THE NEOGENE OF THE GUADALQUIVIR BASIN (SW SPAIN)

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INTRODUCTION

The Guadalquivir Basin is an important depression, elongated in the ENE-WSW direction, which is almost entirely made up of soft sediments. Starting at the eastern end it has an altitude of more than 800 m above sea level, descending gradually to the west, reaching the coast, in the provinces of Huelva and Cádiz. Sedimentation continues today below sea level in the Gulf of Cádiz.

Today it is a very rich land, from an agricultural point of view; the predominant irrigated crops being cotton, sunflowers, corn, strawberries, fruit trees, and others. The water for irrigation comes from the Guadalquivir river which runs through the entire basin. In the non irrigated area olives are cultivated. It is a hot dry climate, particularly in summer when temperatures can reach over 40 ^{o}C.

Traditionally the Betic orogene has been divided by spanish Geologists into 3 regions, according to the different paleogeographic characteristics during deposition (Fig. II). The Betic sensu stricto consists of Paleozoic and Triassic rocks that form the "internal zones". The Subbetic is the thrust belt formed by allochthonous, mainly deep pelagic sediments of the Mesozoic and Cenozoic, accumulated in the Basin, whereas the Prebetic constituted the northern passive margin, covered by shallower shelf sediments.

The Guadalquivir basin, as we can see now, is the last expression of a long foredeep (the Betic foredeep) which spreads between the Atlantic and the Mediterranean in the South of Spain.

On the spanish Geological map the northern boundary of the Guadalquivir Basin is clearly defined by an almost straight line which separates the Paleozoic and Mesozoic rocks of the foreland Basement (the "Sierra Morena" region) from the marine Cenozoic materials. This is an erosive contact which was previously reported as the Guadalquivir Fault, but now it seems evident that this important fault does not exist. On the contrary, an important flexure in the basement has been recognized by seismic studies and petroleum wells.

The eastern end of the basin is defined by the Segura and Cazorla mountains which consist of Prebetic Mesozoic materials and reach above 2000 m, from where a beautiful panorama of the basin can be seen. On the contrary, the southern margin of the basin is defined by low hills, Prebetic on the East and Subbetic on the West. At the surface, on the northern half of the basin, autochthonous

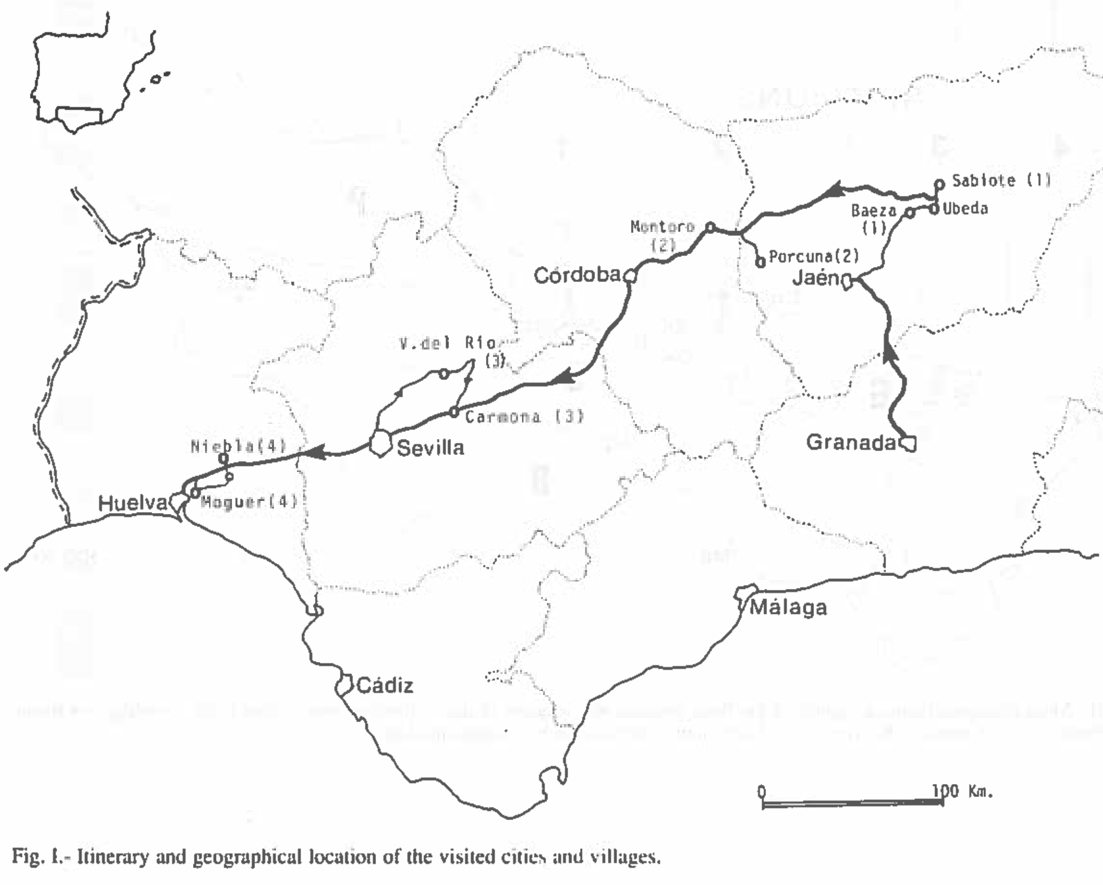

Fig. I.- Itinerary and geographical location of the visited cities and villages.

sediments crop out, while the southern half is made up of important olistostromes which slid from the Subbetic. These olistostromes consist of Mesozoic and Cenozoic rocks with chaotic disposition.

The Betic foredeep originated between the Betic orogene in the South and the Iberian Foreland to the North. Like other typical foreland basins the northern margin (passive margin) is characterized by the gradual deepening of the basement towards the South. However, the southern margin is very steep because of its position at the front of the active subbetic thrust belt.

Throughout the major part of the Miocene a northward migration of the foreland depocenters took place as a consequence of the displacement of the subbetic thrust belt in the same direction. This migration probably culminated during the Latest Miocene when a general upflit of the central and eastern part of the foredeep occurred, causing erosion of the sedimentary cover in this region and defining the recent geography of the Guadalquivir basin restricted to the western part of the ancient foredeep.

The evolution of the Betic foredeep has a special significance because it was the key that controlled the Atlantic-Mediterranean communication, probably constituting a deep passage between both realms during most of the Neogene.

MARTINEZ DEL OLMO *et al.* (1984) have divided the sedimentary fill of the western Guadalquivir Basin into five tectosedimentary units based on seismic data and drilling results carried out there.

From the micropaleontological point of view, a succession of Calcareous Plankton events was defined (SIERRO, 1984, 85; FLORES, 1985; FLORES & SIERRO, 1987) (Figure III). These discontinuities of the paleontological record allow us to recognize a series of time reference planes and to define sedimentary units deposited between synchronous surfaces.

This way it is possible to interpret the depositional history of the basin, and correlate its fill with the following depositional sequences and their relationship to cycles of global sea level change.

Several depositional sequences were proposed (SIERRO *et al*, 1990) (Figure IV) which partly coincide with the tectosedimentary units of MARTINEZ DEL OLMO *et al.* (op. cit.). The proposed interpretation to explain the depositional history of the basin consists of large clinoforms prograding to the west (Fig. V). However we can not forget that a southward and northward progradation also exists. A brief description is included on the following pages.

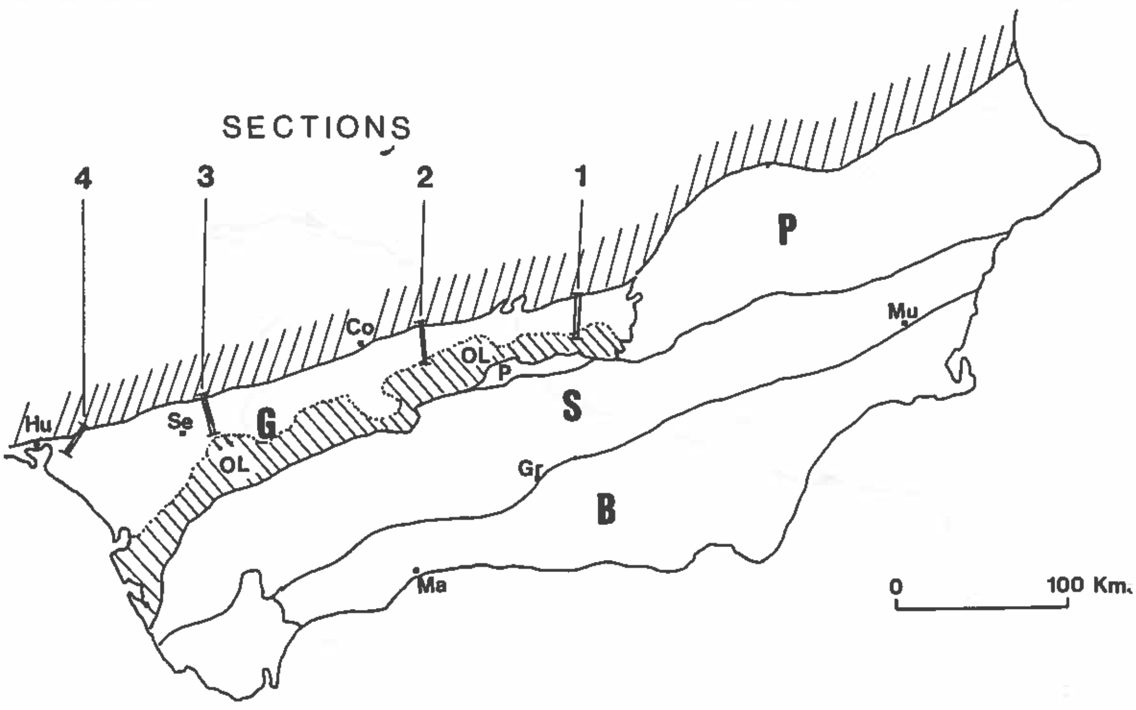

Fig. II.- Main paleogeographical regions of the Betic orogene and location of the 4 cross-sections visited in the Guadalquivir Basin. (P): Prebetic, (S): Subbetic, (B): Betic, (G): Guadalquivir Basin, (OL): Olistostrome Unit.

In an east-west cross-section of the Basin, five offlapping depositional sequences can be observed which are progressively younger towards the west. The tops of the successive sequences have been denuded by erosion and the resulting surface dips gently towards the west.

SEQUENCE A (Lower to Middle Tortonian) only crops out in the eastern part of the Basin from Bailén to Iznatoraf. Consequently, it will be visited the first day. It begins in the northern margin with shallow marine deposits, transgressive over the Mesozoic Basement (STOP 1-1) which rapidly pass upwards into rich planktonic foraminifera silts deposited in a deep environment and overlaid by grey marls and clays which are very difficult to study in the field because of the absence of good outcrops. Good sections can only be seen in the quarries. The basal calcarenitic or terrigenous sediments and the marls represent the transgressive and Highstand Systems Tract and the basal rich planktonic foraminifera marls represents the condensed section (as summarized in POSAMENTIER *et al.*, 1988). The deposition probably occurred during the global sea level rise of Cycle 3.1 (HAQ *et al.*, 1987).

SEQUENCE B (Middle to Late Tortonian) is well represented in the whole Basin. A major paleogeographical change took place between the deposition of Sequences A and B related to a dextral rotation of the Betic foreland basin. Rotation caused a displacement of the depocenters to the northwest, allowing the new depositional sequences to progress directly upon Paleozoic and Mesozoic rocks in the central and western regions of the Basin. The cause for this rotation might be related to a change in the main direction of tectonic compression from WNW-ESE (during the Early and Middle Miocene) to N-S during the Late Miocene (SANZ DE GALDEANO, 1989). A symmetrical rotation probably happened in northern Africa (South Riff Foreland Basin, Morocco).

In the eastern part of the Basin, Sequence B begins with turbiditic sedimentation (Lowstand Systems Tract, probably correlated to Cycle 3.2 of HAQ *et al.*, 1987) resting upon the deep-water

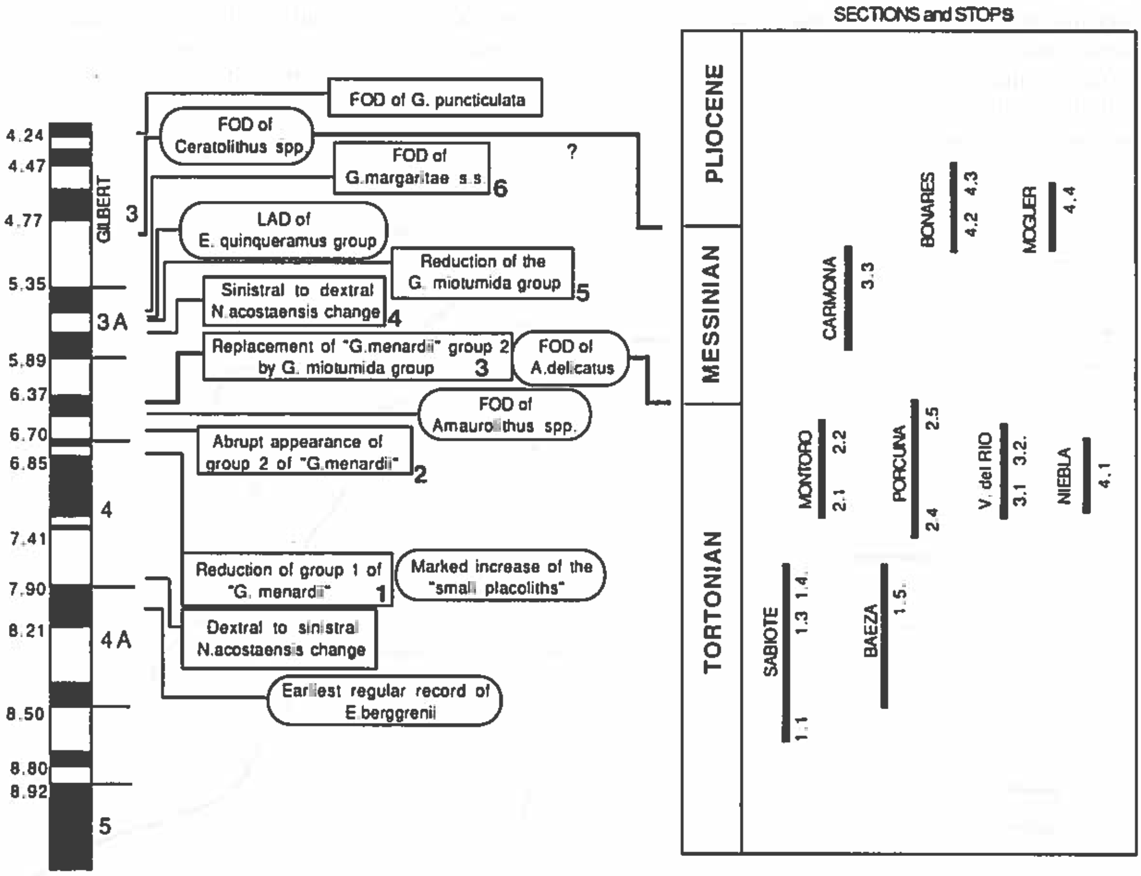

Fig. III.- Main Calcareous Plankton events recognized in the Guadalquivir Basin and chronostratigraphic situation of the visited sections. Magnestostratigraphical data from BERGGREN *et al.* (1985).

marls of Sabiote (STOP 1-3). However, in the central and western parts, these deposits do not appear at the surface, and the base of the sequence is defined here by the coastal transgressive deposits overlying pre-Neogene rocks in the northern margin.

