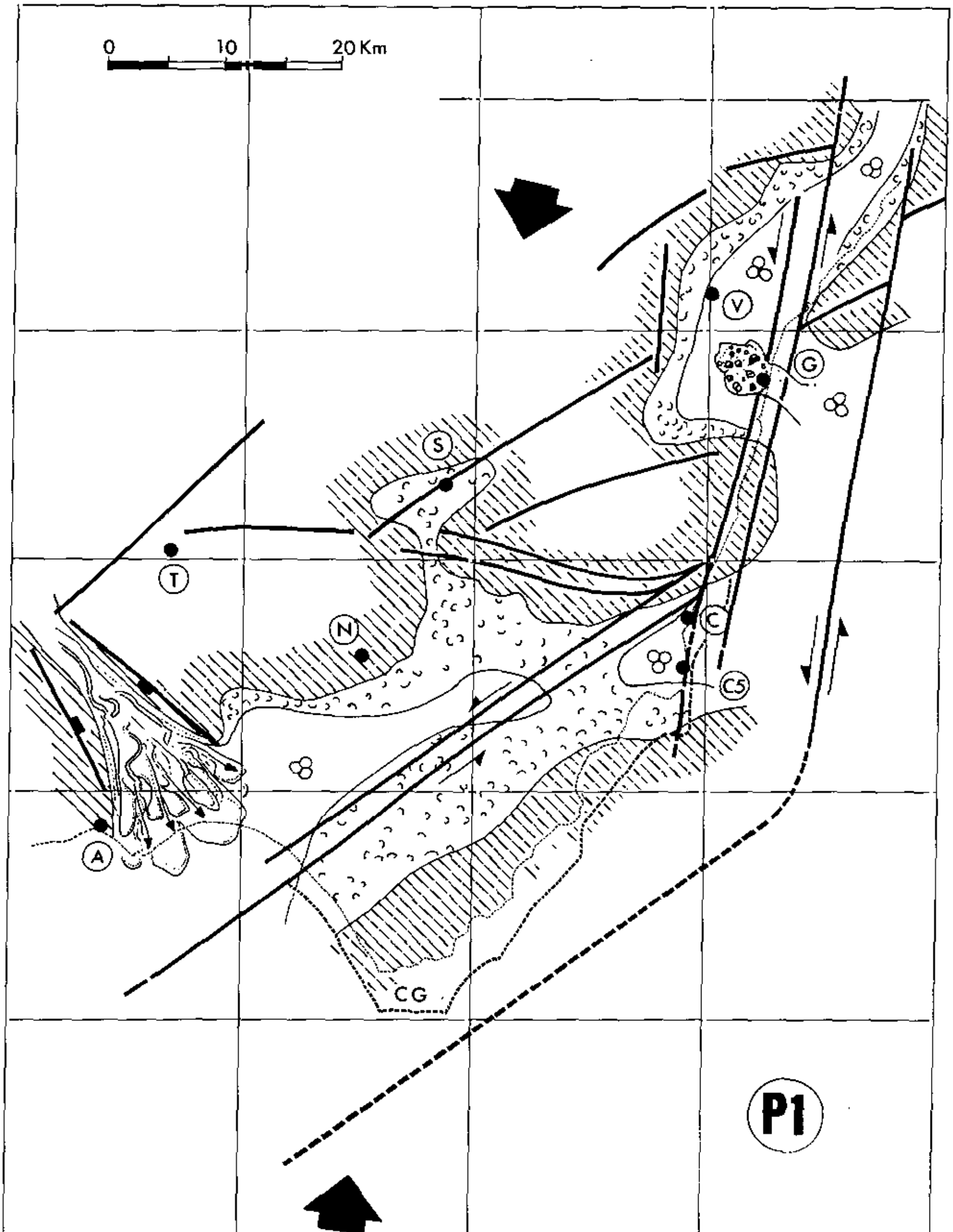

Figure 8.—Paleogeographic sketch-map: early Pliocene (P1).

