MIOCENE TEMPERATE CARBONATES IN THE AGUA AMARGA BASIN (ALMERÍA, SE SPAIN)

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Abstract: The Agua Amarga Basin is a small Neogene Mediterranean basin in the volcanic area of Cabo de Gata (Almería, SE Spain). The Miocene infill of the basin is made up of two units of Tortonian temperate carbonates separated by the youngest volcanic rocks in the area. These temperate carbonate units are unconformably overlain by Messinian reefs and locally brecciated, oolitic/ stromatolitic limestones. The lower Tortonian temperate carbonate unit consists of fan-delta volcaniclastics and bryomol calcarenites/ calcirudites. These sediments, arranged in a subsequence, were deposited in coastal palaeonviroments around small emerged reliefs. Volcanic rocks 8.1-8.7 Ma-old cut, engulf and overlie these lower carbonates. The upper Tortonian-lower Messinian temperate carbonate unit consists of four subunits: a) debris-flow conglomerates and trough cross-bedded, bryomol calcarenites/ calcirudites; b) a bioclastic and volcaniclastic breccia; c) bryomol calcarenites/calcirudites; and d) calcarenites/calcisiltites. The first three subunits represent the Lowstand Systems Tract and the expansive fine-grained sediments of the fourth subunit the Transgressive Systems Tract of a sequence interrupted by a tectonic pulse. Higher orders of cyclity can be recognised within this sequence. The palaeogeography of the upper temperate carbonate unit, with facies belts trending N80E from a northern palaeocoast, was probably controlled by the strike-slip Carboneras fault system.

Key words: Temperate carbonates, Miocene, Agua Amarga Basin, SE Spain.

Resumen: La Cuenca de Agua Amarga es una pequeña cuenca sedimentaria neógena situada en la región volcánica de Cabo de Gata (Almería, SE de España). El relleno mioceno de la cuenca se inicia con dos unidades de carbonatos templados del Tortoniense, separadas por las rocas volcánicas más jovenes de este área. Sobre los carbonatos templados se disponen discordantemente unidades arrecifales messinienses y calizas oolíticas y estromatolíticas, localmente brechificadas. La unidad inferior de carbonatos templados está formada por depósitos volcanoclásticos de abanico deltaico y calcarenitas/calciruditas compuestas por fragmentos de briozoos, moluscos, macroforaminíferos, equínidos y algas rojas. Estos materiales, ordenados en una subsecuencia, se depositaron en medios costeros, alrededor de pequeños relieves emergidos. Rocas volcánicas, con edades de 8.1 a 8.7 Ma, atraviesan, engloban y recubren a los carbonatos templados de la primera unidad. La segunda unidad de carbonatos templados, de edad Tortoniense superior-Messiniense inferior está constituida por cuatro subunidades: a) conglomerados y calcarenitas/ calciruditas de briozoos con grandes estratificaciones cruzadas en artesa; b) una brecha bioclástica con cantos volcánicos; c) calcarenitas/ calciruditas de briozoos; y d) calcarenitas/calcisiltitas. Las tres primeras subunidades constituyen, en conjunto, el cortejo de bajo nivel de mar y los sedimentos expansivos de grano fino de la cuarta subunidad el cortejo transgresivo de una secuencia interrumpida por un pulso tectónico. En el interior de esta secuencia pueden apreciarse ciclicidades de mayor frecuencia. La paleogeografía de esta unidad superior, caracterizada por cinturones de facies con orientación N80E desde una paleocosta situada en el margen norte de la cuenca, fue probablemente controlada por el sistema de fallas de Carboneras. Este es un sistema de fallas de salto en dirección, orientado N45E, cuyo movimiento ha sido sinestrorso desde el Tortoniense superior.

Palabras clave: Carbonatos templados, Mioceno, Cuenca de Agua Amarga, SE España.

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Neogene sediments occur between the volcanic rocks in the Cabo de Gata area (Almería, SE Spain). These deposits are the relics of small sedimentary basins linked to the Mediterranean sea that developed in this region during the Late Cenozoic. One of these basins is the Agua Amarga Basin, where Neogene sedimentary rocks, mainly carbonates, crop out over some 10 square kilometres to the west of the village (Fig. 1).

The Neogene deposits of the Agua Amarga Basin have been reported in previous studies dealing with the regional geology of the area (van de Poel *et al.*, 1984; Montenat *et al.*, 1990; van de Poel, 1991). These authors considered the Agua Amarga Basin to be a subbasin of the Almería-Níjar Basin located to the west. However, although the connections between the two basins are evident for certain time intervals, the Agua Amarga Basin had an independent sedimentary evolution resulting in a unique stratigraphic record. Two upper Miocene temperate carbonate units, which are the main subject of this report, are especially well developed and exposed. The excellent outcrops of these materials favour analysis of their sedimentology and of their stratigraphic relationships with the volcanics in the area.

Stratigraphy of the Agua Amarga Basin

The basement of the outcropping sediments is made up of pyroclastic breccias («Unidad del Plomo», Fernández-Soler, 1992) that yield a radiometric age of 9.6 Ma (Bellon *et al.*, 1983; Montenat, 1990). The lowest sedimentary deposits consist of terrigenous sediments and calcarenites/calcirudites with abundant fragments of bryozoans, bivalves, echinoids, and benthic foraminifers together with smaller amounts of barnacles, brachiopods, coralline algae, and solitary corals (Figs. 2 and 3). They contain lower Tortonian planktonic foraminifers (Braga *et al.*, 1994). An angular unconformity and, locally, a well-developed red soil separate this lower carbonate unit from overlying calcirudites and calcarenites that are similar in composition (Figs. 2 and 3). To the northeast and south of the basin, volcanic rocks around 8 Ma old (Bellon *et al.*, 1983; Fernández-Soler, 1992) occur intercalated between the two carbonate units (Fig. 4). The calcirudites/ calcarenites of the second unit grade upwards into fine-grained calcarenites and silty marls (Figs. 2 and 3). Planktonic foraminifer assemblages record the Tortonian-Messinian boundary at the base of the marls (Braga *et al.*, 1994).

A reef unit of Messinian age unconformably overlies the previous sedimentary units and/or the circa 8 Ma-old volcanics. This unit consists of bioherms, reef blocks and coral breccias dispersed among silty marls and turbiditic calcarenites (Figs. 2 and 3). Reef blocks, together with slumped beds, concentrate in the eastern outcrops of the unit.

In localities of Cabo de Gata to the south of Agua Amarga, such as Sierra de San Pedro and La Molata de Las Negras, this unit is unconformably overlain by prograding Messinian reefs (Franseen, 1989; Franseen and Mankiewicz, 1991; Brachert *et al.*, 1996) (Fig. 3).

The last Miocene rocks in Agua Amarga consist of locally brecciated, oolitic, and stromatolitic limestones from the upper Messinian (Addicott *et al.*, 1977; Dabrio and Martín, 1978; Esteban and Giner, 1980; van de Poel *et al.*, 1984) (Fig. 2). In Mesa de Roldán they include small *Porites* patch reefs (Riding *et al.*, 1991).