The Transgressive Systems Tract is represented by a calcarenite unit (STOPS 2-1, 2-2, 3-1, 3-2 and 4-1), and the Highstand Systems Tracts by the greyish blue marls (STOPS 2-2, 2-4, 3-1 and 3-2), whereas the glauconitic and pelagic silts correspond to the condensed section (STOPS 2-2, 3-2, 3-2).

The age of this glauconite layer is very close to 7 m.a. which strikingly coincides with the global condensed section of Cycle 3.2.

SEQUENCE C (Latest Tortonian to Early Messinian) comprises the sandstone Unit of Porcuna (STOP 2-2) which forms the base of the sequence constituting the Lowstand Systems Tract. The overlying Lower Messinian blue marls of Carmona (STOP 3-3) are representative of the Transgressive and Highstand Systems Tracts. Materials of this sequence crop out in the northern edge (central and western parts) and in the axis (central part) of the Basin.

We estimate an age of 6.6 m.a. for the first turbiditic sediments in the region of Bujalance-Porcuna which led us to correlate it to cycle 3.3. Turbiditic units of the same age have been described in different places of the Guadalquivir Basin and Gulf of Cádiz.

SEQUENCE D (Late Messinian to Early Pliocene) consists of the Carmona Calcarenites (STOP 3-3), the younger, upper part of the Gibraleón Clays, and the Huelva Sands (STOPS 4-2, 4-3 and 4-4).

The lower boundary coincides with a relative fall of sea level responsible for the deposition of the Carmona Calcarenites. The age of this event closely coincides with that proposed for the limit of global Cycles 3.3 and 3.4 by HAQ *et al.*, (1987). In the axial region, the clay sedimentation seems continuous throughout this limit. These clays pass upwards to sands (Huelva Sands) progressively later towards the West.

The transition between the clays and the overlying sands is progressively younger towards the west. In the province of Huelva an interesting glauconite layer (STOPS 4-2 and 4-4) is found approximately in the contact between both units. It could be interpreted as the condensed section deposited during the maximum transgression of the Latest Messinian or Earliest Pliocene (Cycle 3.4). However, in this case, the relative sea-level rise should be slower than the rate of sedimentation, causing a regressive sequence to be generated in a context of a global sea-level rise.

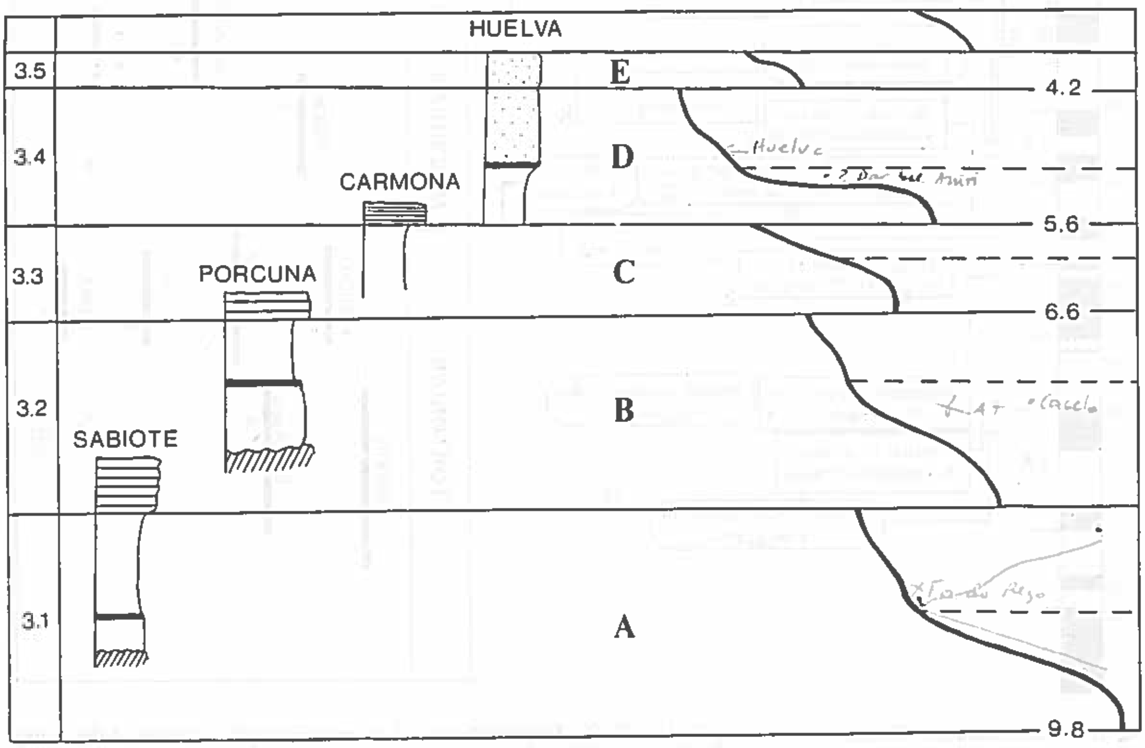

Fig. IV.- Correlationship of the depositional sequences distinguished in the Guadalquivir Basin to the Global Sea Level Cycles of HAQ *et al.* (1987) (after SIERRO *et al.*, 1990).

SEQUENCE E (Early Pliocene) crops out in the western part of the basin. It is represented by the Bonares Sands (poorly exposed in STOP 4-2). The base of the Sequence is a gentle unconformity detected by paleontological studies, probably related to a fall of sea level which caused the erosion of the underlying sequence particularly in its eastern part. The first record of *G. puncticulata* (4.24 m.a.) several meters below the unconformity, strongly suggests that this unconformity is correlated to the global sea-level fall between Cycles 3.4 and 3.5 (4.2 m.a.). This is the last marine sequence in this region though younger marine sediments crop out in some localities of the Cádiz Province.

The paleobathymetric interpretation of some sequences leads us to discuss an interesting feature of the basin's depositional history. In those sequences, like the second part of sequence B, that can be seen for some distance in the E-W direction, it was noted that the estimation of depth increases from West to East. This pattern seems contradictory to the above given interpretation if we do not take into account that the line which presently defines the northern margin of the basin is erosive. This erosion has denuded a large part of the sedimentary cover in the eastern part up to a depth near the basin's depocenters.

On the contrary, in the western part, shallower sediments far away from the depocenters were preserved. The northern margin of the olistostrome units, which define the line of depocenters of the Late Tortonian inmediately after the sliding, is exposed in the eastern part, whereas in the western region this line progressively sinks to reach more than 1000 m. depth near Carmona (SIERRO *et al.*, 1990).

These data suggest that after deposition of the oldest sequences previously defined, a general uplift of the eastern part of the basin took place.

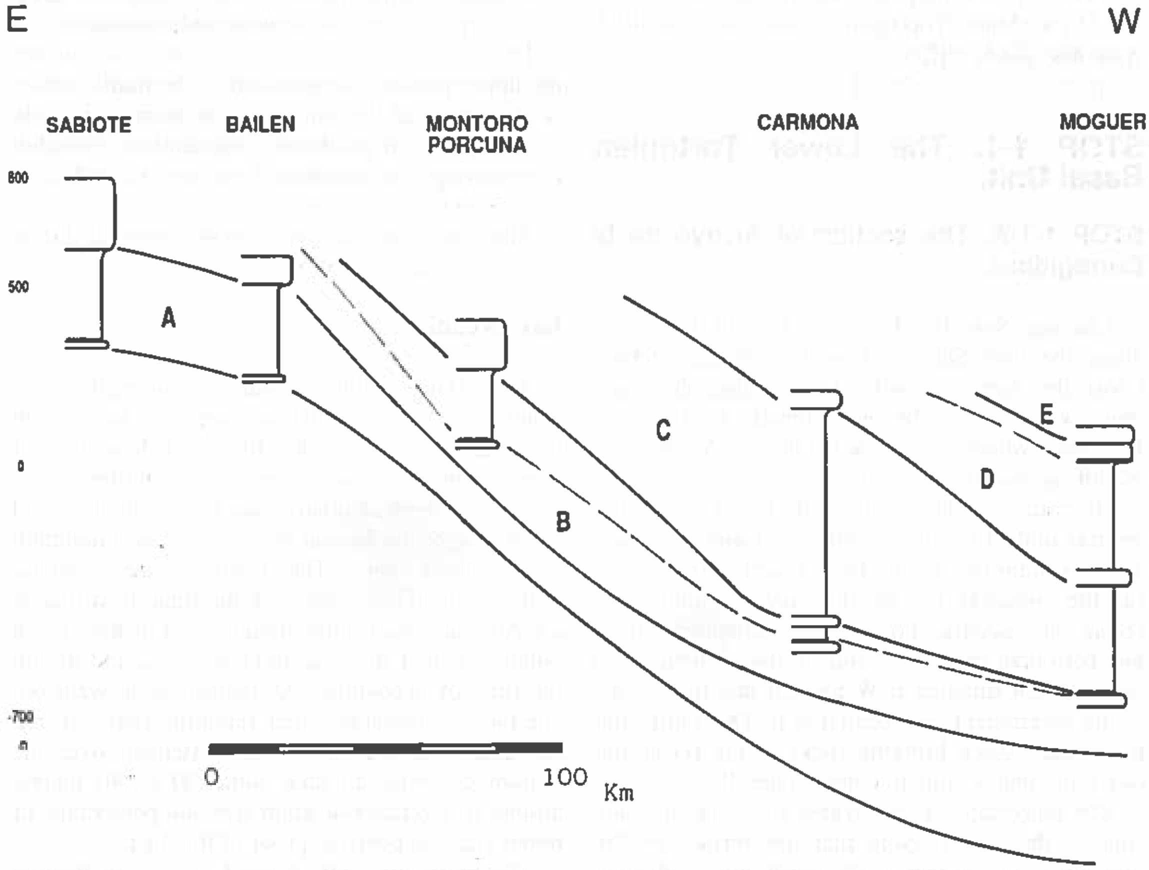

Fig. V.- Depositional history of the Guadalquivir Basin after SIERRO *et al.* 1990. East-West cross-section along the axial region showing the sequence boundaries. Black layers are condensed sections. Continuous lines: sequence boundaries. Discontinuous lines: condensed layers. A to E: depositional sequences.

FIRST DAY

In the eastern part of the basin, north of Sabiote, three principal units can be distinguished from bottom to top (Fig. 1.1). The basal unit over the Mesozoic basement consists of 0 to 20 m thick calcarenites, sands or conglomerates (STOP 1.1.) which are overlain by a more than 200 m thick series of grey marls, which is very problematic to study and sample because of its bad exposure. In STOP 1.1.C, the transition between the basal unit and the marls can be seen. Overlying the marls an alternation of 200 m of marls and sandstones appears in the topmost part of the section, near the village (STOPS 1.2, 1.3, 1.4, in Sabiote, and 1,5 in Ubeda). The contact between the last 2 units is difficult to situate in the field because of the absence of good outcrops.

STOPS 1 to 4 are placed on map 20-36 (906) of the MTN (Mapa Topográfico Nacional), STOP 5 is on map 20-37 (927).

STOP 1-1. The Lower Tortonian Basal Unit.

STOP 1-1-A. The section of Arroyo de la Corregidora.

Leaving Sabiote, drive 8.5 km to the north along the road Sabiote- Castellar de Santisteban. Cross the Arroyo (creek) de la Corregidora and you will reach the abandoned Cortijo del Escribano where you can leave the car. Walk 50 m N250E across the olive grove.

Here an excavation allows us to trace laterally several units for approximately 40 meters. There are two important points to be taken into account: (a) the irregular top of the Jurassic dolostones (Beas de Segura Formation) indicative of a pre-Tortonian paleorelief and (b) the existence of a normal fault directed E-W located just to the east of the escarpment and parallel to it. This fault sunk the eastern block bringing rocks of the Basal and overlying marly units to contact laterally.

The paleorelief is observable from the opposite side of the valley. Note that the surface of the dolostones lies higher at the north and south than in the center of the outcrop, although it is not fully exposed. The Neogene deposits lie horizontally onlapping the sides of the gentle paleovalley.

Three intervals (named informally, just for descriptive purposes 2, 3, and 4, see Fig. 1-1-A) can be distinguished. Intervals 2 and 3 display accumulations of medium to coarse gravel which change laterally into cross bedding towards the west. They are thought to represent nearshore bars. Unit 4 includes several erosional surfaces with accumulation of pebbles. Unit 5 is a conglomerate of large pebbles to small boulders. Many of the clasts are bored by *Cliona* and bivalves. Interestingly enough, both grain size and amount of bored clasts decrease when moving from west to east.

A burrowed microconglomerate marks the base of unit 6, which is considered to indicate the change to the marly unit. Three fining upwards units, a few decimeters thick, were distinguished: from calcareous very fine sand (and silt) to marl. However, the lower one includes wedges of fine calcareous sands. These wedges are interpreted as distal facies of nearshore deposits related to the transgression at the base of the marls.

Coarser grained layers a few centimeters thick (cf. meter 11.1) record turbidite sedimentation.

Behind the fault, inside the cave, you can see the upper part of the transition to the marls, which is characterized by thin layers of burrowed sandy silts very rich in planktonic foraminifers, probably representing the condensed section related to a maximum transgression.

The rest of the section is poorly exposed due to intensive olive cultivation.

Interpretation.

The Basal Unit records sedimentation in shallow marine, nearshore areas covering an irregular paleotopography. Repeated deposition of fining upwards sequences are interpreted as successive rises of relative sea level which caused reworking of the coastal deposits and accumulation of nearshore bars. The topmost conglomeratic units are thought to represent the final drowning of a local paleorelief, immediately west of the visited outcrop, which stood as an emergent island during the time of deposition. As transgression went on, coastal conglomerates and regoliths that covered the island were removed and extended over the bottom covering an area some 30 to 40 meters around it. Decrease of grain size and percentage of bored clasts is possible proof of this fact.