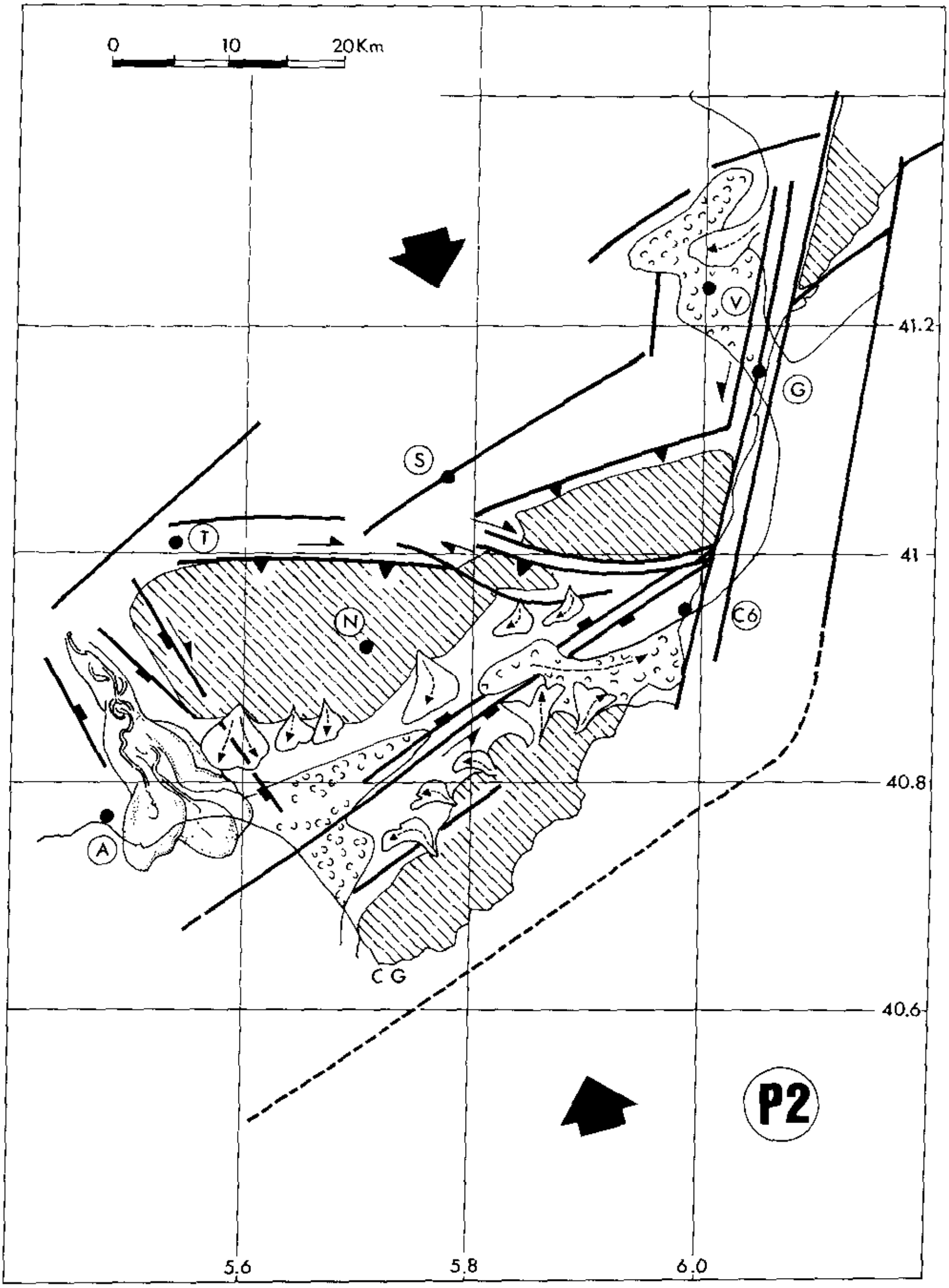

Figure 9.—Paleogeographic sketch-map: late Pliocene (P2).