A thin Pliocene unit of calcareous conglomerate/ sand beach deposits (Martín *et al.*, 1994) completes the Neogene stratigraphy of the Agua Amarga basin (Fig. 3).

Lower temperate carbonate unit

This unit lies over 9.6 Ma-old pyroclastic breccias («Unidad del Plomo», Fernández-Soler, 1992) locally

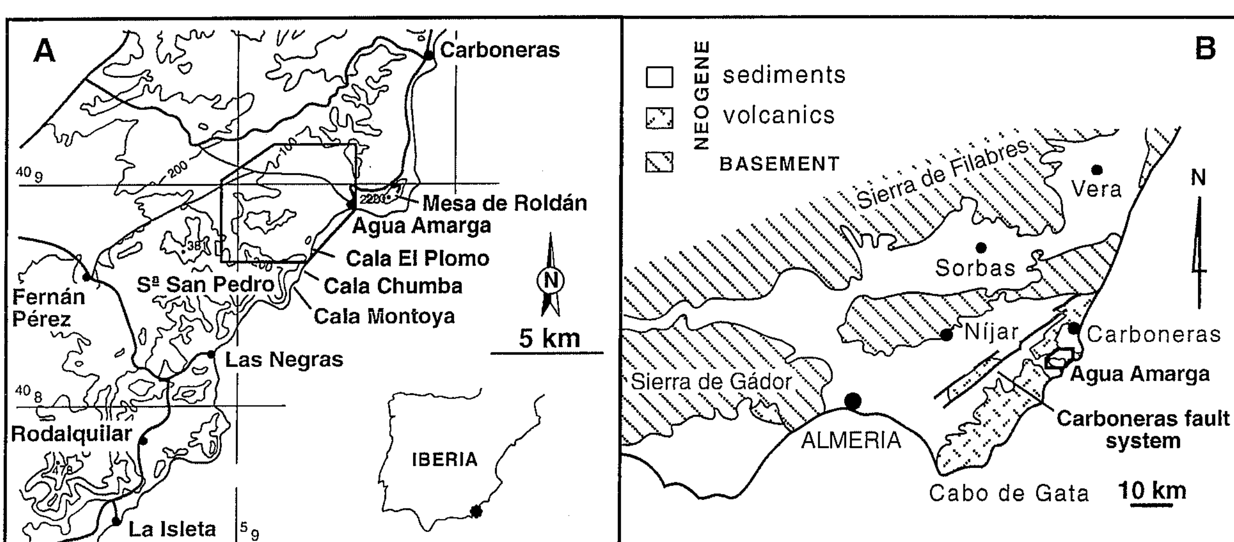

Figure 1.- **A**. Geographical location of the Agua Amarga Basin in SE Spain. - **B**. Neogene basins in SE Spain. Insets show the study area.

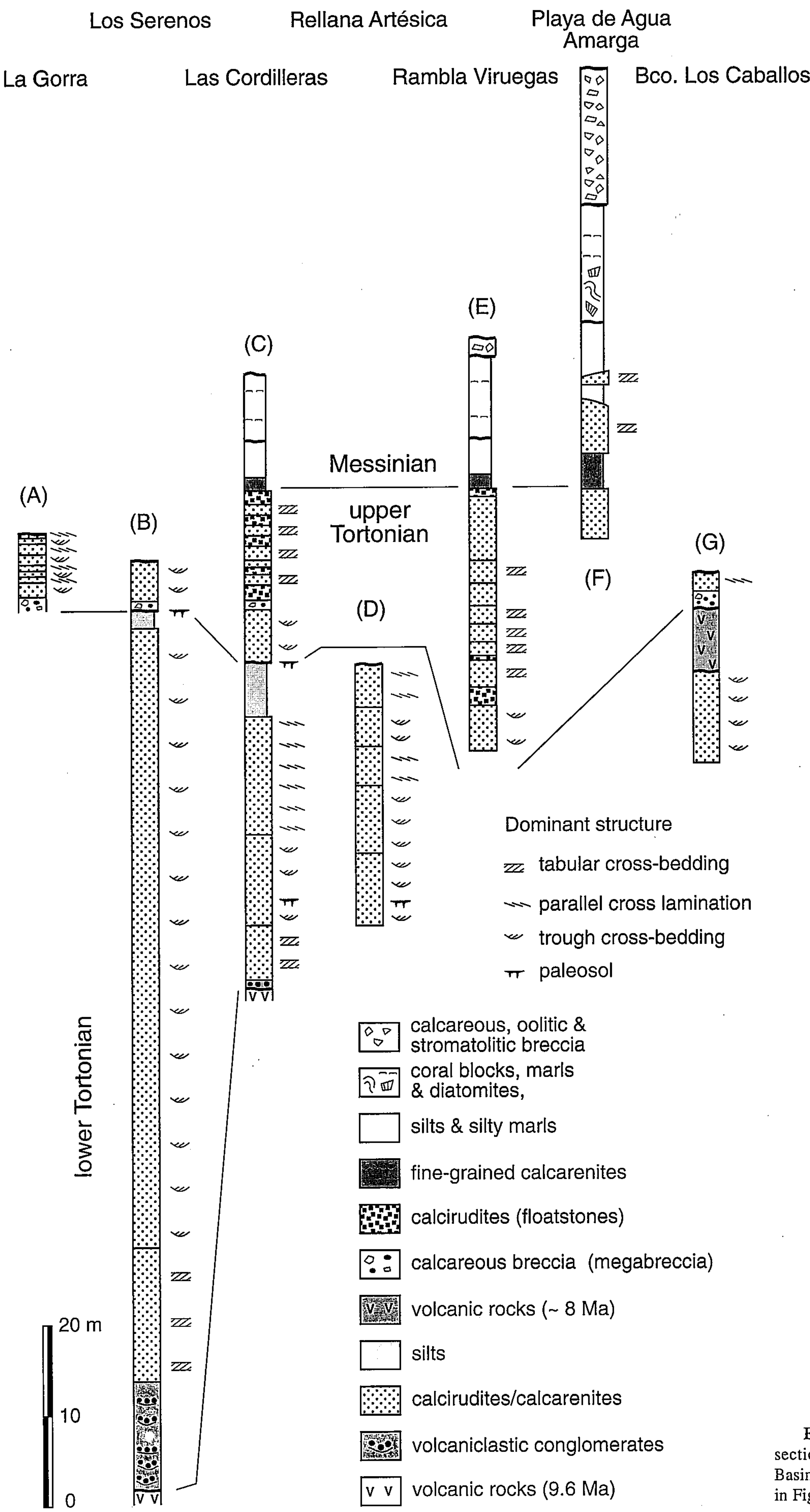

Figure 2.- Selected simplified sections from the Agua Amarga Basin. Locations (A to G) shown in Fig. 4.