The marls are characterized by a deep benthic foraminiferal assemblage with abundant *Cibicidoides pachyderma*, *Oridorsalis umbonatus*, *Melonis pompiliodes*, *Gyroidina* spp., *Planulina wuellerstorfi*, *Uvigerina proboscidea*, *Sigmoilopsis*, *Laticarinina pauperata*, etc. In some samples, Radiolarians, sponge spicules, Silicoflagellates and Diatoms are frequent. Planktonic foraminifera are always abundant but with a variable state of preservation. They usually represent more than 80% of the Foraminifers. From the bottom of the marls typical dextral *Neogloboquadrina acostaensis*, sinistral keeled Globorotalids close to the *Globorotalia merotumida-Globorotalia plesiotumida* group, and abundant *Globoquadrina* are present. Towards the central part of the section, prior to the first sandstone body a dextral to sinistral coiling change in the *Neogloboquadrina acostaensis* group was recorded not very long after the first record of *Eu-discoaster berggrenii*.

The rest of the section is poorly exposed due to intensive olive cultivation.In the upper unit a mixed assemblage of deep and shallow Benthic Foraminifera was found. *Melonis pompilioides*, *Planulina wuellerstorfi*, *Oridorsalis umbonatus*, etc. appear together with *Ammonia beccarii*, *Nonion boueanum*, etc. *Neogloboquadrina humerosa* is recorded for the first time in these levels.

STOP 1-1-B. The unconformity with the pre-Neogene substratum.

The base of the Neogene section can be observed lying unconformably on top of the Jurassic dolomitic Beas de Segura Formation about one kilometer to the northeast along the road Sabiote-Castellar de Santisteban.

Here, a one meter-thick layer of matrix-supported breccia is visible. Clasts are angular boulders and large pebbles of dolomitic rocks removed from the underlying dolostones. The matrix consists of loosely-cemented sandstones and calcarenites. Walking along the road to the east and north, in situ dolostones are observed as well.

Neogene deposits consist of white and light-brownish sandstones with carbonate cement. No fossils were found.

STOP 1-1-C. Transition to the grey marls.

The transition to the marly unit is exposed along a roadcut of the same road, some 400 m north of the Cortijo de Escribano. Decimetric layers of median-to-fine sandstones with calcareous cement appear interbedded with 30 centimeter-thick layers of whitish silty marls.

STOP 1-2. A panoramic view of the Lower to Middle Tortonian section.

Drive to Sabiote and go to the south of the village (San Januario street). You will find a

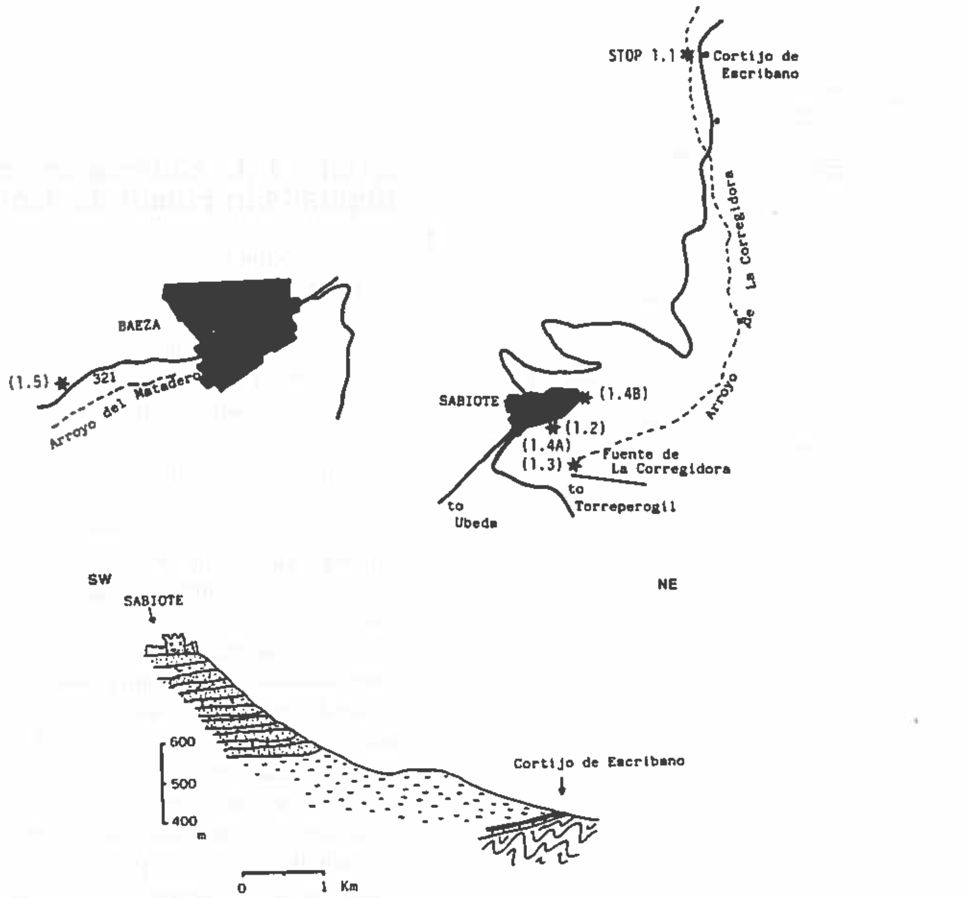

Fig.1-1.- Location map of stops in Sabiote and Baeza. Below, schematical geological cross-section of Sabiote.

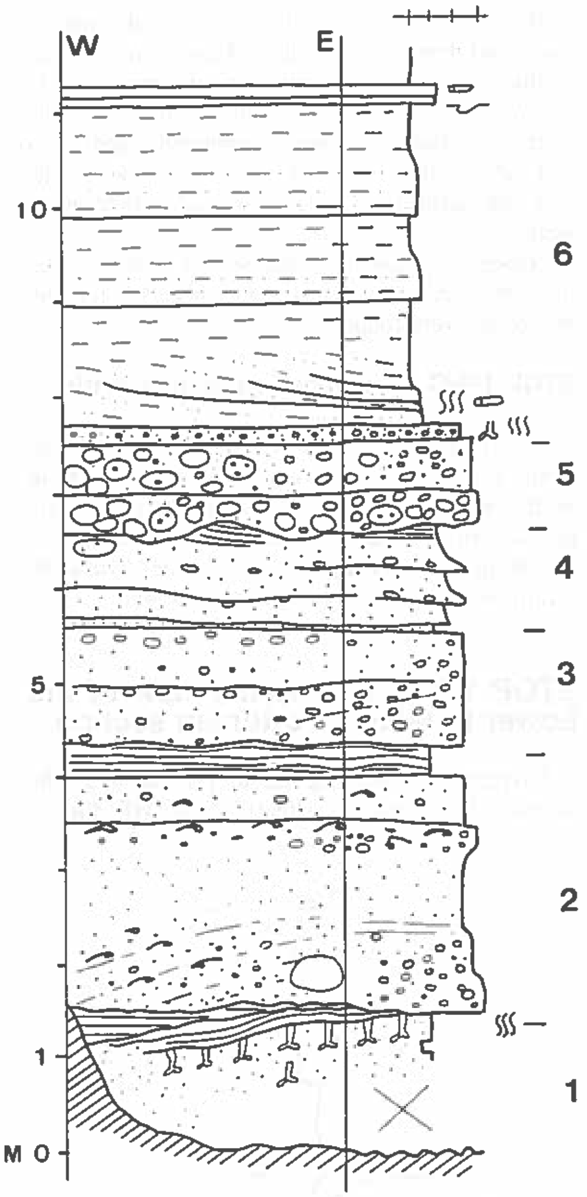

Fig. 1-1-A. Section of the Lower Tortonian Basal Unit in Arroyo de la Corregidora. It has been extended to visualize lateral arrangement of facies. Note that the lowermost part of the section is not exposed in the eastern side of the outcrop.

square with a reconstructed decorative oil mill. From here, a panoramic view of the more than 400 meter thick succession is observed.

Some interesting remarks:

(a) the flat, almost horizontal tops of the hills (lomas) indicative of the more cohesive, less erodible, sandstone layers forming the upper part of the exposed section.

(b) looking south and east, intervals of steeper slope in the hills opposite the valley indicate the existence of sandstone units interlayered with the marls, poorly visible due to cultivation. These units have been interpreted as fills of channels or gullies related to turbidite fans in the deeper parts of the basin.

(c) several of these breaks of slope are observed in the hill where Sabiote is. In detail they are due to the occurrence of layers of sandstone. Some of these sandstone units are channelized. STOPS 1-3 and 1-4 will be devoted to visiting these units.

(d) looking southwards, the escarpment of the Corregidora Spring (STOP 1.3) is seen.

STOPS 1-3 and 1-4 are intended to show various features of the submarine channel-fill deposits which will be observed in ascending stratigraphic order. This means moving away from Sabiote and back. Another possibility is to change the order and visit them from top to bottom. We decided against it because we think that the large, wonderful exposure of La Corregidora makes it easier to understand the more reduced ones.

STOP 1-3. Submarine channel-fill deposits in Fuente La Corregidora.

Leave Sabiote heading south following the road to Torreperogil up to km 2.9. Turn north along an unpaved road and follow it for about 150 meters.

Alternatively, you can also reach STOP 1-3 directly from STOP 1-2: drive or walk southwards about 950 meters from the other extreme of the poor-quality, unpaved road leaving Sabiote at the eastern side of the square.

Leave the car and walk down to the spring (Fuente de la Corregidora) and the beautiful outcrop. The spring flows at the boundary between a thick unit of sandstones and the underlying blue marls.

Along the escarpment, several intervals can be distinguished, which have been indicated in the general section as well. The zigzagging wall allows a good observation of the shape and internal structure of the sandstone body (Fig. 1-3).

(1) Loosely cemented coarse to medium sandstone rich in bioclastic skeletal fragments and lumachelle (called piedra franca by local quarrymen). Fragments of several types of bryozoans, very frequent Ostreids and Pectinids,

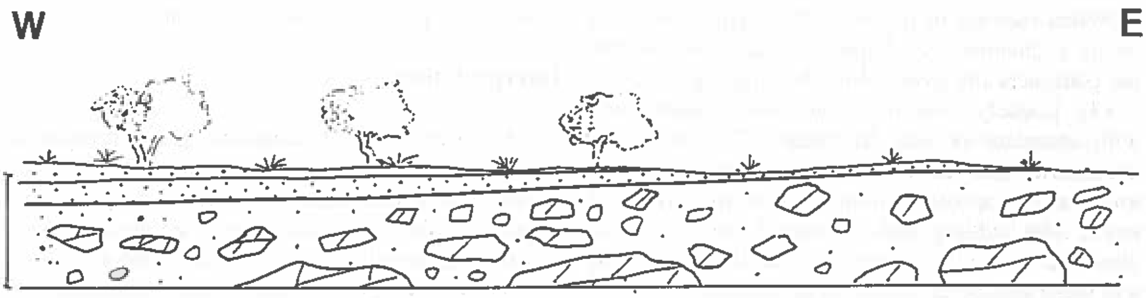

Fig. 1-1-B. Exposure of the base of Neogene sediments in the roadcut of km 9.5. Almost horizontal whitish sands overlie a boulder-sized breccia of Lower Jurassic dolostones.

Cirripeds, abundant needles of echinoids, and *Heterostegina* were found.

Thinner layers of more-cemented, yellow, medium sandstones occur interbedded (the so-called piedra viva, or live stone). The internal structure is not preserved due to ubiquitous sinsedimentary deformation which caused the more cohesive medium sands to convolute. There is an evident lateral component of deformation towards the southwest. We interpret it as a result of initial slump coupled with water escape along a paleoslope dipping towards the southwest.

This is covered by alternating sandstone and marls visible towards the west (just below the zigzagging path used to reach the outcrop).

(2) Lithologies similar to the former. Fossil content includes fragments of two types of Ostreids, Pectinids (of the *Chlamys* type), encrusting Bryozoans forming balls and scarce Echinoids.

A most characteristic feature is the large scale water escape structures. No remains of current- or wave-induced sedimentary structures have been found so far.

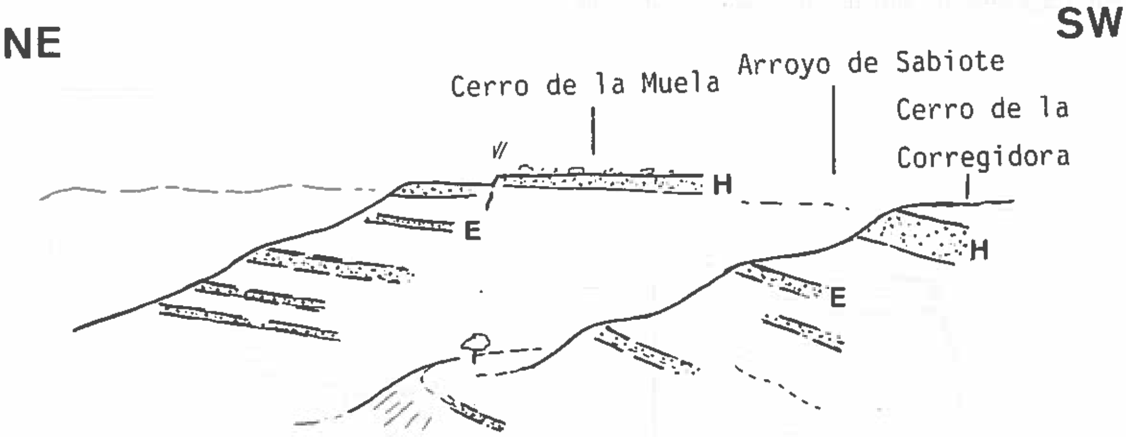

Fig. 1-2 (b). Panoramic view from Sabiote, looking southeast. The Lower to Middle Tortonian section. Dotted areas indicate outcrops of sandstone which have been indicated with letters for correlation.

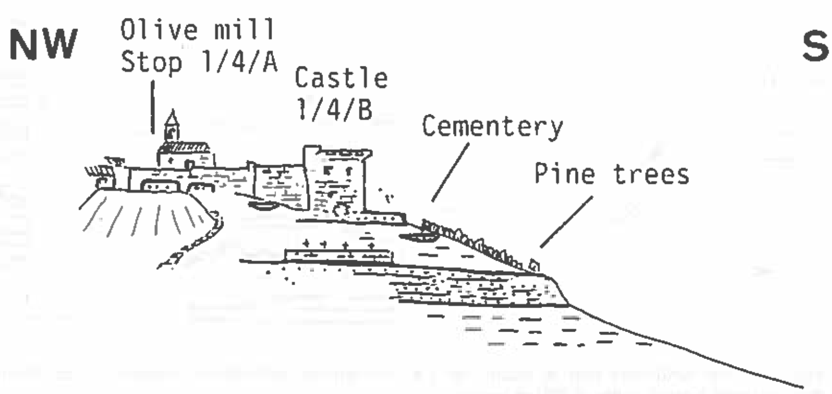

Fig. 1-2 (c). Idealized sketch of the southern side of the Sabiote hill to show sandstone layers (dotted) and location of STOPS 1-4-A & B. Channels filled with yellow, ferruginous sands are also observed behind the pine trees, near the road to Castellar de Santisteban.