I. THE NEOGENE SERIES

1. *Tortonian series* are essentially terrigenous deposits. They are partitioned by a regional unconformity (fig. 10). Lower Tortonian beds (Tortonian I) are coarse continental conglomerates and red grits (alluvial fans), cropping out in the Sorbas and Vera basins; they are lacking in the Nijar basin. Upper Tortonian beds (Tortonian II), widely developed, rest unconformably on the previous deposits or extend transgressively onto the basement. They are composed of a thick alternation of detrital discharges (debris-and mud-flows, turbidites) and epibathyal planctonic-rich oozes (about one thousand meters), accumulated within deep subsident furrows (Sorbas, Vera).
2. *The Tortonian-Messinian boundary* is underlined by the deposition of a calcarenitic horizon, the so-called «Calcaires Algues», inset between late Tortonian and Messinian pelagic deposits. These carbonates rest unconformably on the late Tortonian beds; they are locally transgressive on the basement.
3. *Messinian sedimentation* is characterized by a decrease in terrigenous input. Widespread reef building are interfingered basinwards with planctonic-rich marls. Turbiditic deposits are restricted to deeper parts of the furrows (Vera, La Serrata near Carboneras). Sulphate evaporites accumulated within discontinuous subsident depressions (Sorbas, Nijar) and were laterally replaced by calcareo-detritic sediments with stromalitic developments. In many places, diatomitic laminites preceded the evaporitic episode.
4. *Pliocene marine deposits* are slightly developed in the Sorbas basin. In other areas (Vera) they include epibathyal marls and calcarenites of early Pliocene age. During the late Pliocene time (Pliocene II), the extension of shallow-water deposits (calcarenites and sandstones) preludes to a generalized emersion. Locally, deltaic fans accumulated considerable amounts of clastics (Nijar, Almeria, Vera), as a result of regional uplift.
5. *Continental Plio-Pleistocene sedimentation* is pellicular in most cases (red loams and caliches); thick conglomerates locally accumulated in the Sorbas basin.

II. MAGMATISM

1. *Miocene volcanics* are widely developed and diversified. They are largely represented in the Cabo de Gata near Almeria: breccias, domes