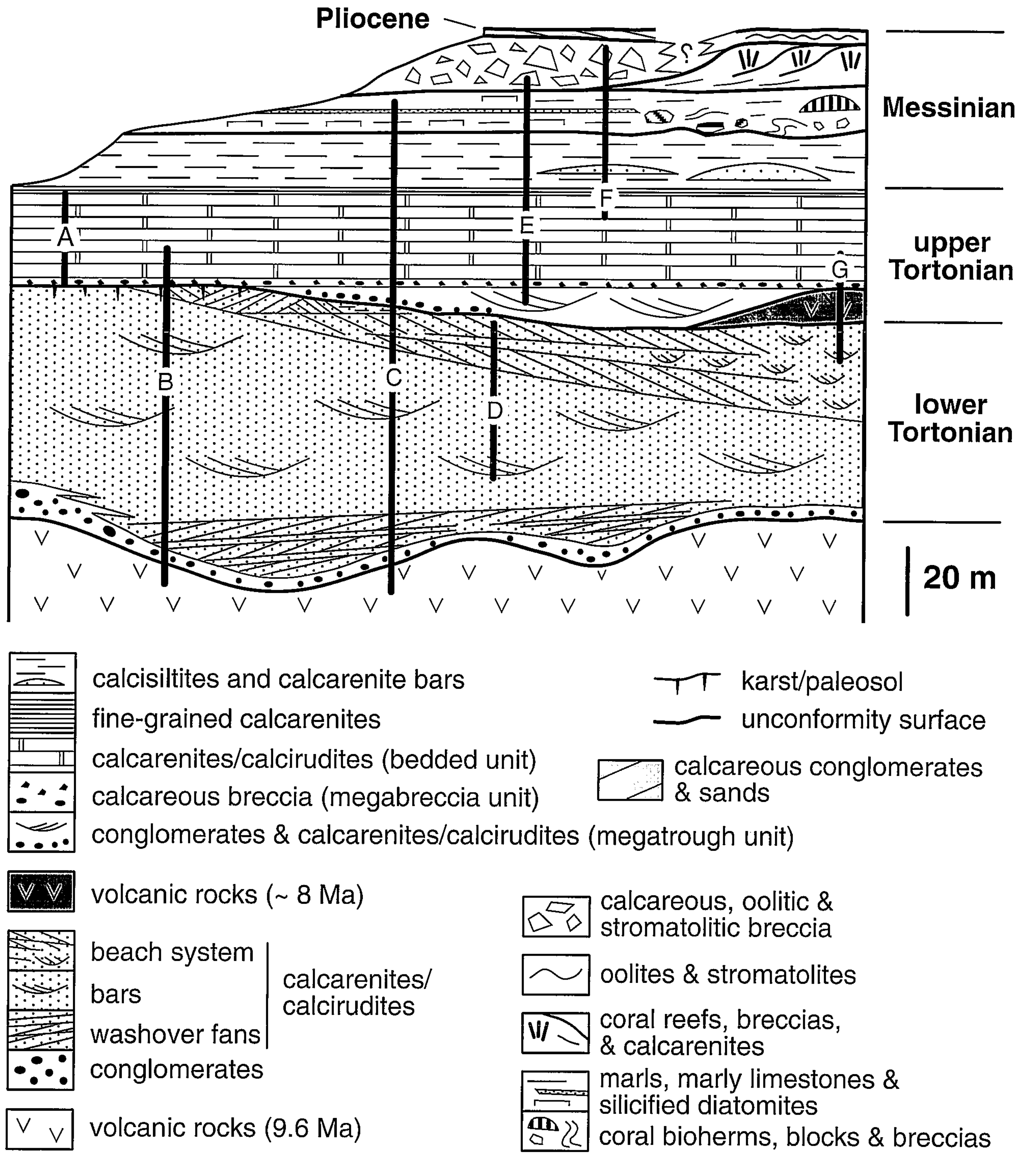

Figure 3.- Stratigraphy of the Agua Amarga Basin and northern Sierra de San Pedro. Vertical bars (A to G) show the stratigraphic position of sections in Fig. 2.

altered into bentonites. The lower part of the unit consists of volcaniclastic conglomerates, microconglomerates, and sands with variable amounts of bioclasts, mainly oysters, bryozoans, barnacles and red algae. In the westernmost outcrops of the unit, channelized debris-flow conglomerates alternate with microconglomerates and sands, sometimes showing trough cross-bedding and small ripples. In some beds most of the volcanic clasts are isolated amphibole crystals. These deposits, up to 13.5 m thick, can be interpreted as fan-delta deposits reworked by waves. In most sections, however, trough cross-bedded volcaniclastic sands and microconglomerates, a few metres thick, constitute the first sediments on top of the volcanic basement.

The bioclastic content sharply increases above the volcaniclastics and the rest of the unit consists of calcirudites/calcarenites made up of fragments of bryozoans, bivalves, echinoids, large benthic foraminifers