When moving to the west, this layer is seen to be of a channelized shape. It pinches-out below the path, near the cave below the large fig tree.

(3) Loosely cemented, yellowish sandstones with abundant skeletal fragments. They occur as decimetric (40 to 50 cm thick) beds which, towards the top of the unit, include thin layers of marls. Flat bedding surfaces were found. The only observed internal structures are parallel lamination and water escape deformation of laminae.

(4) Alternation of decimetric beds of loosely cemented sandstones and marls. The latter are progressively thicker upwards until they become largely dominant. Eventually, the marls (interval 5) are reached.

(5) Grey-bluish marls, with interbedded sandstone beds.

(6) At the top of the hill, removed layers of sandstone were piled up to prepare the land for agriculture. There, excellent sole marks (groove and flute casts) and several types of burrows are observed. Spreiten of echinoids, horizontal worm tracks and galleries, Fucoids and *Chondrites* are the best represented ichnofossils. There are also thin layers of microconglomerate (very fine gravel) with fragments of Ostreids; the coarser clasts tend to accumulate in the grooves and other sole marks.

Interpretation.

The large body of sandstone is interpreted as the filling of a submarine channel (a canyon) connecting a carbonate shelf to a deeper basin located to the southwest. Rapid accumulation of mostly calcarenitic, coarse sand (piedra franca) -probably by grain flow- was followed by deposition of finer, more siliciclastic sandstones (piedra viva). Thin interlayers of hemipelagic marls are preserved at some places but most of them were subsequently eroded and either resedimented as mud pebbles (cf. meter 12) or re-incorporated to the rapidly-moving flow and washed away. In this way, surfaces of amalgamation were generated as observed all through the succession of Fuente de la Corregidora (Fig. 1-3).

This unit was interpreted as the Lowstand Systems Tract of Sequence B, related to a relative sea level fall. However, it is not easy to separate the precise influence of tectonic movements on this relative change of sea level.

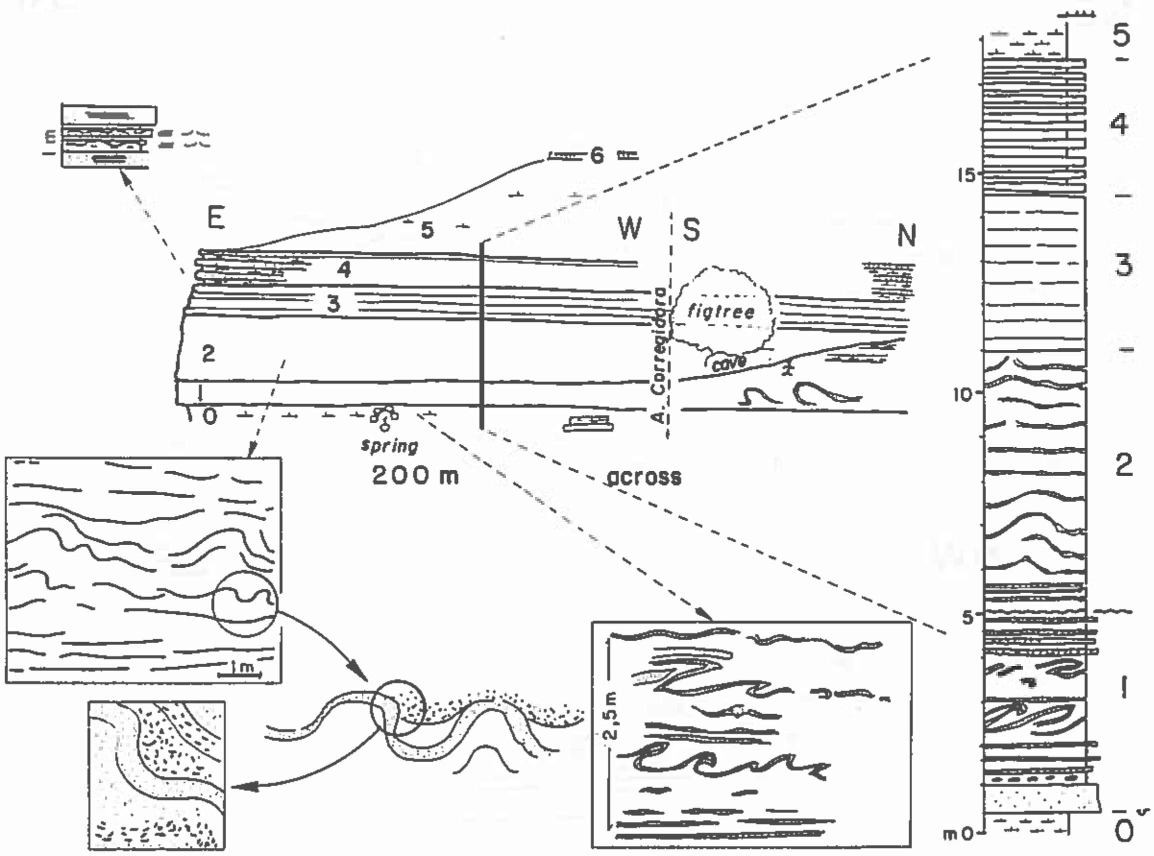

Fig. 1-3.- Idealized sketch of the sandstone unit in Fuente de La Corregidora and selected details of the internal structure in representative spots. The pictured section is about 200 m across.

STOP 1-4. The topmost part of the section of Sabiote.

STOP 1-4-A. The walls of San Januario Street.

Drive back to STOP 1-2. Leave the car and look northwards. There, below the ancient walls (murallas) of the village, there are two good exposures of the uppermost part of the section visited in Sabiote. Putting them together, a 6.5 m thick section can be measured.

A most prominent feature is the occurrence of two major types of sandstone. Thicker light yellow coarse sandstone (piedra franca) and thinner, often contorted layers of darker yellow, more cemented sandstone (piedra viva). Thin layers of green marls occur between sandstones.

Primary sedimentary structures are scarce. Only a few examples were found, all of them in the first type of sandstone: some parallel lamination (cf. meters 2.5 and 3.2) and poorly preserved cross bedding pointing N120° E (cf. meter 1.0) suggest current activity. There are also wave ripples (cf. meter 4.6) and wavy lamination (hummocky cross stratification ?, cf. meter 4.4) indicative of more complex sedimentary processes. Subtle changes of grain size allow us to distinguish erosional surfaces inside some layers of sandstone which are indicative of amalgamation.

In our opinion the genesis of such an arrangement of facies is related to intense deformation by water escape which affected a succession of amalgamated layers of sandstone having diverse textural characteristics, namely grain size and degree of cementation. The lower parts of the contorted interval suffered comparatively gentler deformation, whereas the middle and upper parts were broken and bent upwards until they lost continuity and the internal structure was obliterated. The upwards movement of sand mixed with water also produced a reduction in the thickness of the lower layers and engrossment of the upper ones.

There is a conspicuous trend of layers to break and move upwards and to the southwest, overthrusting in this direction. We propose that this fact might represent the answer to a sinsedimentary slope dipping to the southwest which caused the movement of the mixture of sand plus water not to be wholly directed upwards but also laterally (downslope).

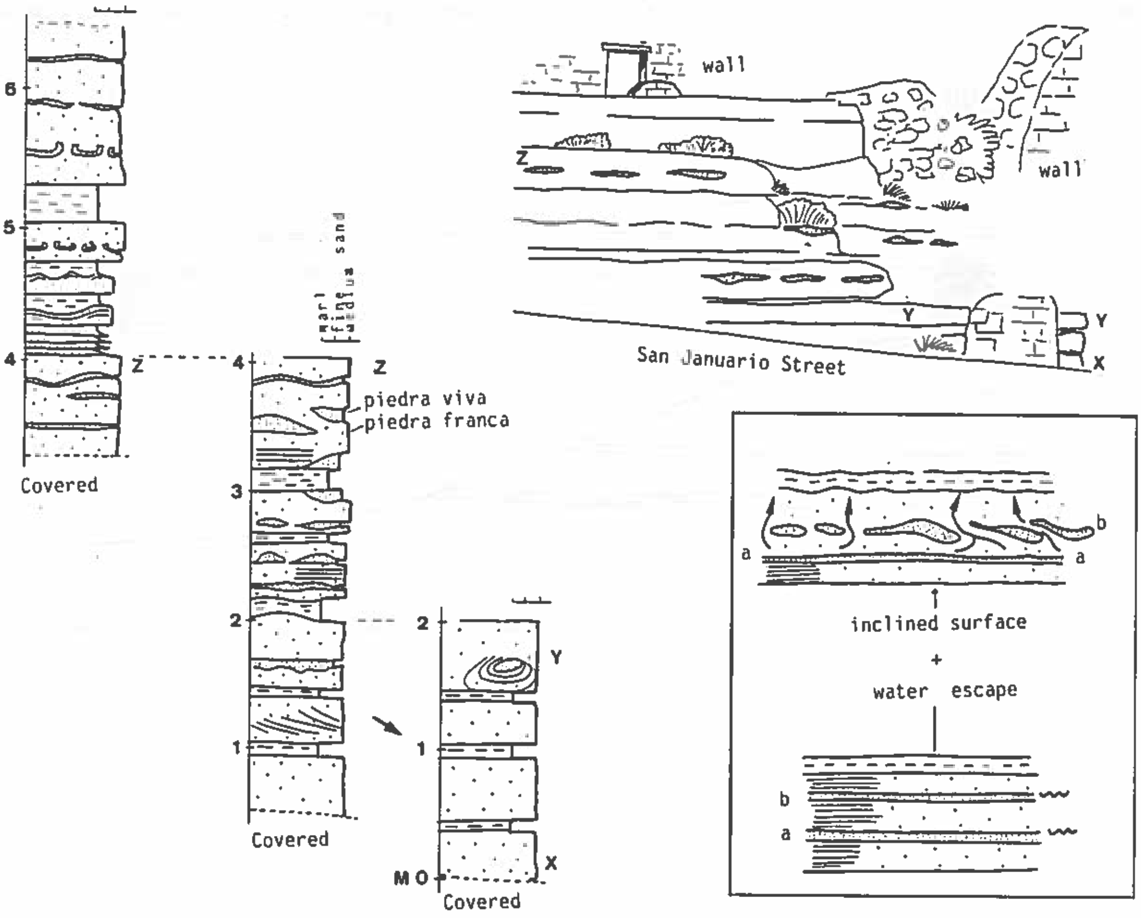

Fig. 1-4-A. Composite section of the sandstone units in Sabiote, below the walls of San Januario Street. Center, top: outcrop near the old entrance to the village (not the one visible in the sketch) where the central and right sections were measured. Letters were used for recognition and correlation of layers across the drawings. Box: proposed model of generation of contorted layers (see text for explanation). Note decrease in thickness of lowermost sandy layer and upwards increase in thickness and deformation. Some pillow structures are observed as well.

STOP 1-4-B. The draw-bridge of the castle.

Walk some 250 m to the northeast, inside the walls, and you will find the castle of Sabiote located on the NE side of the village. You can also go along the walls without entering the village. A part of the section slightly-lower than in STOP 1-4-A is observed below the castle and along the moat. There, just below the foundations of the former draw-bridge, a channel-fill structure is observed.

The underlying sediments (left, below) are decimetric layers of medium and fine grained sandstones with thinner layers of marls, similar to those visited in STOP 1-4-A, and yellow fine to very fine sands with fining upwards trends. The scoured surface of the channel (right, below) is covered by green marls. The thickness of this layer is about 30 cm at the bottom but it thins down to 5-10 cm at the margin. Yellowish, loosely cemented, medium to coarse sands form the larger part of the filling of the channel with a maximum observed thickness of about 1.4 m. The original internal structure has been completely obliterated by water escape.

STOP 1-5. The topmost part of the section near Baeza.

On the way to Baeza via Torreperogil and Ubeda (about 24 km) a similar alternation of marls and sandstones can be seen. The marls crop out just north of Torreperogil in a quarry next to the crossroad (km 159, road N-322).

A shorter drive Sabiote-Baeza via Ubeda does not offer good outcrops of these materials.

STOP 1-5 is located southeast of Baeza, along a roadcut to Puente del Obispo (approx. at Km 11).

The most characteristic feature of this outcrop are the thick layers of sandstone (30-50 cm thick) interbedded inside the marls.

The internal structure of the sandstone beds is parallel and (above it) convolute (after cross lamination) lamination. Casts of groove and skip marks and burrows were found in removed pieces (not in situ).

They are interpreted as proximal turbidite layers (facies B and C, MUTTI & RICCI LUCCHI, 1978). There is a gentle trend to develop a thickening upwards megasequence. However, a thick layer of grey marls appears to the uppermost part.

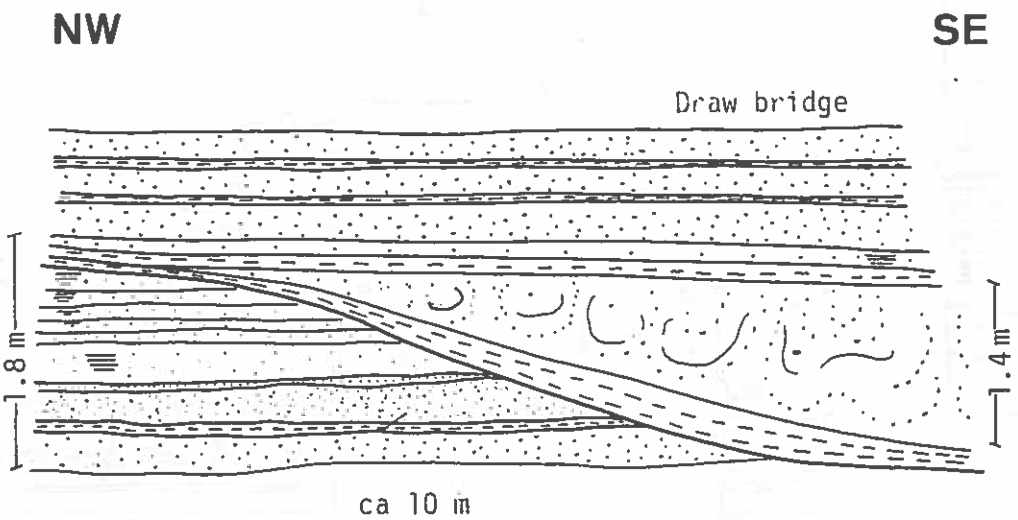

Fig. 1-4-B. A submarine channel fill below the draw-bridge of the Sabiote castle. Note intense water-escape deformation in the sandstone filling of the channel.