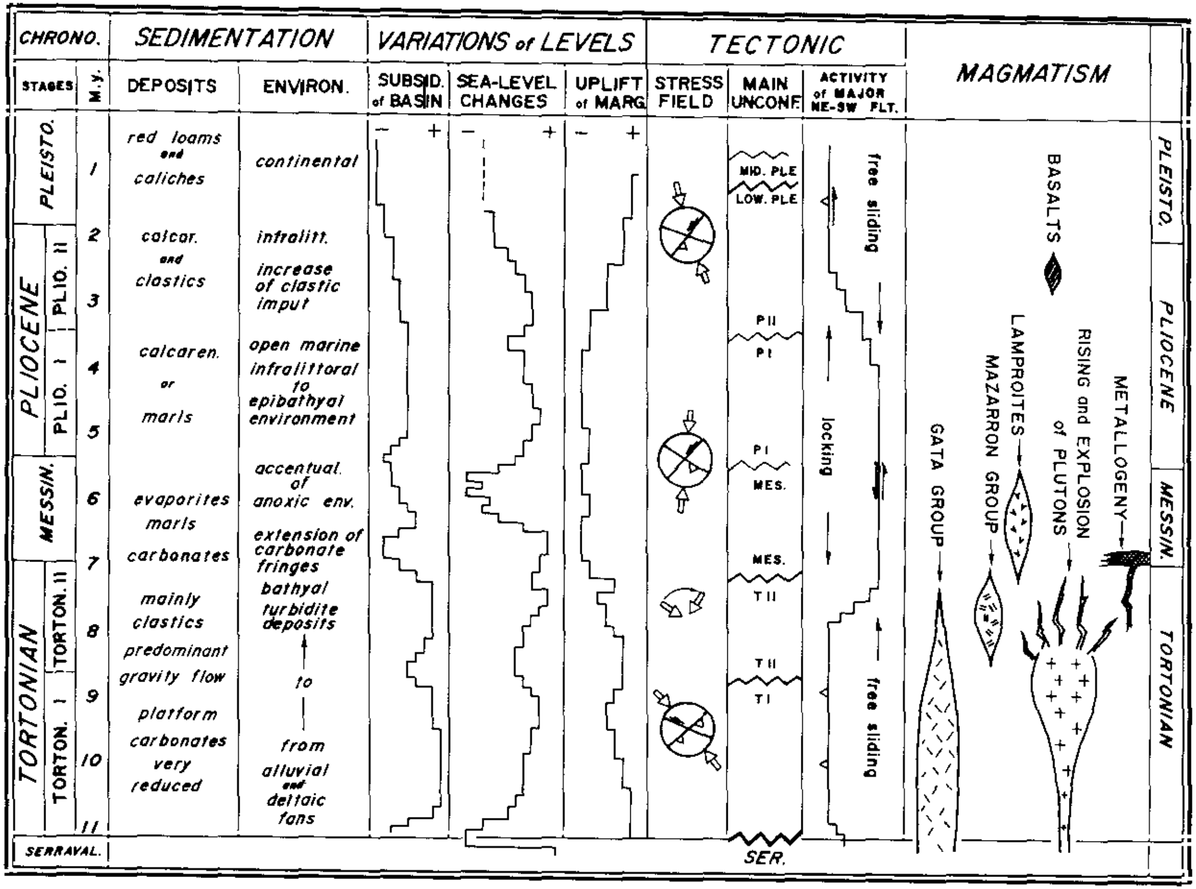

Figure 10.—Sedimentary, tectonic and magmatic late Neogene events in the Eastern Betic Cordilleras.

and ignimbritic outflows (more than 1000 m in thickness). They include different calc-alkaline sequences (Bordet, 1985; Di Battistini *et al.,* 1987): low-K series with dacites and rhyolites; low-K_2O and Na_2O group, ranging from andesites to dacites; ignimbritic rhyolites locally enriched in K_20 and hydrothermalized. These rocks are Serravallian/Tortonian in age (12,6 to 7,2 M. a.). The volcanic activity culminated during Tortonian times (Bellon *et al.,* 1983).

Another calc-alkaline sequence with high-Al content is represented by peraluminous cordierite-bearing dacites and rhyolites, including numerous xenoliths (almandine, andalusite, sillimanite) and metamorphic rocks inclusions. They are derived from a high temperature shallow crustal anatexis from the gneiss of the Betic basement (Zeck, 1968). These volcanics (Mazarron group), late Tortonian in age, are represented by domes and breccias, near Nijar (Cabezo Hoyazo) and within the Vera basin.

Messinian lamproitic outflows originating from a mantellic source are interbedded within basinal marls in the Vera basin.

2. *Miocene plutonism* displays various expressions. Tourmaline-bearing leucogranite veins of an early Miocene age, are intruded into the metamorphic basement along the Carboneras fault. In the Cabo de Gata, various blocks of plutonic rocks (granodiorites to gabbro) originating from explosive phenomena such as «pebble-dike» and «pebble-pipe» (Montenat *et al.,* 1984) are resedimented into late Tortonian and Messinian shallow marine deposits. Radiometric ages (K-Ar and Rb-Sr) indicate Tortonian ages (11 to 8,2 M. a.) (Bordet *et al.,* 1982a) for these materials issued from plutons rising close to the surface.
3. *An important metallogenic event* gave rise to metallic concentrations (Rodalquilar, Vera-Garrucha, Sorbas). The paragenesis bear siderite, Fe-Mn oxides, barite, blend, galena with Ag-Pb combination, and pyrite-gold (Rodalquilar). Ore deposits are veins, stockwerks, stratiform and unconformables accumulations. The enclosing rocks are composed of Miocene volcanics, Tortonian deposits and materials from the basement. The metallogenic event occurred during a short period, close to the Tortonian-Messinian boundary (fig. 10).

III. STRUCTURAL FRAMEWORK

The general structural framework is presented on figure 1. In the concerned area it comprises three major bundles of faults (fig. 2), active during late Neogene times: 1) the NE-SW Carboneras fault acted as a left-lateral fault with a variable reverse component. 2) the E-W Gafarillos or Lucainena fault acted as a right-lateral or reverse fault. 3) the submeridian Palomares fault acted as a left-lateral fault, sometimes with a normal component. The three trends of faults play a determining part in the basin dynamics; various data indicate that they are inherited from pre-Tortonian tectonics.

To the North of Almeria (El Alquian) a group of NW-SE trending faults acted as normal or right-lateral faults.

The polyphased movements of faults resulted from rotations of the stress field during late Neogene times (Ott d'Estevou et Montenat, 1985; Boccaletti *et al.,* 1987). The direction of regional shortening changed from NW-SE (Tortonian), to N-S (late Tortonian to early Pliocene) and to NNW-SSE (from late Pliocene onwards; fig. 10).