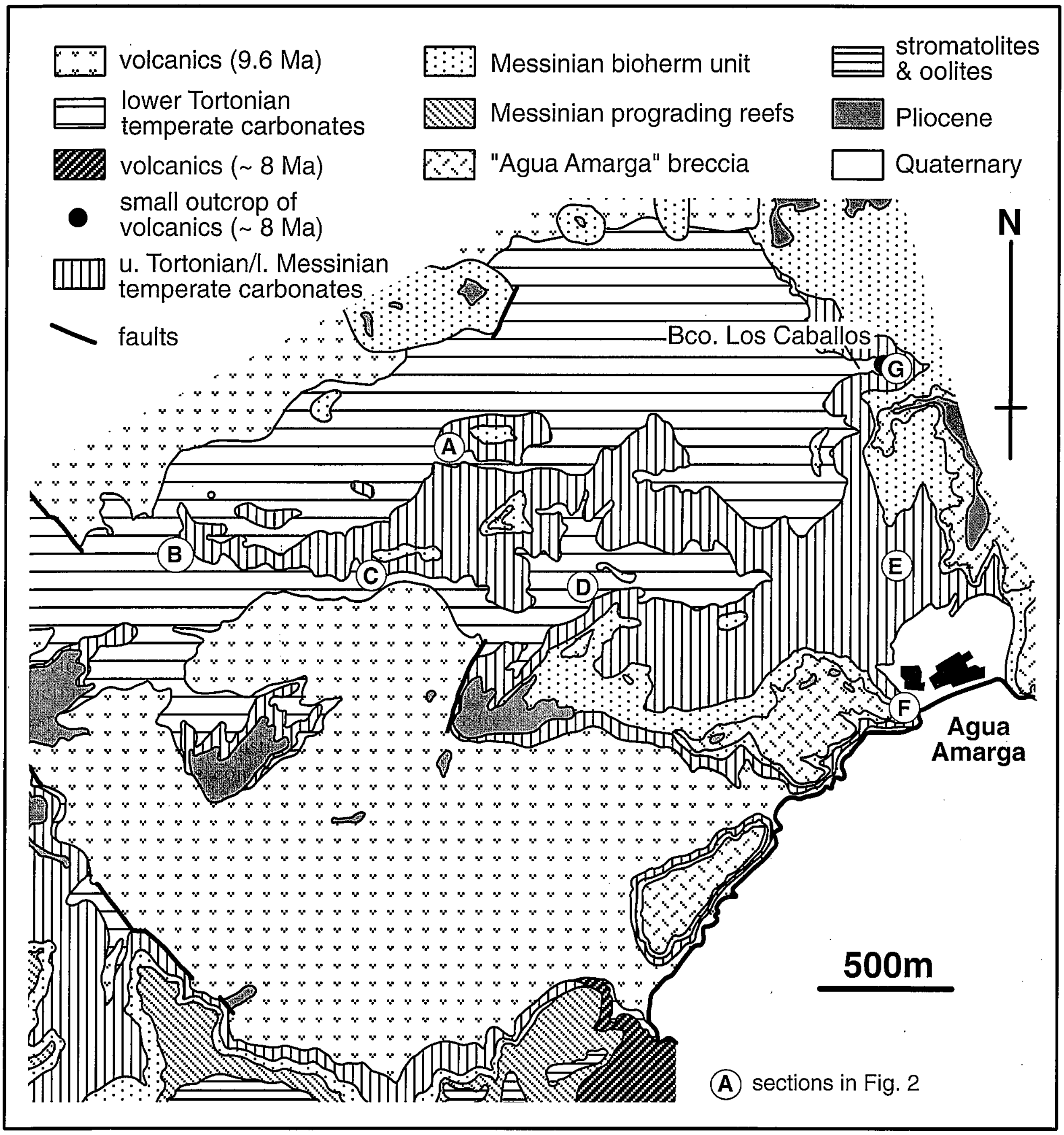

Figure 4.- Geological map of the Agua Amarga Basin and northern Sierra de San Pedro.

(*Heterostegina* and *Amphistegina*), with minor solitary corals, brachiopods, barnacles, and red algae. Volcanic clasts represent a low percentage of the rocks (always less than 10%). The scarce sparry calcite cements are mainly syntaxial rim cements around echinoid fragments. These «bryomol facies» (in the sense of Nelson *et al.*, 1988) are temperate carbonates that lack the components characteristic of tropical/subtropical carbonate facies.

Three subunits can be distinguished according to the sedimentary structures in the calcirudites/calcarenites. The first subunit occurs in the western half of the basin at the bottom of the bioclastic carbonates. Horizontal to low-angle cross beds separate sets of cross-laminated beds with the topsets and bottomsets highly bioturbated by burrows of irregular echinoids. Cross laminations point to the northwest (from west to northeast). They can be interpreted as washover fan deposits (Betzler *et al.*, 1997).

Overlying this subunit or directly on top of the volcaniclastics, the dominant structure is trough cross-bedding of various dimensions, up to 70 m in length and 10 m in amplitude. These beds are also affected by centimetric to decimetric ripples. Trough cross-bedding predominantly points to the east, with a subordinate westward direction. Laterally discontinuous

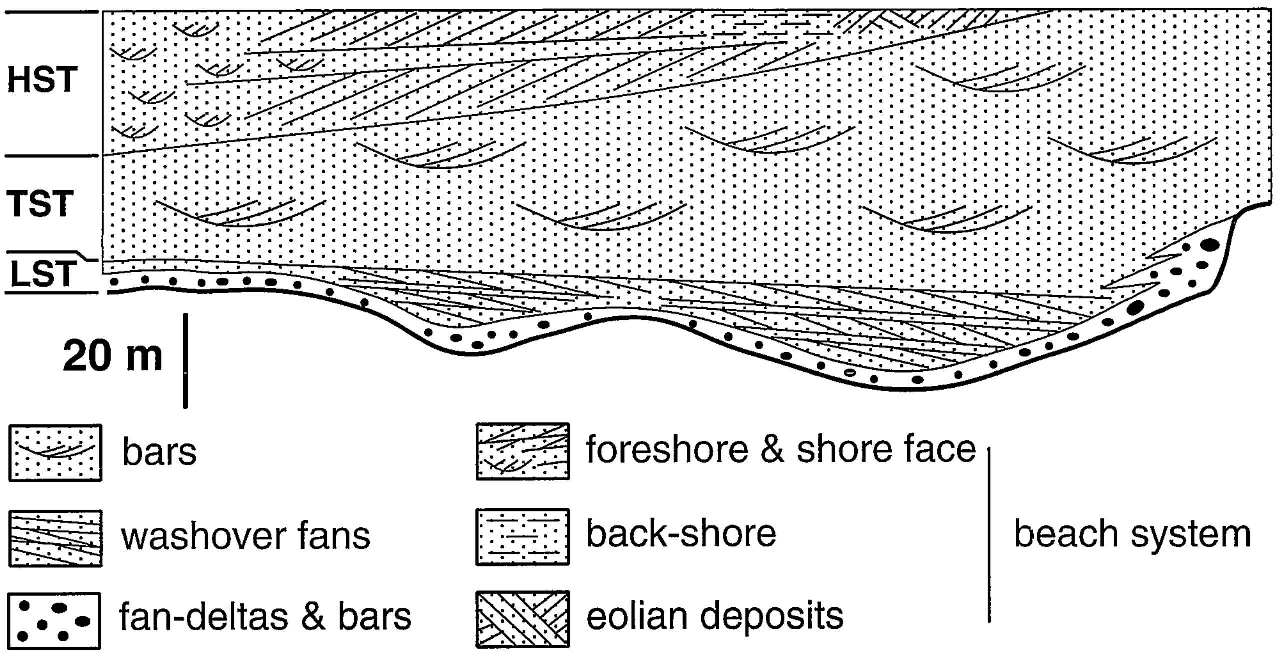

Figure 5.- Stratigraphy and sequence interpretation of the lower temperate carbonate unit. See text for further explanation.

red paleosols, lag horizons of volcaniclastic pebbles, and intraformational breccias locally appear among the trough cross-bedded calcirudites/calcarenites. They represent submarine bars and dunes deposited under the influence of currents flowing to the east. At the northern and eastern margins of the basin these deposits are directly attached to subvertical palaeocliffs of volcanic rocks. In such places boulders of volcanic rocks are embedded in the bioclastic sediments. The bars locally emerged and paleosols formed at certain points. Planktonic foraminifers are abundant in some samples (Betzler *et al.*, 1997).

The third subunit crops out on top of these deposits in the eastern part of the basin. Its overall geometry is that of a wedge increasing in thickness to the southeast. Low angle parallel laminated beds grade to the southeast into trough cross-bedded calcirudites/ calcarenites, bioturbated by irregular echinoids. These can be interpreted as beach deposits in which foreshore beds change to the southeast to shoreface sediments. A layer of silty marls up to 7 m thick occurs to the west of the topmost foreshore deposits. The silty marls change to the west to high-angle cross-bedded, well-sorted calcarenites. They probably represent backshore, lagoonal and eolian deposits (Betzler *et al.*, 1997).