SECOND DAY

During the day, five stops are visited which allow you to complete a north south cross section in the central part of the basin. In this section you will see three sedimentary units which constitute the autochthonous filling of the basin and a fourth allocthonous unit in the southern margin (Fig. 2-1).

Over a paleorelief carved into Triassic and Paleozoic rocks, transgressive, Upper Tortonian nearshore sediments form the basal unit that we will visit in Montoro (Córdoba) (STOPS 2.2 and 2.2). This unit which gently dips to the south is overlain, in this direction, by a thick series of grey marls of more than 200 m thick. These marls are very poorly exposed covered by cultivated fields that can be seen along the trip from Montoro to Porcuna (Jaén) before reaching Lopera. The lowermost part of the marls is seen in STOP 2.2 and 2.4, in the northern and southern margins respectively.

The marls pass upwards to an alternation of marl and sandstone layers of Late Tortonian-Early Messinian age, which will be visited near Porcuna (STOP 2.4).

In the southern margin of the basin, south of Porcuna, white diatomitic marls and laminated diatomites crop out (STOP 2.4). They are part of a large olistostrome mainly composed of Neogene and Triassic materials that slid during the Upper Tortonian from the subbetic towards the basin depocenter. After the sliding a new northern depocenter was defined.

These units were named by TJALSMA (1971), from bottom to top, as Marmolejo, Andújar and Porcuna Formations, respectively.

STOP 2-1 and 2-2, Montoro, are on map 17-36 (903) of the MTN; STOP 2- 3, Porcuna, on maps 18-37 (924) and 17-37 (925); STOP 2-4, Arroyo del Saladillo, on map 17-37 (925); and STOP 2-5, Porcuna, on map 17-37 (925).

STOP 2-1. The Upper Tortonian Basal Unit in Montoro.

Drive to Montoro leaving N-IV at km 358.5 to reach the village from the south. There are several parts to this STOP.

STOP 2-1-A. Panorama and vertical relationships of geologic units.

After passing by the first houses of Montoro

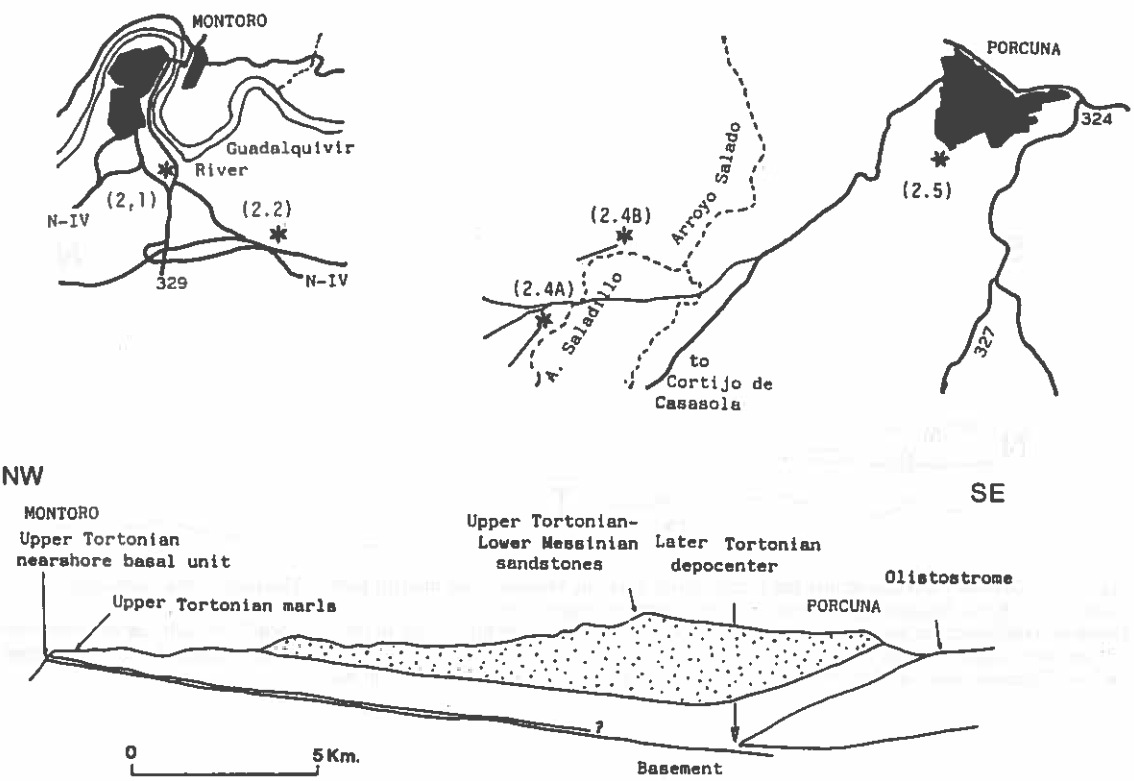

Fig. 2- 1.- Location map of localities visited near Montoro and Porcuna. Below, schematic geological cross-section between both cities, showing the main sedimentary units.

and a factory named "Mazapanes de Montoro La Logroñesa" there is a place to sit (look for km 1) by the Guadalquivir River. Looking north there is a panoramic view of the village and the geologic units on top of which it is built. These units crop out due to the erosion of the river which cut a meander belt around the village.

Three unconformable units can be distinguished. In the lower part, along the Guadalquivir River, grey Devonian conglomerates and quartzites. Above them, below the old part of the village and forming the highest part of many of the hills at the background, reddish Triassic mudstones and sandstones. To the left (east and south), topping the section, Neogene deposits below the modern quarter of the village.

STOP 2-1-B. The paleorelief and basal unconformity.

A few meters to the west, across the road, there is a cliff where detailed observations are made.

A most impressive view of the unconformity between the Triassic and Neogene deposits is observed. The red Triassic fluviatile deposits consist of mudstones and cross-bedded layers of

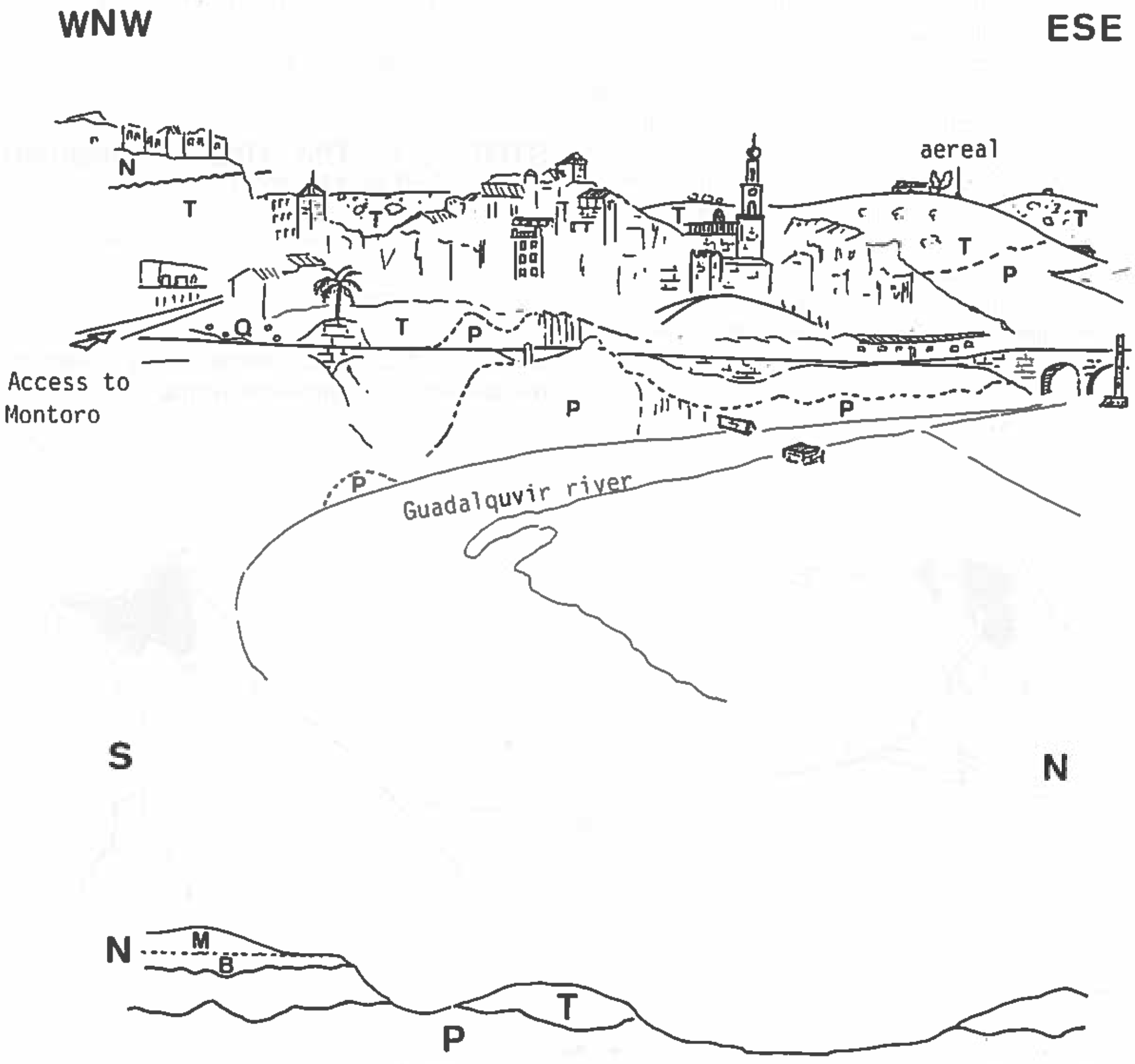

Fig. 2-1-A. (above) Panorama across the Guadalquivir River in Montoro. The modern part of Montoro, to the northwest (left), is built on top of the Neogene Basal Unit (NB) lying unconformably above reddish Triassic mudstones and sandstones (T). Grey Devonian conglomerates and quartzites (P) occupy the lower part of the hills, close to the river bed. Some alluvial conglomerates (Q) are also found attached to the hill side. Paleozoic and Triassic rocks are seen in the far end forming the hilly landscape. (below) Schematic cross section. N: Neogene deposits divided into B: Basal Unit and M: marls.

sandstone. Mudstone with interlayered sandstone beds, about 15 to 20 cm thick, correspond to flood-plain deposits. Lenticular, cross-bedded layers of sandstone record channel-fill deposits of a fluvial system with paleocurrents directed towards the south (N170ºE).

The irregular surface of the unconformity was weathered before Neogene times. Accumulations of boulders of sandstone suggest reworking of a regolith-like mass covering the Triassic paleorelief. However, it must be emphasized that no formal study of the related pedogenesis was carried out by the present authors.

The overlying Neogene deposits adapted to this irregular surface and grain-sizes are observed to fine down when moving away from the paleohill.

Several intervals were distinguished for explanation in this, up to 11 m thick section, above the boulder sized conglomerate.

(1) Medium to coarse sands with interbedded gravel sized conglomerate, onlap the irregular paleoslope. Ophiomorpha burrows are abundant in layers of medium sand. An evident decrease of grain size and wedging out of the coarser grained units is easily observed all across the outcrop, when moving away from the paleohill. The whole interval pinches out laterally to the east against the paleoslope.

(2) A conglomeratic layer which fines out and thins towards the west (i. e. away from the paleorelief) changing from fine boulders to gravel. This interval can be traced across all the outcrops described in Montoro.

(3) Conglomerate (fine gravel and skeletal calcarenite (2.3 to 3 m in total) with *Clypeaster*, some *Chlamys*, Bryozoans, Rhodoliths Red Algae and Bryozoan balls.

(4) Glauconitic *Heterostegina* sands with *Ophiomorpha* burrows. Other fossils are: Pectinids and other Bivalves, Gastropods (locally forming accumulations, cf. m 11) and Brachiopods.

(5) Fine to very fine yellowish sands with delicate shells of *Pecten (Amussiopecten)* and clear signs of burrowing.

STOP 2-1-C. The lower part of the Neogene section.

Move about 60 m to the south (along the western side of the road) to a warehouse in front of a man-made escarpment. There, the base of Neogene deposits is exposed in a section largely perpendicular to the former, but the thickness is only 3 to 4 m.

The intervals described at STOP 2-1-B are also present here.

Layer (1) adapting to an irregular erosional surface, consists of large boulders (up to 70 cm measured along the maximum diameter) of Triassic sandstone in a matrix of coarse sand. The rest of this lower interval is made up of fine to medium gravel conglomerate. The coarser grain size of intervals 1 and 2 is in agreement with the more proximal place occupied, in respect to the previously described paleorelief.

(2) A boulder sized conglomerate made up of Paleozoic quartzites and pieces of beds of Triassic sandstones.

(3) + (4?) Coarse to very coarse sandstone with scattered large to very large pebbles. Skeletal fragments and grains derived from Triassic sandstones and other rocks (quartz, quartzite, etc) are recognizable. Fossil content is Red Algae, Serpulid worms, Bryozoans, fragments of bored Bivalves, etc.

(4 + 5) Climbing to the top of the cliff (it is easily done making a little detour), the transition to the marly Unit is visible. Here it consists of fine to very fine yellowish sands which yielded *Pecten (Amussiopecten)*, and can be traced up to the top of the hill using the excavations behind the school and the hotel. Those sediments are also visible in an isolated outcrop, 100 m east of the bullfighting ring. This site is located more than 150 meters to the west of STOP 2-1-C.

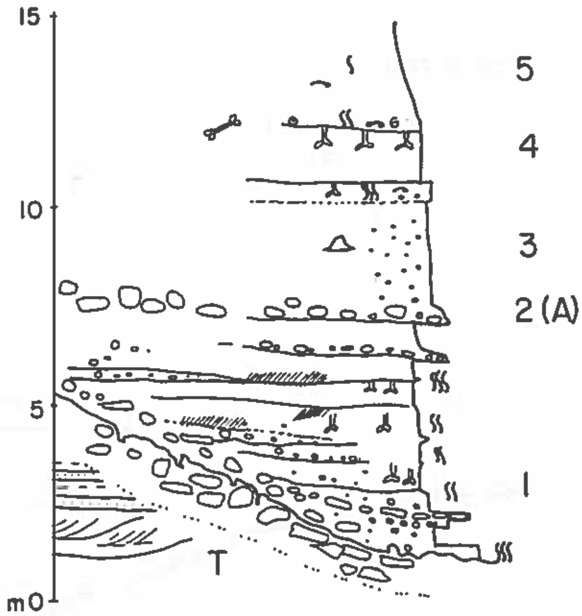

Fig. 2-1-B. Section of the Upper Tortonian Basal Unit. Figures indicate intervals described in the text. Note the wedging out of interval 1 to the south following the onlap and the fining of grain size moving away from the paleorelief. Oblique lines: cemented layers.