Due to these variations, the fault system was submitted to alternating periods of locking and free sliding which directly influence the basin evolution (Montenat *et al.,* 1990). During the same period, different types of basins evolved jointly (Montenat *et al.,* 1987a,b; 1989): 1) groove-shaped faulted synclines (compressional) are narrow and deep furrows, lying along the main wrench faults, whatever their orientation: E-W (Sorbas), NNE-SSE (Vera), NE-SW (Carboneras). These subsident basins accumulated thick turbiditic series. 2) extensional graben controlled by N-S or NW-SE normal faults have minor development in the Nijar area.

IV. PALEOGEOGRAPHIC EVOLUTION AND KINEMATICS OF THE BASINS

The reconstruction of the paleogeographic evolution and kinematics of the Sorbas, Nijar-Carboneras and Vera basins just takes into account the part played by the three major strike-slip faults previously quoted: the Carboneras, Palomares and Lucainena-Gafarillos faults. The amplitudes of horizontal movements from one stage to another are indicative; few confident data are available concerning the quantification of displacements. Moreover, the amplitude of the shortening due to folding and crushing is not precisely known. Therefore, the displacements illustrated on the maps are of a minimum value.

According to offshore geophysical data, the Palomares trend of faults is represented without southwards continuation in the Mediterranean.

The general movement of the Gata block during late Neogene times is illustrated on figure 3; C1 to C6 indicate the successsive positions of the locality of Carboneras, related to stages 1 to 6 of displacements, illustrated on figure 4 to 9. Variations in the direction of displacement are related to changes in stress field orientation. The quantity of movement along the Carboneras fault (left lateral slip) is about 30 km from the beginning of late Miocene times (Bordet *et al.*, 1982b; de La Chapelle, 1988) and about 35 km along the Palomares fault (Alvado, 1986; Weijermars, 1987), during the same period. The shortening of the Nijar-Gata area (including the sierra Alhamilla), perpendicular to the NE-SW trend of the Carboneras fault, is roughly estimated to 10 km.

1. Early Tortonian (TI)

Figure 4 gives a general view of the region at the beginning of Tortonian times. The whole area was emerged. Alluvial deposits are localized within structural depressions in the Tabernas-Sorbas and Vera basins. Alluvial fans are predominant close to fault escarpments; flood plain deposits are slightly developed (southern part of the Vera basin).

The piling of volcanic in the southeastern compartment of the Carboneras fault indicates an active subsidence of that area, while the northwestern part (Nijar area) was a relief free from deposits. The position of the Gata block is indicative. It might be located more to the southwest. A northeastwards continuation of this magmatic trend is inferred from off-shore data and volcanic outcrops located near Aguilas (Coppier *et al.*, 1989).

2. Late Tortonian (TII)

The sea invaded a large part of the concerned area during late Tortonian times (fig. 5). Marine sediments accumulated in various depressions related to tectonic activity. Groove-shaped synclines are strictly controlled by strike-slip faults: Carboneras and the Sorbas-Vera corridors. They are deep-water turbiditic furrows supplied with lateral detrital fans.

A part of the clastics is redistributed by longitudinal turbiditic currents, canalized east- or northeastwards (Bedu, 1990).

A large volume of volcanic material (olistostrome of the «Brèche rouge») collapsed in the Carboneras furrow by the end of Tortonian times. The olistostrom originated from the volcanic reliefs of the Malco or similar late Serravallian/early Tortonian volcanoes (Bordet *et al.*, 1982b), located close to the present shore line.

Pelagic oozes deposited within the Nijar area; turbidites are scarcely developed. Some fans and turbiditic flows are controlled by NW-SE faults which display a predominant normal component (Almeria graben). These faults gave rise to a succession of faulted blocks, inducing a westwards thickening of the pelagic deposits.

Volcanic activity in the Gata block is now reduced and located close to the present day shore, along a NE-SW trending line. Rhyodacitic volcanoes (Mazarron group) are active (Nijar, Garrucha). The reliefs of Gata were partly covered by shallow marine deposits (calcarenites). A deeper zone extended on the Agua Amarga area, south of Carboneras.