According to the stratigraphic relationships, and to the geometry and sedimentary facies of the different subunits, this unit can be interpreted as a (sub)sequence (Fig. 5). The fan-delta volcaniclastics, the back-barrier, washover fan deposits and the laterally equivalent bar deposits constitute the Lowstand Systems Tract; the expansive trough cross-bedded bar deposits that lie over the previous sediments and onlap the substrate represent the Transgressive Systems Tract; and the beach deposits, together with their back-shore equivalents, the Highstand Systems Tract (Betzler *et al.*, 1997).

Sedimentological evidence indicates that during the lowstand these materials formed in a coastal area with local development of fan deltas. Bars and barrier islands, probably promoted by substrate swells, sheltered small areas in the western half of the basin where washover fans developed. With ascending sea level the outcropping part of the basin was covered by a shoal area with locally emerged bars. Beach deposits, prograding to the SE, eventually filled the basin at the end of the sedimentary cycle (Betzler *et al.*, 1997) (Fig. 6).

Volcanic rocks between temperate carbonate units

A red paleosol, partially eroded, occurs on top of the lower temperate carbonate unit. This palaeosol fills fissures that developed in the underlying unit, suggesting previous karstification of these carbonates.

In some localities of the eastern part of Agua Amarga Basin, volcanic rocks lie over the lower temperate carbonate unit. At the Barranco de los Caballos a wedge of volcanic breccias overlies trough cross-bedded calcirudites/calcarenites (Fig. 2, section G). The volcanics are in turn covered by conglomerates and calcirudites from the upper temperate carbonate unit. This is the closest outcrop of the lower unit to Mesa de Roldan where similar andesitic breccias yield a radiometric age of 8.65-8.67 Ma (Di Battistini *et al.*, 1987; Bellon *et al.*, 1983). At the southern side of Cala del Plomo, lower unit calcirudites/calcarenites are covered by andesitic lavas and breccias from a small volcanic dome

(«Vitrófido del Plomo», Fernández-Soler, 1992) dated 8.1 Ma (Bellon *et al.*, 1983). To the west of Cala del Plomo these volcanics are also overlain by the upper temperate carbonate unit. At the coastal cliffs of Mesa de Roldan, Cala del Plomo, Cala Chumba and Cala Montoya there are good exposures of volcanic rocks around 8 Ma old cutting through, covering, and engulfing blocks of the lower temperate carbonate unit (Fig. 7). These outcrops confirm that the youngest volcanics in the area erupted after the deposition of the lower temperate carbonate unit, sometimes incorporating its materials into the volcanic products.

Upper temperate carbonate unit

This unit unconformably overlies the lower temperate carbonate unit or the circa 8 Ma-old volcanics (Figs. 2, 3 and 4). It consists of four subunits (Fig. 8). The lower three constitute the so-called «Azagador Member» defined by Ruegg (1964) in the Vera Basin. The uppermost subunit can be considered to be part of the «Abad Member» defined by Ruegg (1964) in the Vera Basin for marls of Messinian age (Sierro *et al.*, 1993; Martín and Braga, 1994). These subunits are, from bottom to top:

a) A megatrough cross-bedded subunit, up to 10 m thick, that changes laterally to the north to debris-flow conglomerates up to a couple of metres thick, with boulders of volcanic rocks up to a metre in size. It consists of a granule-to-pebble-sized calcirudite (rudstone) with abundant fragments of bryozoans, bivalves, echinoids, and benthic foraminifers, with minor coralline algae, brachiopods, barnacles, and solitary corals. Single troughs, pointing mainly to the S and E, may be more than 100 m in wavelength and several metres (3-4) thick.

b) A megabreccia unit, up to 3 m thick. Northwards it lies directly on the lower Tortonian carbonates. It is made up of lithoclasts from the underlying carbonates, volcanic pebbles, and cm-sized bioclasts of bryozoans, oysters and pectinids, solitary corals, coralline algae, barnacles, and gastropods embedded in a calcarenite/calcirudite matrix.

c) A bedded subunit of an outstanding white colour, up to 25 m thick. It is made up of bioclastic, bryozoan/bivalve-dominated calcarenites/calcirudites («bryomol facies» in the sense of Nelson *et al.*, 1988), with abundant fragments of echinoids and macroforaminifers, and minor coralline algae, brachiopods, barnacles and solitary corals (Braga *et al.*, 1994). Calcirudite (calcarenite) beds showing well-developed, low-angle parallel lamination, prograding to the SE, pass laterally to trough cross-bedded sediments. These in turn grade to floatstones that laterally change to fan-bedded floatstones/rudstones (Fig. 9). The inferred depositional model (Martín *et al.*, 1996) is that of a gentle ramp with beaches and shoals in its shallower parts. Seawards of the shoals, probably below fairweather wave-base, was the factory area, where maximum carbonate production took place. From the factory area some of the skeletons were transported landwards by waves and/or currents

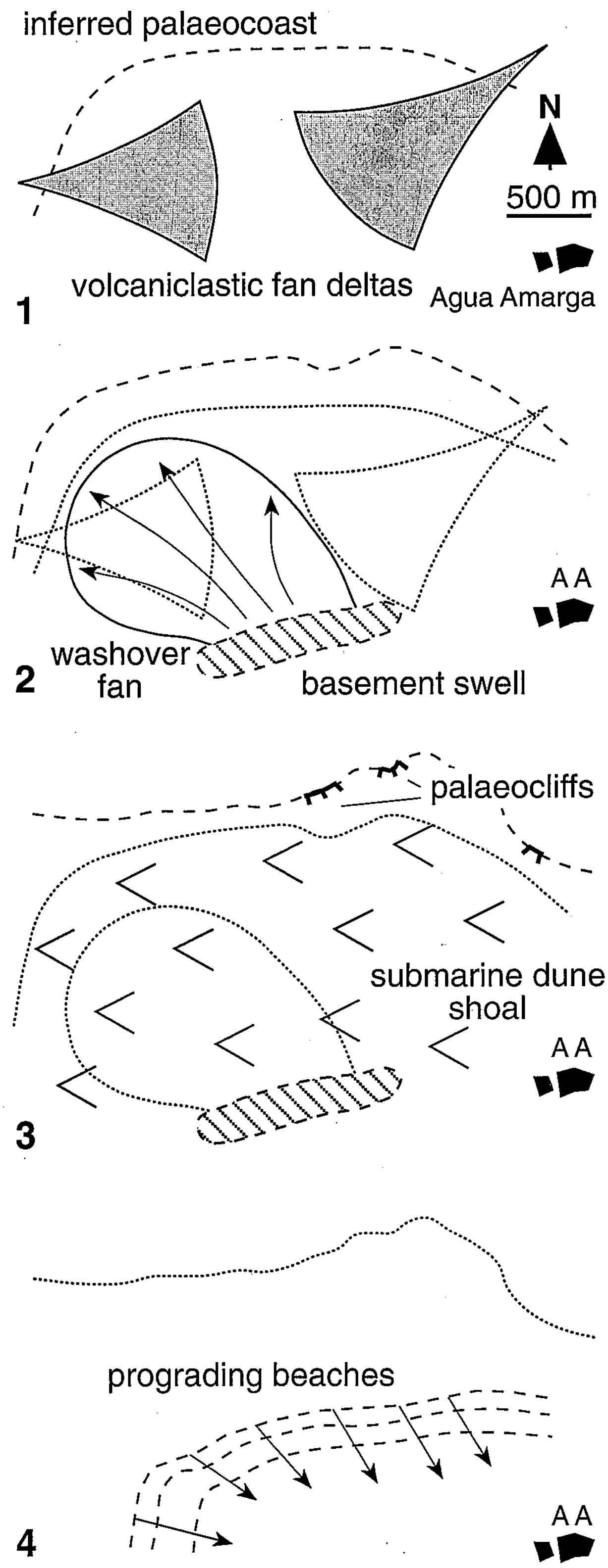

Figure 6.- Sketch of the palaeogeography of the Agua Amarga Basin for the four successive subunits of the lower temperate carbonate unit.

during storms, and incorporated into the shoals and beaches while others moved downslope, accumulating to form the fan-bedded floatstones and calcirudites.