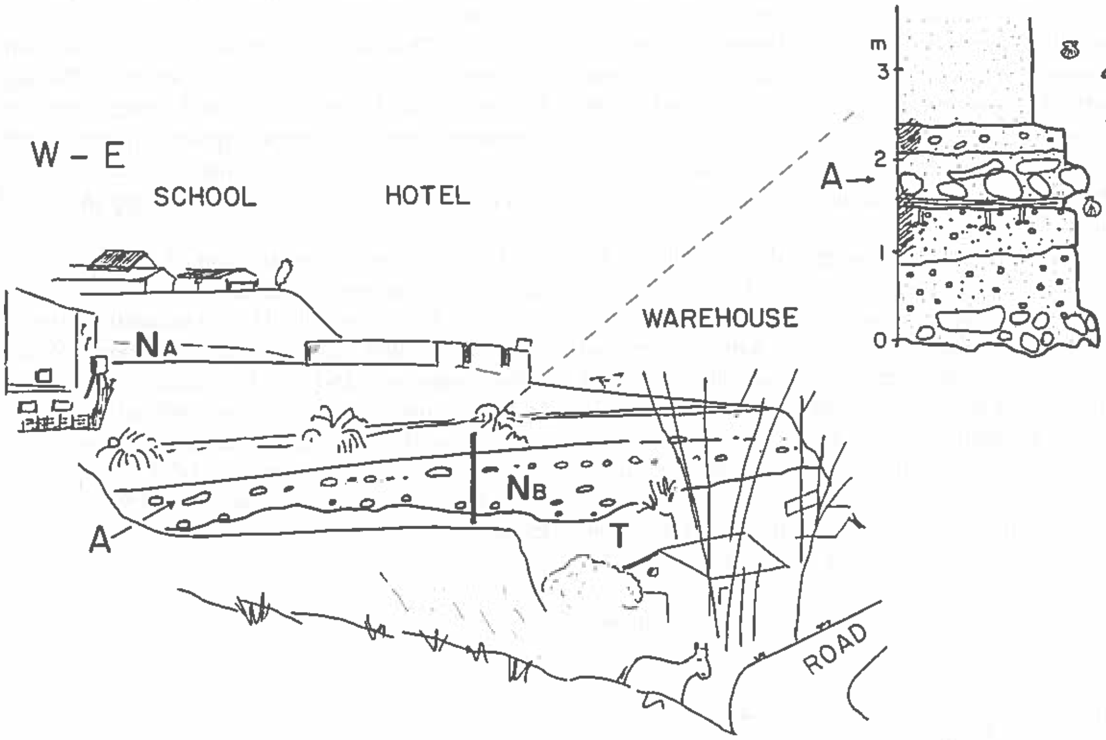

Fig. 2-1-C. (a) Panorama and section of the Basal Unit (NB) and the yellowish fine sands (NA) units between the warehouse and the schools near Montoro. (T): Triassic rocks; (A): reference layer traced across the outcrops. Oblique lines: cemented layers.

Interpretation.

The Upper Tortonian Basal Unit of Montoro is a coarse grained, terrigenous unit which covered a paleorelief carved into Paleozoic and Triassic siliciclastic rocks. As a result, grain sizes record the position in respect to the variable height and depth of the area of sedimentation. The visited sections correspond to sedimentation covering a slope dipping to the north.

This implies that the thickness of the Basal Unit is most variable and also that it will not be

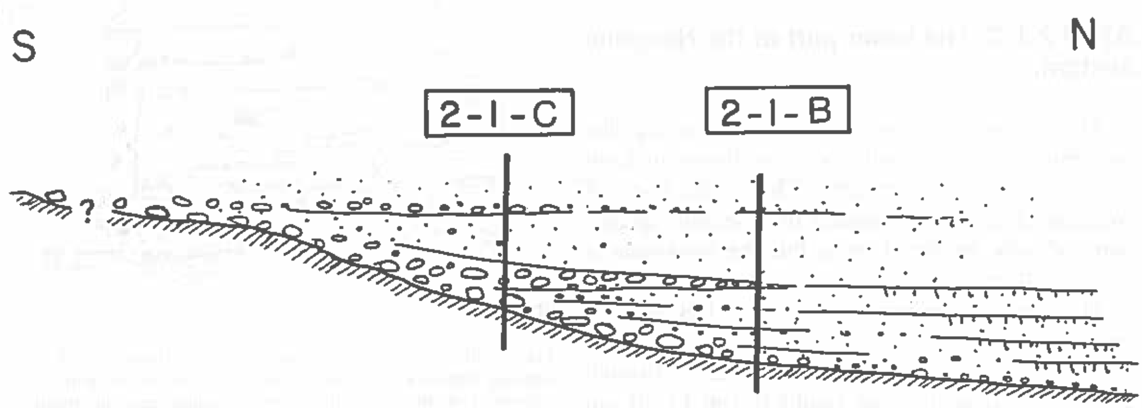

Fig. 2-1-C. (b) Facies relationships in the Basal Unit near Montoro.

represented in many places. In particular it is not found when moving to the southeast to the area around STOP 2-2.

STOP 2-2. The transition from fine sands to the marly unit in the quarry east of Montoro (Late Tortonian).

The quarry is located 160 m north of the road N-IV. UTM coordinates 380.2; 4208.2.Leave the car on the old road diverging (south) from N- IV or use as parking the paved entrance to the olive grove (km 357.1). Walk due north through the olive trees for about 160 m.

The quarry can also be reached using an unpaved road leaving N-IV to the north at km 356.5. It is a 900 m long detour.

The transition from the fine sands seen in Montoro (STOP 2-1-C) to the marly unit (Late Tortonian) is well exposed in the quarry.

In the lower part of the quarry, burrowed yellowish fine to very fine glauconite sands with *Korobkovia* and *Pecten (Amussiopecten)* shells. Two intervals can be distinguished according to grain size and type of burrowing. Up to 4.8 m of the lower were visible in 1989 but the water table rose and since then only 2 m were still above it. The top of the 2 m thick, upper interval is intensely burrowed with abundant glauconite inside the galleries.

The unit of marls is recognized by its whiter colours in the upper part of the quarry. In detail they are not really marls, but homogeneous marly silts with intercalations of 30 to 40 cm thick layers of silty sands protruding off the walls because of its more cemented nature. Both the marly silts and the silty sands consist mainly of biogenic (planktonic foraminifera) material and are strongly bioturbated. Grains of quartz, and rock fragments are also present.

The topmost layer (no. 6 in Fig. 2-2 a) is parallel laminated with glauconite filling the microgalleries.

A most interesting remark is the apparent divergence of the lower, more calcareous strata of the marlstones which can be observed looking north from the southern end of the quarry (Fig. 2-2 a). A possible interpretation for this fact is that the convergence represents the downlap at the base of the prograding marly sequence.

General interpretation of Neogene sediments in Montoro.

A probable interpretation of the Upper Tortonian deposits in the northern margin of the Guadalquivir Basin in the area of Montoro can be extracted from the previously exposed data. The transgressive deposits of the Basal Unit record a repeated shallowing upwards trend but progressive

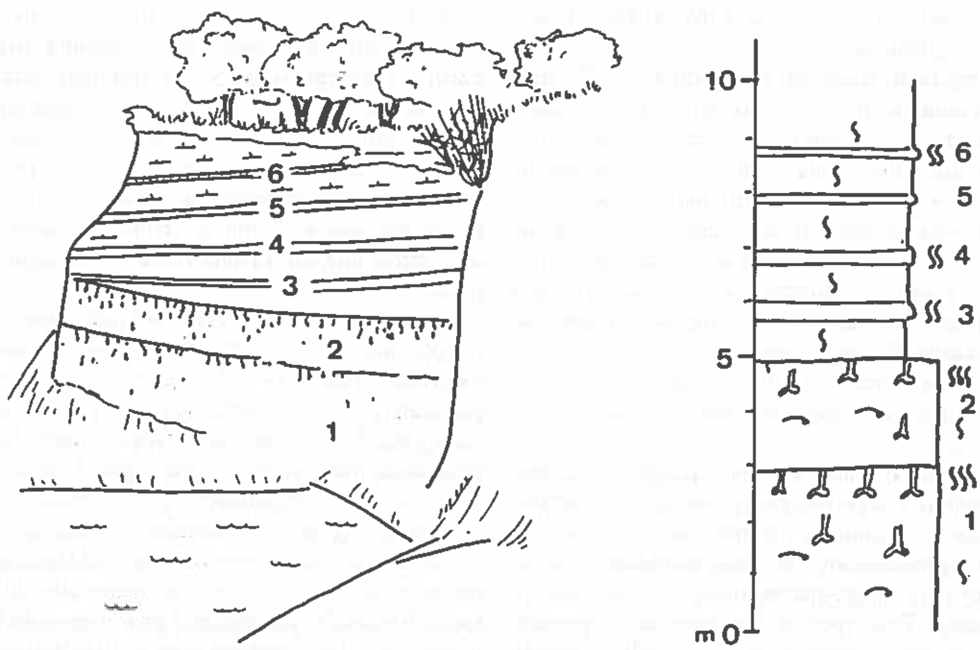

Fig. 2-2 (a).- Transition from the fine sands to the marly unit in the quarry of Montoro. Note the divergence of the lower, more calcareous strata of the marlstones.

(rapid?) transgression continued until deposition of the deeper burrowed yellowish *Pecten* (*Amussiopecten*) fine sands.

The strongly burrowed, glauconite-rich layer of the top of the yellow fine sands interval and the overlying foraminiferal silts and sands could be interpreted as the condensed section deposited during the maximum transgression before the rapid progradation of the marly units to the southwest. This relative sea-level rise has been widely recognized throughout the Betic-Riff system.These particular deposits of the lowermost part of the marls were found at many sites in the basin, always presenting high planktonic Foraminifera concentrations and a low proportion of Nannoliths. These unusual characteristics allow us to interpret them having been deposited in an upper slope or external shelf with bottom currents winnowing fines. The burrowing activity of bottom animals could contribute to accelerate the process in an important manner. The present authors are now studying the possible relationship of these currents with the Atlantic- Mediterranean communication at this time through the North Betic Strait.

Downlap of the distal parts of the marly wedges may cause the cited unconformity between the more cemented layers of calcareous marls and the underlying yellowish fine sands. In the Guadalquivir Basin deposition of the condensed section occurred just prior to event 1 which has been dated in 6.7-6.8 m.a. So an age of 7 m.a. is very likely for this condensed layer which clearly coincides with that proposed by HAQ *et al.*, (1987) for global sea level cycle 3.2.

The regional study of TJALSMA (1971) and our own studies allowed us to define a succession of calcareous plankton events into the lithologically monotonous marls by correlationship with other sites in the western part of the basin. Event 1 was located at the base of the typical marls, probably only 1 or 2 m above the top of the Montoro quarry. Sinistral *N. acostaensis* and Keeled *Globorotalia* (*Globorotalia*) with respect to the Planktonic Foraminifera and *E. berggrenii* and *E. quinqueramus* among the Calcareous Nannoplankton are recorded from the base of the quarry.

In the marly silts of the quarry, *Bolivina*, *Stilostomella*, *Uvigerina peregrina* and *Uvigerina proboscidea*, *Planulina ariminensis*, *Oridorsalis* and *Anomalinoides* are the most abundant taxa. In the upper part some specimens of *P. wuellerstorfi* were found. This species becomes an important element of the assemblage in the overlying marls joined to *Cibicidoides*, *Uvigerina peregrina*, *Globocassidulina*, *Gyroidina*, *Oridorsalis* etc. It is interesting to note that today *P. ariminensis* is replaced by *P. wuellerstorfi* at a depth of more than 700 m in the Northwest African continental margin. Towards the top of the marls the benthic assemblage is indicative of shallower waters.

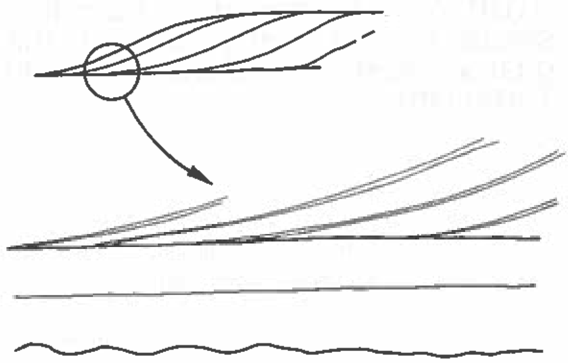

Fig. 2-2 (b).- Proposed interpretation of the Upper Tortonian deposits in the area of Montoro (northern margin of the Guadalquivir Basin). See explanation in text.

STOP 2-3. Panoramic view of the Betics and the Middle to Upper Tortonian delapsional olistostrome) and autochthonous marlstones and sandstones.

Drive along N-IV to km 346.4, turn south and go 18 km along roads C- 327 and N-324 to Lopera and Porcuna. You will reach Porcuna from the north. Go to km 64 of N-324 and then, turn south (Rafael Quero street). Proceed to the end and turn to the right (A. Modesto Aguilera street) to the center of the city marked by a decorate pole with street lamps. Turn south (left) and, at the end of the street, you will find the House of Stone (Casa de Piedra) and the Ermita (church) of Jesús in the park.

This is an excellent lookout post for a panoramic view of the calcareous mountainous external zones of the Betic Cordillera, in particular, the Subbetic Zone, visible in the background: to the left (east) the Jabalcuz mountains near Jaén; to the south Martos at the foot of the cone-shaped Peña (rock); to the southwest (right) the mountains of Alcaudete.

Closer to the observer the olistostrome, a melange of Mesozoic and Neogene allochthonous rocks formed by delapsional processes which took place along the southern side of the basin during the advance of the subbetic overthrusts. Here it consists mostly of Neogene sediments which, interestingly enough, are of almost the same age as the assumed autochthonous marlstones. The olistostrome favours a hilly landscape (lomas)

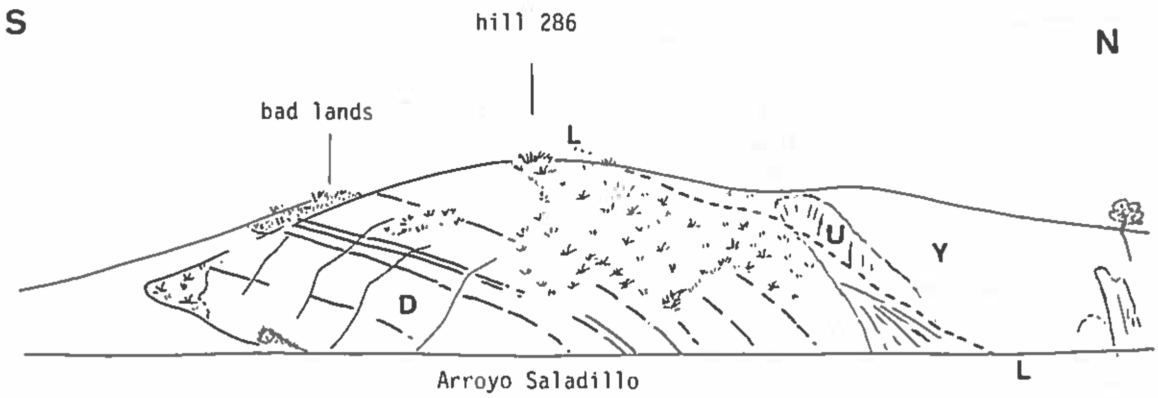

Fig. 2-4-A. Panorama of the olistrostrome across the southern outcrop of Arroyo del Saladillo. The pictured part is about 200 m long. The boundary (L) between the diatomites (D) and the overlying blue - grey marls (Y) dips to the north crossing a landslide (indicated by letter U).

covered with olive groves. Looking N245° E locate a white hill (height 286 m) in the bottom of the valley: that is STOP 2-4.