3. Messinian (M1 and M2)

Open marine environment existed during the first part of Messinian times (M1; fig. 6). The paleogeographic configuration obviously changes from late Tortonian to early Messinian times. The Sorbas and Vera basins migrated respectively northwards and westwards. It should be noted the development of reefs on the basin margins and around the Gata block, whose volcanic activity is now stopped. Late Tortonian metallogenic event definitively stopped at the early beginning of Messinian time (Garrucha, Las Herrerias).

As a result of the previous right lateral movements along the Lucainena-Gafarillos faults, a strait opened between the Alhamilla and Cabrera ridges (Polopos strait). This strait was colonized by Messinian reefs. In many places, olistolites and gravitary flows originating from the reefal fringes are packed within pelagic deposits. Basinal sediments are mainly planktonic-rich ooze; turbidites are restricted to the depressions stretching along the Carboneras and Palomares faults. In the Vera corridor, turbiditic flows transited southwards.

In the Nijar area (southern part of Alhamilla), faulted blocks are now bounded by N-S normal faults, while the preexisting NW-SE faults are reactivated with dextral component.

An intense wrenching within the Carboneras corridor is responsible for the dilaceration of the «Brèche rouge» olistostrome and a strong synsedimentary structuration of the Messinian pelagic deposits. Magmatic activity is restricted to lamproitic eruptions in the Vera basin.

The Messinian evaporitic event (M2 fig. 7) is characterized by a contraction of the basinal domain. The movement of the Gata block, migrating northeastwards, probably favoured the realization of a restricted environment.

The evaporites were deposited within discontinuous evaporitic «pools» corresponding to subsident areas under tectonic control. Stromatolitic carbonates covered shallow flats (Agua Amarga). The confined depression of Vera remained free from evaporites. The evaporitic depressions are still connected, at least periodically, with marine environment.

The dismemberment of various rock bodies (olistostrome, volcanic domes), evidenced by mapping, indicates that an important part of the lateral displacements occurred during Messinian times.

4. **Pliocene (T1 and T2)**

During the early Pliocene (PI; fig. 8), the Nijar-Carboneras basin is a large strait which links the Carboneras area to the gulf of Almeria. The opening of the Carboneras area to the Pliocene sea results from important throws along submeridian faults (Palomares trend) located close to the present day shoreline. The opening eastwards of the Vera basins at the beginning of the Pliocene results from the same process. It was preceded by the setting up of a large olistostrom at the Messinian/Pliocene boundary (Garrucha). The disruption of late Tortonian rhyodacitic volcanoes of Garrucha, as a result of the left-lateral movement of the Palomares fault, occurred prior to the Pliocene sedimentation.

The Pliocene sea extended a short time to the North, over the Sorbas basin, through the Polopos strait (Ott d'Estevou, 1980). An important delta fan prograded southeastwards in the Andarax area (Almeria), canalized by NW-SE faults (Weijermars *et al.*, 1985).

The contraction of the marine domain and the generalization of shallow water sedimentation are recorded during the late Pliocene (fig. 9). It is to note the development of clastic fans (Andarax, Nijar, Vera) due to the general uplift of the reliefs. The extrusion of the flower structure of La Serrata along the Carboneras faults and an important episode of folding of the sierras Alhamilla and Cabrera occurred during that period.

CONCLUSION

These preliminary palynspastic sketch maps have to be improved with more data concerning the quantification of displacements. From available data, the average of lateral displacement along the major strike-slip faults is between 20 and 30 km during late Neogene times.

However, as a result of the rotation of the stress field, inducing alternation of locking and free sliding of the faults, the movements were not continuous. Moreover they were accompanied by an important shortening of the basement, evidenced by large-scale folds (i. e. sierra Alhamilla and Cabrera folds with northern vergency) (Weijermars *et al.,* 1985). These folds, responsible for important vertical displacements, play a noticeable part in the basin development.

The table (fig. 10) summarizes the numerous events that occured during the short late Neogene period. It is to note that the important Tortonian thermal anomaly (crustal anatexis, plutonic bodies rising close to the surface, metallogeny) (Larouzière *et al.,* 1988) preludes to large lateral sliding recorded from the beginning of Messinian times.

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