The factory floatstones and the fan-bedded floatstones and calcirudites alternate with well-defined beds of

Figure 7.- View of the Cala Chumba cliffs. Carbonates from the lower unit (C) are cut and overlain by 8.1 Ma-old volcanics (V) («Vitrófido del Plomo», Fernández Soler, 1992). Note carbonate blocks included in the volcanic rocks (middle right).

calcarenites/fine-grained calcirudites. They are made up of highly-abraded bioclasts and show internal tabular cross-bedding pointing to the N-NW. These beds, probably representing migrating sand waves, pinch out and disappear to the north, through an area where only small, isolated bars occur. In contrast, they thicken southwards and become locally amalgamated (Martín *et al.*, 1996).

This alternation has been interpreted as the result of internal cyclicity of the subunit. The bars and sand waves alternating with fan-bedded layers developed at coastal settings during lowstands. Those interbedded with the factory floatstones were formed during the transgressive events; while prograding beaches, shoals, factory facies, and fan-bedded layers developed during highstands. Net carbonate production took place mainly during the highstands. Reworking of skeletal particles predominated during the lowstand and transgressive stages (Martín *et al.*, 1996).

d) Fine-grained calcirudites that grade upwards to calcisiltites, up to 20 m thick, with local, mound-shaped calcarenite bars several tens of metres in wavelength and up to 7 m high. Large bioclasts of oysters, pectinids, echinoids, bryozoans, barnacles, and rhodoliths are locally abundant and some beds are highly bioturbated. At the base of the calcisiltites, the planktonic foraminifer assemblages record the Tortonian-Messinian boundary (Braga *et al.*, 1994).

The three underlying subunits can be tentatively assigned to the Lowstand Systems Tract and the expansive fine-grained calcirudites to calcisiltites of the fourth subunit to the Transgressive Systems Tract of a sequence interrupted by a tectonic pulse evidenced by the unconformity at the top of the unit (Fig. 8). The Lowstand Systems Tract constitutes in turn a subsequence of immediately higher frequency (Fig. 8) that can be subdivided into a lowstand (the «megatrough unit»), a transgressive (the «megabreccia unit», a lag deposit presumably linked to erosive coastal retreatment) and a highstand stage (the «bedded unit») (Martín *et al.*, 1996).

Palaeogeography can be partially reconstructed by facies distribution and orientation of sedimentary structures in the «bedded unit». It was deposited in a small trough (approximately 1.5 km wide and at least 4 km long), with facies belts trending N80E in the northern part of the basin (Fig. 9). Beach deposits developed at the emerged northern margin. At the southern margin a shoal area separated the Agua Amarga Basin from small, adjacent basins (Martín *et al.*, 1996).

Palaeogeography and tectonic context

The lack of abundant sedimentological evidence does not allow the palaeogeography of the lower temperate carbonate unit to be precisely reconstructed. However, available data indicate the existence of a northern palaeocoast during the early Tortonian around the present-day northern margin of the Agua Amarga Basin. The position of the palaeocoast moved landwards and then seawards following relative sea level changes during the deposition of the unit. The trend of this palaeocoast was roughly N80E to E-W. A basement swell promoting the development of enclosed areas filled by washover fans probably had a similar trend (Fig. 6). In the last stage of the lower temperate carbonate unit sedimentation, beaches prograded from a western coast with a roughly N-S strike as well as from a northern one trending N80E.

A N80E to E-W trend of the northern palaeocoast and facies belts charaterizes the palaeogeography of the upper temperate carbonate unit (Fig. 9). The paleogeography of the Agua Amarga Basin during the deposition of both units was probably controlled by the Carboneras fault system. At least from the late Tortonian to the Recent, this system of strike-slip faults

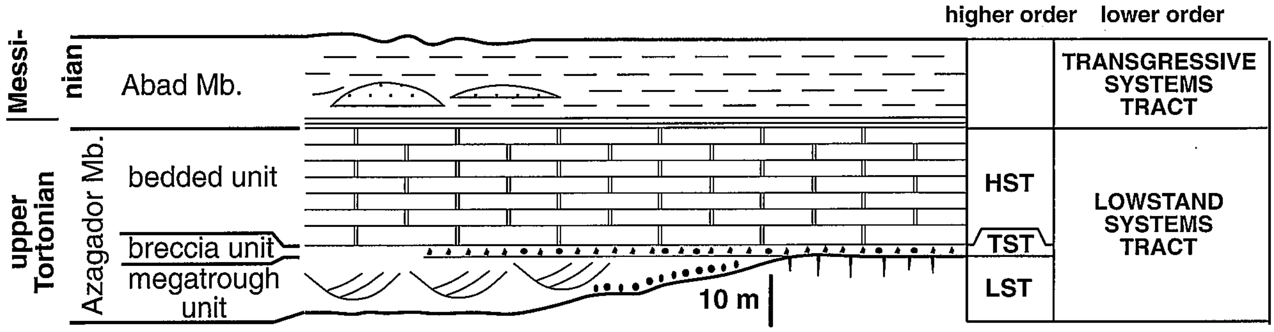

Figure 8.- Stratigraphy and sequence interpretation of the upper Tortonian/lower Messinian temperate carbonates. Symbols as in Fig. 2 (after Martín *et al.*, 1996). See text for further explanation.

oriented N45E suffered sinistral displacements in a compressional context with the maximum stress oriented N-S (Boorsma, 1993). P shear faults (Riedel-shear terminology) under this regional stress are oriented N80E (Boorsma, 1993).

Narrow depocentres and swells with E-W palaeogeographical trends, similar to those of the upper temperate carbonate unit combine with N20E palaeocoast alignments during deposition of different Neogene units in a small strike-slip basin that developed at the southern margin of the Carboneras fault system (Boorsma, 1993).