Late Tortonian to Messinian marlstones and sandstones form the slopes and tops of the hills of Porcuna and Cerro de Albalate (height 400 m) 3.5 km to the west. Part of STOP 2-5 is also visible along the northeast-trending escarpment.

STOP 2-4. Middle to Upper Tortonian olistostrome (delapsional diatomites and marls) in Arroyo del Saladillo.

These outcrops can be reached via the unpaved road to Cortijo de Casasola. It starts at km 63.6 of N-324, opposite (south) Bar El Parral; follow the street to a small square with a chapel (Ermita de Santa Ana). Turn south (left) to José Santiago street which, downhill, turns into the above mentioned unpaved road. Follow the road until you cross Arroyo Pozo Piojo, turning to the west (right) in the direction of Cortijo de Albarizas. Cross Arroyo Salado and proceed one more kilometer to Arroyo del Saladillo.

Two sections, named STOP 2-4-A and 2-4-B, are exposed along the creek.

STOP 2-4-A. The southern outcrop of Arroyo del Saladillo: hill 286.

It is located 500 m southwest of Cortijo de Albarizas, on the eastern side of hill 286. The outcrop can not be reached by car; it is necessary to walk the last 200 m. UTM coordinates 391.5: 4189.8.

In this outcrop a thick (more than 20 m) diatomite unit is seen dipping to the north. It is covered by grey marls. The age of these deposits (Middle to Late Tortonian) is slightly older than the overlying marls found between Porcuna and Arroyo Pozo Piojo.

STOP 2-4-B. The northern outcrop of Arroyo del Saladillo.

It is located about 250 m north of Cortijo de Albarizas. UTM coordinates 392; 4190.450.

In this outcrop, excellent exposures of allochthonous diatomites, although partly obscured by weathering, occur between layers of grey marls. These delapsional rocks are covered by blue marls.

In the laminated diatomites cycles of different hierarchy may be observed. White and grey layers of 1 to 8 mm thick alternate to form the second order cycles. White layers consist mainly of siliceous biogenic elements (Diatoms, Radiolarians, Silicoflagellates and Sponge spicules) with a minor terrigenous composition, whereas in the grey layers, the terrigenous matter is dominant. Within the white layers an alternation of white and black 20 µm thick laminae were seen in thin section (polarised light). The black laminae originated by the accumulation of aciculate Diatoms (*Thalassionema nitschioides* and *Thalassiosira longissima* are dominant) (SCHRADER 1975, SIERRO *et al.*, 1989). On the contrary, in the white laminae the siliciclastic elements are more abundant. This alternation of thin laminae form the third order microsequences.

Every 40 to 70 cm a dark grey bed of 10 to 20

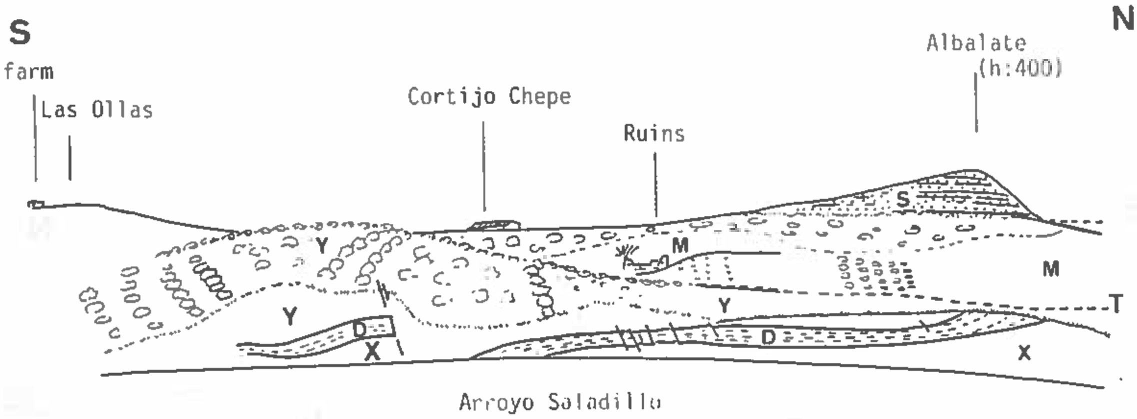

Fig. 2-4-B. (a) Panorama of the olistrostrome across the northern outcrop of Arroyo del Saladillo. The section exposed along the river is approximately 300 m long. Well stratified diatomites (D) are thinner than in the former STOP. Diatomites are interlayered between marls (X, below, and Y, above). These delapsional rocks are covered by blue marls (M) cropping out in the hills before Albalate mountain and to the west. The limit of the allochthonous and autochthonous rocks (T) can be traced across the landscape at the base of Albalate, before the ruins and behind the hill covered with olive trees (the one located between Chepe farm and Las Ollas).

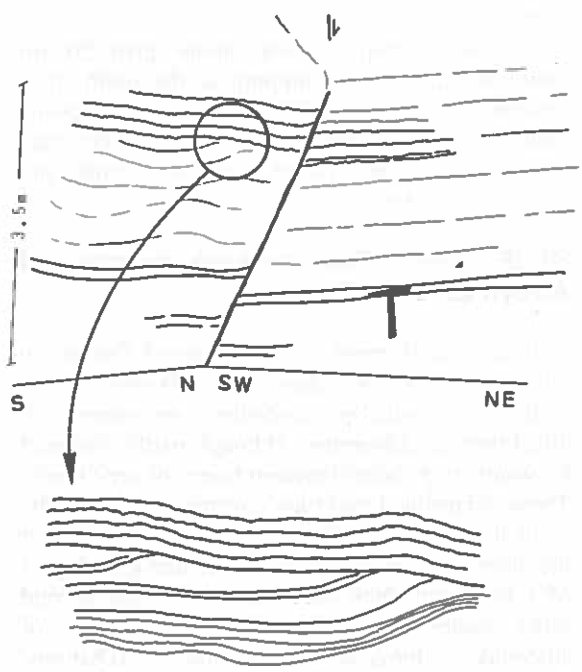

Fig. 2-4-B. (b) Close up of the diatomites in northern outcrop to show (detail, below) that they were affected by sinsedimentary deformation. In the N-S wall of the outcrop (left), an increasing-upwards deformation is observable which, at a certain stage, is truncated before deposition of the overlying darker layers of varve-like diatomites.

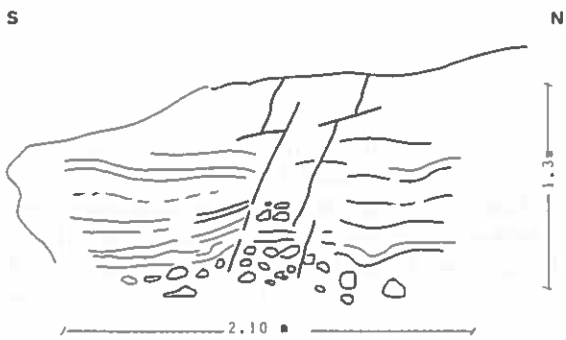

Fig. 2-4-B. (c) Close up of the diatomites in the same outcrop, about 30 m to the south and essentially in the same layers. Intraformational brecciation coupled to contortion of parallel laminated diatomites. The upwards bending of laminae and the normal faulting suggest that water escape played a major role in the generation of the structure.

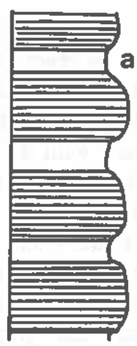

Fig. 2-4-B. (d) 1st order sequences in the diatomite beds. A dark grey (a), dominantly terrigenous layer is interbedded every 20 to 80 cm of laminated diatomites.

cm thick is interbedded defining the first order sequences. This dark grey layer was not deposited in a single event because it consists of terrigenous sediment with thin, approximately 1 mm thick white diatomaceous laminae sporadically interbedded. These deposits were interpreted as formed in a steep slope situated in the oxygen minimum zone related to highly fertile waters in the sea surface. The third order microsequences may be produced by seasonal changes in water fertility or terrigenous input in a coastal upwelling region. Approximately 150 pairs of laminae were counted in a thin section of a 6 mm thick white layer. Every certain number of years, a mud layer is deposited probably in a single flood or distal muddy turbidite event.

The first order sequences may be related to relative changes in water fertility or terrigenous input at a larger scale. The present authors are studying the relationship of these sequences with the Milankovitch cycles.

The occurrence of these diatomitic sediments on the southern margin of the Betic strait was interpreted by SIERRO *et al.* (1989) as having been originated by upwelling of deep atlantic waters in a context of estuarine circulation between the Atlantic and the Mediterranean.

From the micropaleontological point of view, Benthic Foraminifera, absent in the laminated diatomites, are common in the underlying marls with a typical relatively deep water assemblage.

The presence of sinistral *N. acostaensis* forms, sinistral keeled *Globorotalia* and *E. berggrenii* is indicative of an Late Tortonian age, prior to event 1.

The autochthonous marls overlying the olistostromic unit could only be sampled for micropaleontological studies in their lower and upper parts which were deposited earlier than event 1 and later than event 2 respectively.

STOP 2-5. Upper Tortonian to Messinian autochthonous Porcuna sandstones and marls.

They are exposed in a group of quarries cut into the southern side of the village. These can be reached driving along the roads N 324 and C- 327 to Valenzuela. Two quarries are visited. For description purposes they were called "Villa Antonia" (km 42.2) and "km 42". There is still a lower part of this unit which is exposed a few hundred meters to the west, along the escarpments on which the village is built.

The sandstones of Porcuna are of a yellow colour when recently cut but tend to turn brownish with black surfaces when weathered. Two different lithologies are observed: loosely cemented and cemented (indurated) sandstones. There is hardly any difference between these two types; both consist of bioclasts, quartz grains and calcareous matrix (a detailed description is found in TJALSMA, 1971). Thin layers of silty to sandy greyish marls also occur.

There is a decrease in grain size from bottom to top of the Unit. Only the upper, finer part of the sandstone unit is exposed in STOP 2-5; this means that most of the change in grain size takes place below our present position. However, an increase of the content in fine sediments (marls) is noted when moving from Villa Antonia (STOP 2-5-A) to km 42 (STOP 2-5-B).

Marls are very scarce in STOP 2-5-A, where they represent only thin interlayers, sometimes hardly more than 1 cm thick, which adapt to bottom irregularities (cf. m 8). However, in STOP 2-5-B they occur in thicker layers (15 to more than 30 cm) which often form a large part of the section (cf m 24, 26, 29 to 30, ...).

Bed thickness is quite variable from 2 cm to 2 or more meters. In some cases, beds of sandstone are separated by interlayers of marls of 2 to 5 cm thick or by milimetric finer-grained sandstone intervals. Amalgamation of the sandstone layers is a common feature. Most of the erosional surfaces separating amalgamated layers are (almost) flat, parallel to bedding.

Bed thickness is laterally constant in some parts of the section, when considered to the scale of the visited quarries. This is the case of the lower half of STOP 2-5-A and the whole wall of STOP 2-5-B. However, the upper part of the wall of STOP 2-5-A shows a higher variability. Scouring of the underlying layers and vertical growth of bar-like bedform account for most of these changes in thickness.

Horizontal, parallel lamination is the best represented primary sedimentary structure of the sandstone layers. Many layers also fine upwards (graded bedding).

Bedding surfaces are quite flat and parallel, but rippled surfaces occur. Sinuous wave ripples with rounded crests pointing E-W, asymmetric oscillatory ripples (indication of wave motion towards the north) and interference ripples are also found in bedding surfaces. The internal structure of these small-scale bedforms is hardly or not visible at all.

Cross bedding and hummocky cross stratification appear at the upper part of STOP 2-5-A (cf. m 9 to 12), with a paleocurrent measurement to the NW. Water escape structures add some disturbance to the internal structure of these layers.

Fossil content includes common shells of *Ostrea*, *Pecten* and other Bivalves. Many of these remains are excellently preserved.

Burrowing is frequent in many layers. Most of it is of the horizontal type: irregular tracks and ramified (branching) galleries are common (cf. m 1). In this layer, just on the floor of Villa Antonia quarry we found many very well-preserved imprints (resting star-like tracks) probably of jellyfish.

The lower part of the section is exposed in the escarpment just west of the village. Here coarser grained sandstones, more irregular layers and large-scale deformation are observed. Layers up to three meters thick pinch out laterally. The internal structure is more or less horizontal bedding with intercalated decimetric layers of marls and several horizons of mud clasts. In our opinion most of the deformation was due to water escape coupled to sinsedimentary slumping.

Interpretation

The visited sandstone unit shows features which can be attributed to several sedimentary environments. Many of these are quite similar to those described in Fuente de la Corregidora (STOP 1-3) including two types of lithologies, common amalgamation of layers, extensive deformation of some layers, etc. There is also evidence of a tranquil environment for a large part of the time of deposition: existence of rich planktonic fauna in the marly interlayers, well preserved delicate shells of Bivalves, preservation of the resting tracks of Echinoids, etc. However, far less channeling and a more distinct influence of wave action (hummocky cross stratification, hummock- shaped bar-like bedforms and wave ripples) were found in Porcuna. In our opinion, the prominent scouring of some beds and even (parallel) lamination also indicate wave action on a sandy bottom. It must be taken into account that parallel lamination generates from rapidly flowing currents but it is not clear whether or not these currents were (in Porcuna) of the density type.

Thus, we must visualize an environment which, to some extent, will integrate all those features suggestive of turbidity currents, shallow waters, and mixed benthic and planktonic living communities. In our opinion this may be achieved by imagining a marine shelf, probably open (and inclined) to the north where storm induced surges deposited sandstones moved from shallower areas of the basin. The mixed carbonate-siliciclastic shelf, rooted to the southern margin of the basin, might be related to the northward motion of the delapsional units of the olistostrome (cf. STOP 3-3). However, it must be noted that the ages involved might be different in accordance to the mobile nature of the substratum.