A tectonic pulse took place immediately after the deposition of the fine-grained deposits of the upper temperate carbonate unit. This event caused the uplifting and partial emersion of the eastern and southern margins of the basin and produced a significant change in its palaeogeography. The newly uplifted reliefs were settled by the Messinian reefs while the distal, basinal facies of the reef unit covered the litoral deposits of the previous unit and onlapped the formerly emerged volcanic substrate of the northern and western margins of the basin. The outcrops of distal silty marls of the Messinian reef units scattered on the volcanics separating the Agua Amarga Basin from the Almería-Níjar Basin suggest that during the deposition of these units the two basins were connected. This tectonic event between the deposition of the upper temperate carbonate unit and the Messinian reef units is a regional phenomenon well documented in the Sorbas Basin (Martín and Braga, 1996).

Correlation with other carbonate units in SE Spain

Bioclastic carbonates that may be temporal equivalents to the lower temperate carbonate unit have been reported in the Cabo de Gata area as the «sedimentario interestratificado en las formaciones volcánicas» (Sánchez-Cela, 1968), «Calcarénites à Hétérostegines» (Bordet, 1985) and lower Tortonian sedimentary rocks (Fernández-Soler, 1992). These sediments, containing the large benthic foraminifer *Heterostegina* but rich as well in bryozoans and molluscs, occur betwen two different episodes of volcanics in several localities. At Los Frailes, Di Battistini *et al.* (1987) assign a lower Tortonian age to these deposits according to their paleontological content.

Lower Tortonian temperate carbonates occur in other Neogene basins of SE Spain, such as the Granada Basin (Rodríguez-Fernández, 1982; Braga *et al.*, 1990), Guadix Basin (Rodríguez-Fernández, 1982; Soria, 1994), Lorca Basin (Baena, 1993), Mula Basin (Baena, 1993) and Almanzora Corridor (Braga and Martín, 1988; Martín *et al.*, 1989).

As previously mentioned the first three subunits of the upper temperate carbonate unit correspond to the Azagador Member defined by Ruegg (1964) in the Vera and Sorbas basins. This unit can also be correlated to the DS1B unit defined by Franseen (1989) and Franseen and Mankiewicz (1991) at La Molata de Las Negras. This latter unit consists of bioclastic carbonates rich in bryozoans, molluscs, and red algae that lack corals and green algae.

These two episodes of temperate carbonate deposition alternate with episodes of reef development and chlorozoan carbonate formation. Where the sequence evolution of carbonate development has been analysed, temperate carbonates are seen to have formed during sea-level lowstands of third-order cycles while reefs grew during transgessive and highstand stages (Martín and Braga, 1994). Such temporal alternation of temperate and subtropical/tropical climatic contexts for carbonate production can be correlated with the global sea-level curve proposed by Haq *et al.* (1987) for the Late Neogene. Temperate carbonates were deposited during low sea-level phases and chlorozoan carbonates formed at high sea-level phases (Fig. 10). All this suggests that the change of climatic context of carbonate formation was driven by glacioeustatism (Martín and Braga, 1994, Brachert *et al.*, 1996). Temperature variations of sea water related to glaciations triggered changes in the style of carbonate production in the western Mediterranean and, at the same time, sea-level oscillations controlled the sedimentary record of the basins.

Conclusions

Two units of Tortonian temperate carbonates occur in the Agua Amarga Basin, a small Neogene basin in the vol-

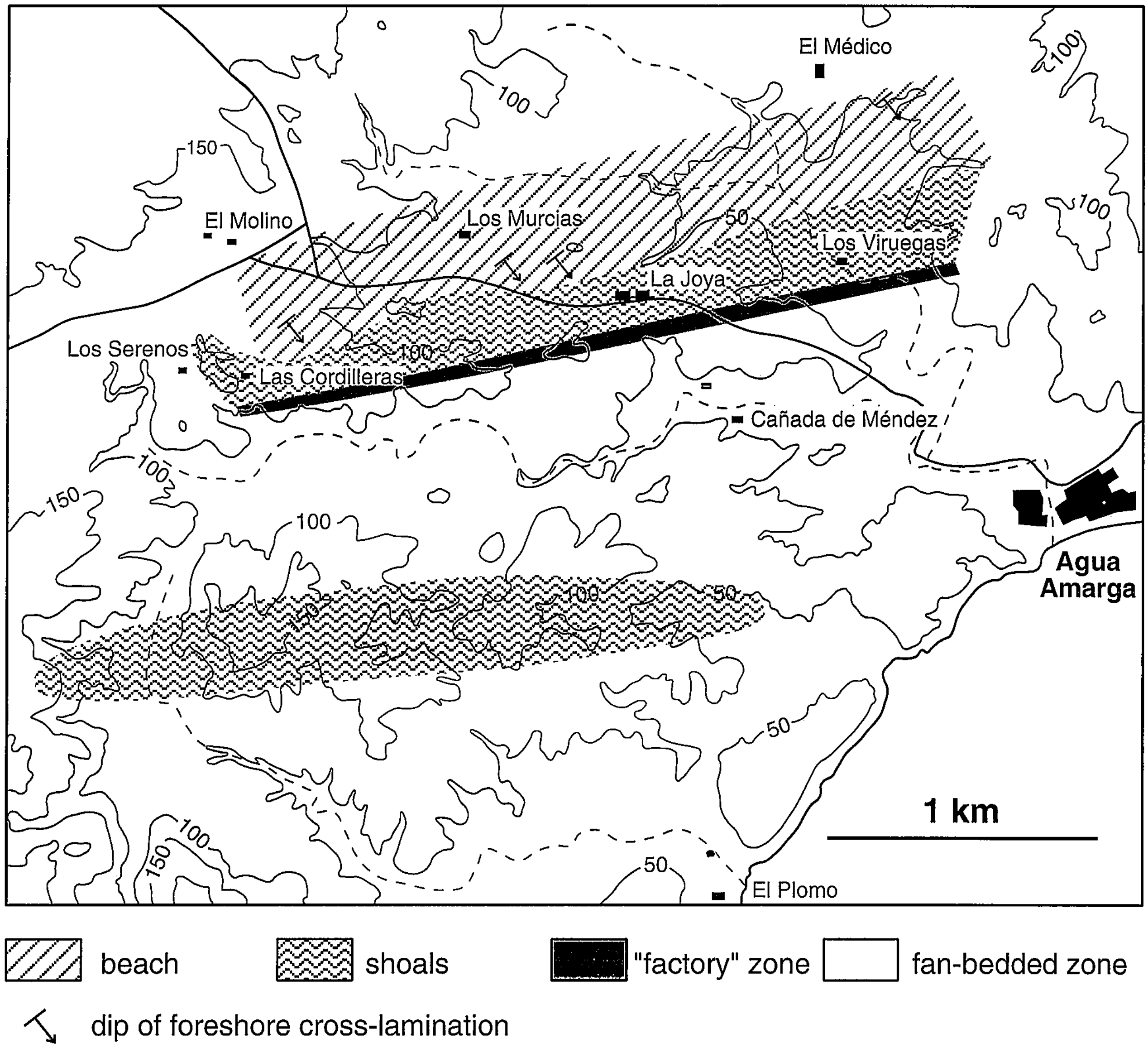

Figure 9.- Palaeogeography of the Agua Amarga Basin for the bedded subunit during relative highstands (after Martín *et al.*, 1996).

canic area of Cabo de Gata (Almería, SE Spain), separated by the youngest volcanic rocks in the area. The temperate carbonate units are unconformably overlain by Messinian reefs and oolitic/ stromatolitic breccias.

The lower Tortonian temperate carbonate unit is made up of fan-delta volcaniclastics and bryomol calcarenites/ calcirudites in which three subunits can be distinguished according to the sedimentary structures. The four subunits are arranged in a (sub)sequence. Fan deltas developed during low sea level at the basin margins. Tabular cross-bedded calcarenites/calcirudites formed in small sheltered areas in the western half of the basin in washover fans. During ascending sea-level, trough cross-bedded carbonates were deposited in a shoal area covering the outcropping part of the basin. Beach deposits, prograding to the SE, eventually filled the basin at the end of the sedimentary cycle (Betzler *et al.*, 1997).

Volcanic rocks 8.1-8.7 Ma-old cut and overlie the lower carbonate unit. Blocks from this unit are locally embedded in the volcanics.

The upper temperate carbonate unit, upper Tortonian-lower Messinian in age, consists of four subunits: a) debris-flow conglomerates and trough cross-bedded, bryomol calcarenites/ calcirudites; b) a bioclastic and volcaniclastic breccia; c) bryomol calcarenites/ calcirudites; and d) calcarenites/calcisiltites. The first three subunits represent the Lowstand Systems Tract and the fine-grained sediments the Transgressive Systems Tract of a sequence interrupted by a tectonic pulse, but higher orders of cyclity can be recognised within this sequence. The inferred depositional setting for subunit c, the best-exposed one, during the highstands of its internal cyclicity is a gentle ramp with beaches and shoals at its northern margin. Seawards of the shoals, probably below fairweather wave-base, maximum carbonate production took place. From this area some of the bioclasts moved landwards and were incorporated into the shoals and beaches while others moved downslope, accumulating to

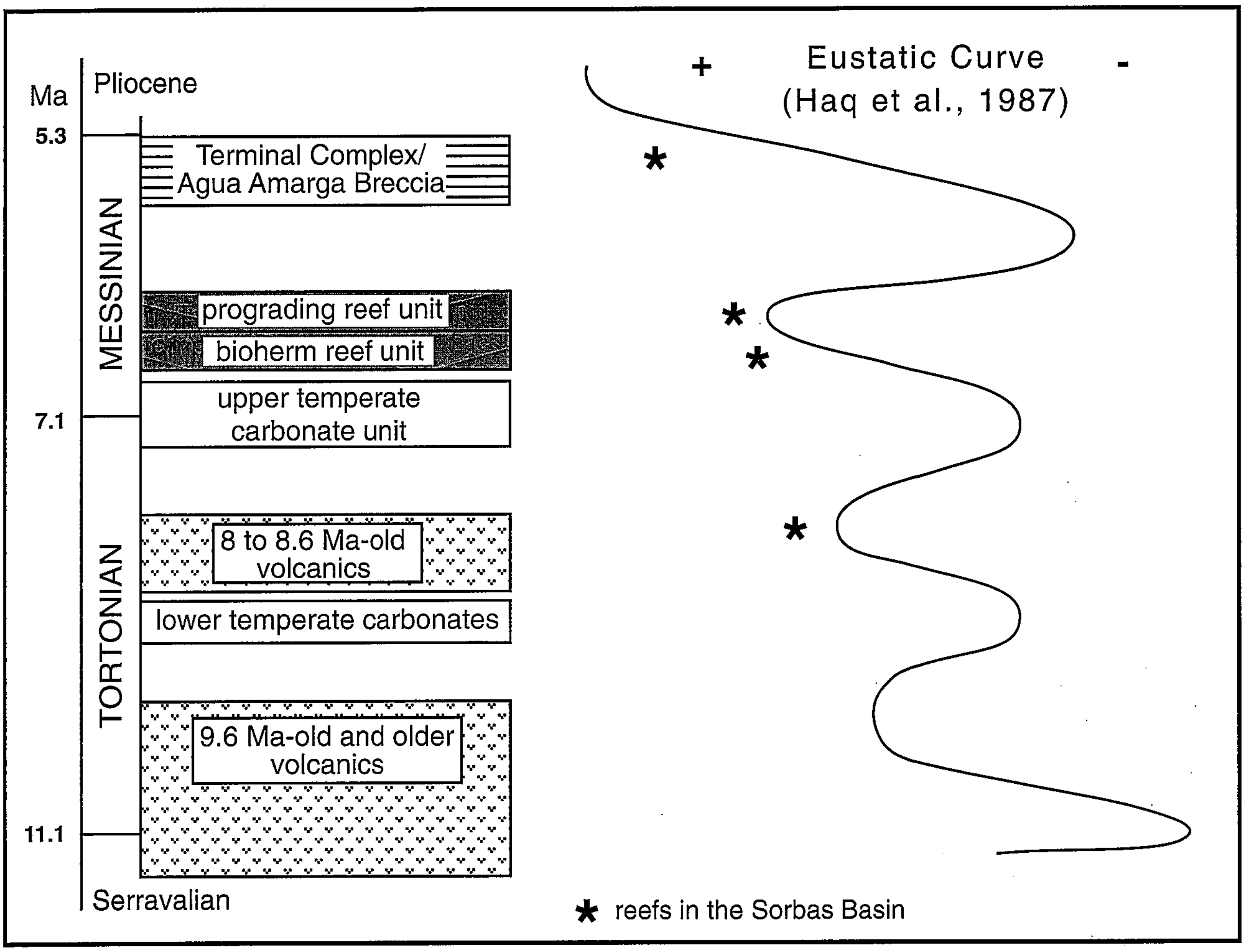

Figure 10.- Chronostratigraphy of Miocene sedimentary rocks in Agua Amarga Basin and their correlation to the eustatic curve (Haq *et al.*, 1987). Temperate carbonates were deposited during low sea levels of third-order cycles while coral reefs in the Agua Amarga and in the nearby Sorbas Basin grew during high sea levels. Absolutes ages after Hilgen (1991) for the Miocene-Pliocene boundary in the Mediterranean and Bergreen *et al.* (1995).

form fan-bedded floatstones and calcirudites. Bars and sand waves developed at coastal settings during lowstand and transgressive events (Martín *et al.*, 1996).

The palaeogeography of the upper temperate carbonate unit, with facies belts trending N80E from a northern palaeocoast, was probably controlled by the strike-slip Carboneras fault system.

These two episodes of temperate carbonate deposition can be recognised in other Neogene basins of SE Spain alternating with episodes of reef development. This alternation of temperate and subtropical/tropical climatic contexts for carbonate production can be correlated with the global sea-level curve of Haq *et al.* (1987). Temperate carbonates were deposited during low sea-level phases and chlorozoan carbonates formed at high sea-level, suggesting that the change of climatic context was driven by glacioeustatism (Martín and Braga, 1994; Brachert *et al.*, 1996).

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