Near Porcuna, the sandstone (and marl) unit is dated as Latest Tortonian, between events 2 and 3, though this unit reaches the Early Messinian towards the NW in the vicinity of Cañete and Bujalance, to the west of Porcuna.

STOP 2-5-A. The lower quarry (Villa Antonia).

Located next to km 42.2 on road C-327. The entrance is to the west of the road, just opposite a house named "Villa Antonia". In this quarry a most impressive vertical cut of the loosely cemented yellow calcareous sandstones exposes the middle part of the Porcuna sandstone (stratigraphically below the other quarry visited).

In this quarry, sandstone beds dominate over marls (Fig. 2-5 A). The lower part of the exposed profile consists of very regular, laterally continuous layers of sandstone with thin marly layers interbedded. Fossil imprints, burrows and wave ripples are observed.

STOP 2-5-B. The upper quarry (km 42).

Located at km 42 of road C-327. In this quarry the upper part of the Porcuna sandstone unit is very well exposed.

There are thick, laterally continuous layers of sandstone with intercalations of alternating sandstone and marls (Fig. 2-5 B). Sole marks (groove, flute and skips casts), *Paleodyction* and oxidized surfaces were found in removed pieces of sandstone carefully piled under a tree growing in the center of the quarry.

Additional outcrops of slightly younger marly and sandstone deposits are visible in Modesto Aguilera street, near the filling station and on the first few kilometers of the road from Porcuna to Arjona.

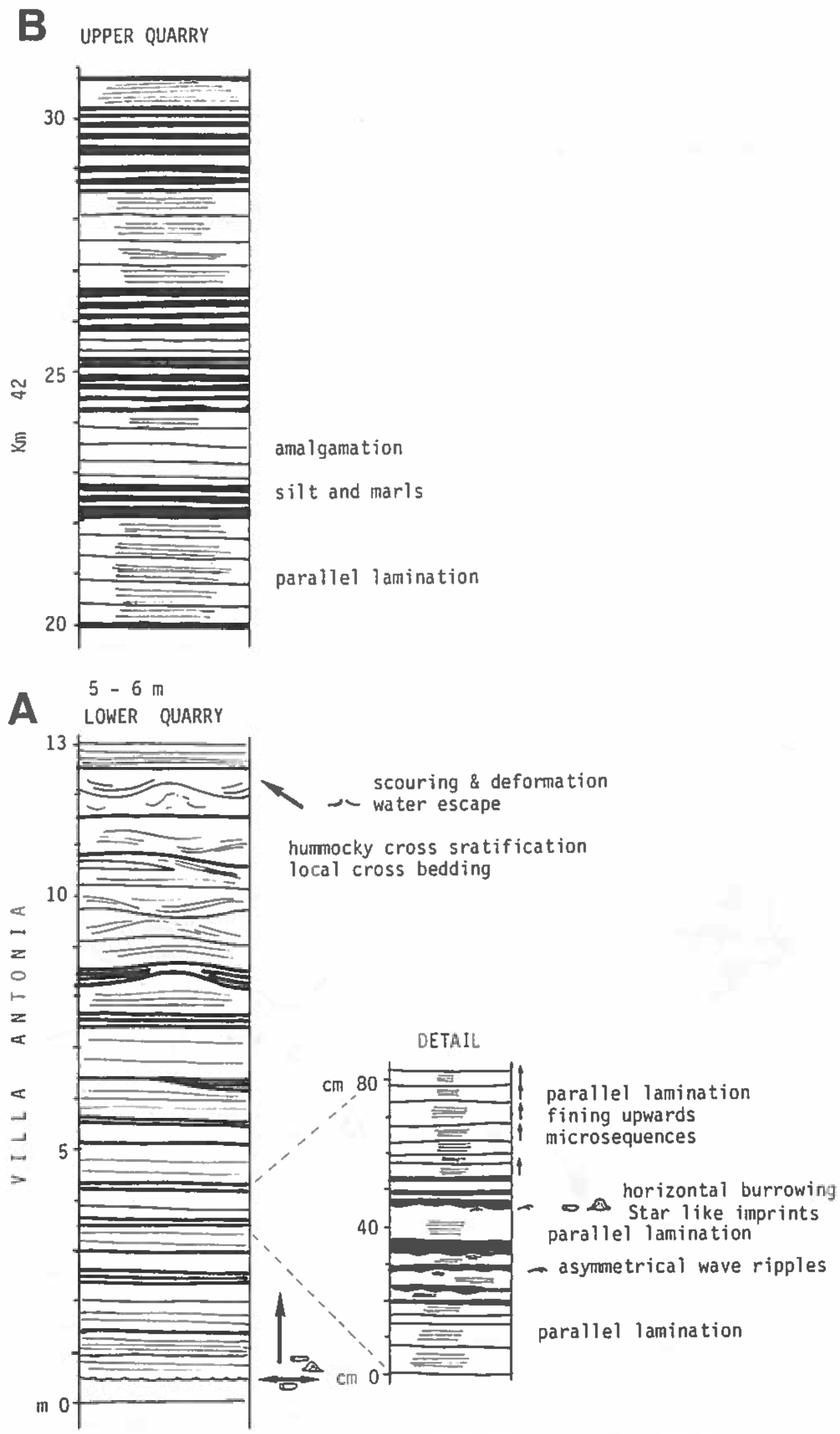

Fig. 2-5. Stratigraphic section measured in the quarries of Porcuna. A (below): section of the Villa Antonia quarry with a magnified detail section to show typical features of the lower part of the profile. B (above): Section measured in the quarry of Km 42 with laterally continuous layers of sandstone and alternating sandstone/marls. Sole marks (groove, flute and skips casts), *Paleodyction* and oxidized surfaces were found in removed pieces of sandstone. Note that there is a gap of several meters between the two sections: those corresponding to the area occupied by machinery of the quarries and streets.

THIRD DAY

In Fig. 3.1 a north-south cross section between Villanueva del Río y Minas and Carmona is seen. This is an equivalent section of the previously described one between Montoro and Porcuna, but approximately 130 Km to the West. Three units, apart from the olistostromes appear in this region. The basal unit is well exposed along a narrow band following the northern margin of the basin; laterally important facies changes were recognized from typical calcareous biogenic sediments to typical deltaic deposits. This unit can be observed in STOPS 3.1 and 3.2 in Arroyo Galapagar and Villanueva del Río y Minas respectively. The basal unit is transgressive over the Paleozoic basement and dips gently towards the south. A thick series of marls that at the depocenter can reach almost 1000 m thickness overlies the basal unit. As in previous cases the exposure of marls is very poor due to the intense cultivation of the region and to the existence of recent alluvial deposits of the Guadalquivir River that cover them. They were deposited from the Late Tortonian, near Villanueva del Río y Minas and Arroyo Galapagar to the Late Messinian in Carmona (SIERRO *et al.* 1987, FLORES and SIERRO 1987). In STOPS 3.1 and 3.2 the transition between the basal unit and the lowermost part of marls is seen.

On the southern margin, near Carmona, the marls are overlain by a unit of marls and sandstones which rapidly passes to the calcarenitic unit of Carmona. These calcarenites were deposited in a narrow fringe linked to the olistostrome changing to marls towards the north as you can see in Fig. 3-1. They are always related to the olistostromes in the southern margin, from Sevilla to Cádiz and their age varies from Late Tortonian to Late Messinian depending on the sites. Near Carmona the calcarenitic unit was dated as Late Messinian.

The sliding of the olistostromes during the Late Tortonian drastically reduced the volume of the basin displacing the depocenter some Km. to the north. After the delapsional events the olistostrome unit was gradually covered by the autochthonous marls of Carmona. Today these olistostromes are exposed 4 Km. to the South of Carmona.

The composite section between Arroyo Galapagar and Carmona was proposed by PERCONIG (1974) as a stratotype for the Andalusian stage.

STOP 3-1 (Arroyo Galapagar) and 3-2 (Villanueva del Río y Minas), are on map 13-39 (963) of the MTN. STOP 3-3, Carmona, is found on map 13- 40 (985).

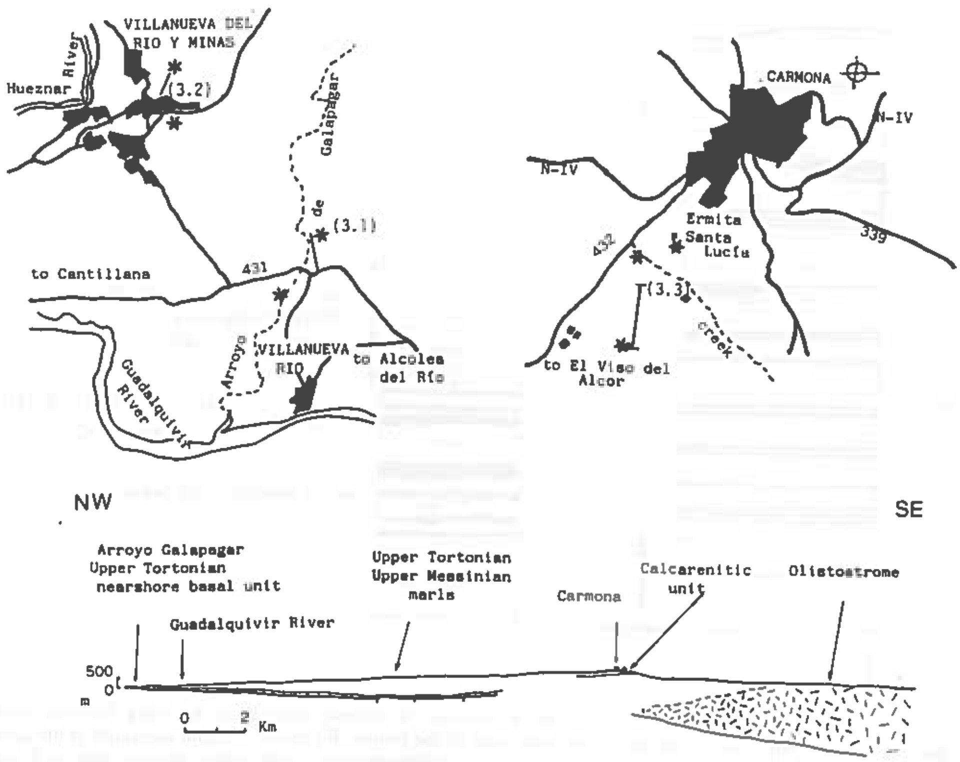

Fig. 3-1.- Location map of stops near Villanueva del Río y Minas and Carmona. Below, geological cross-section between Arroyo Galapagar and Carmona. Modified from IGME (1975, 88).

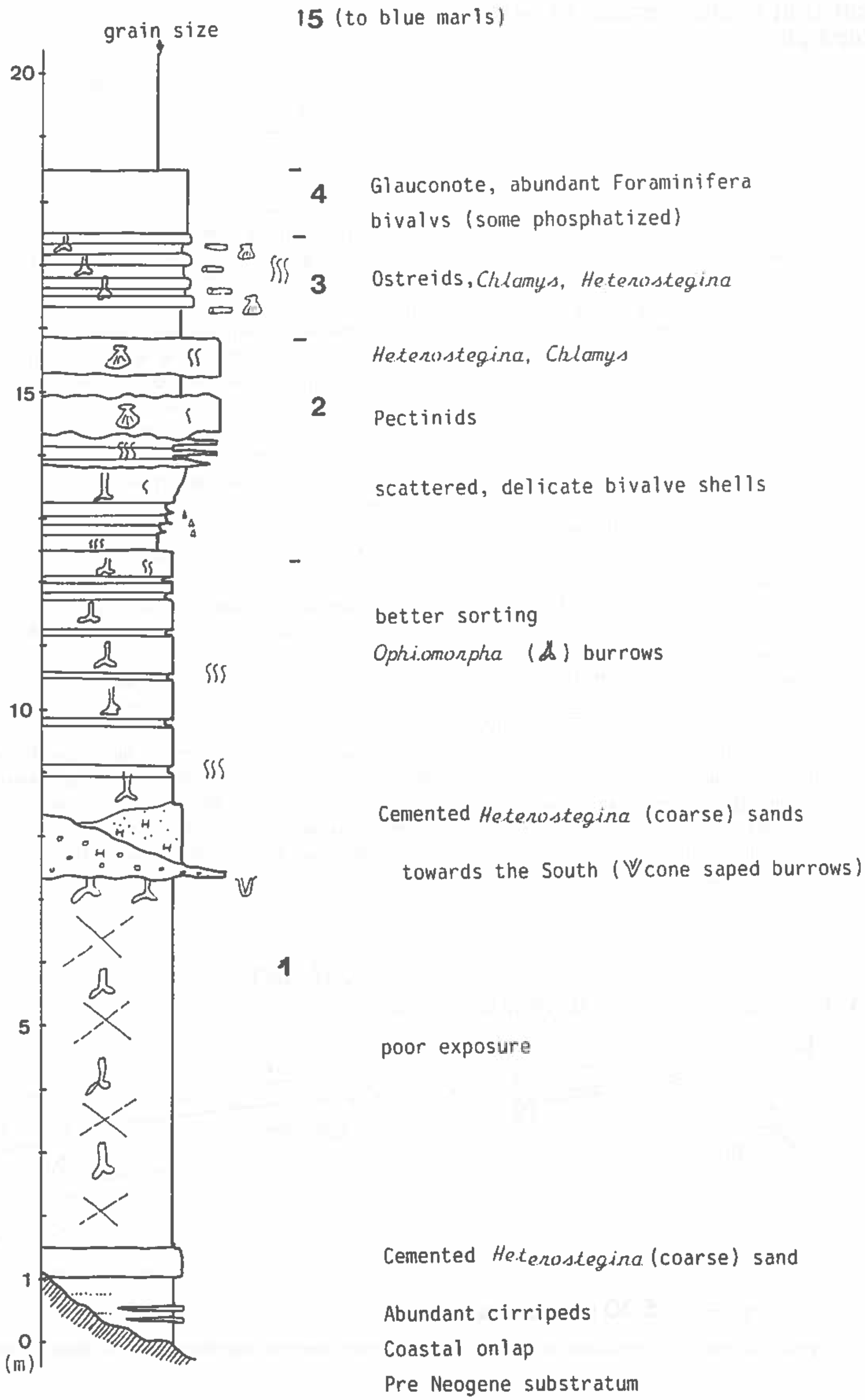

Fig. 3-1 (b). Section of the Upper Tortonian Basal Unit in Arroyo Galapagar. Numbers indicate intervals described in the text.

STOP 3-1. The Upper Tortonian Basal Unit in the section of Arroyo Galapagar.

The Upper Tortonian Basal Unit is well exposed along the east margin of the river, some 250 m. north of the bridge. UTM coordinates: 262.7; 4169.5.

The famous Section of Arroyo Galapagar can be reached using road C-431 (comarcal Córdoba-Sevilla). A bridge over the river at km 92.5 is a good reference to leave the car and to walk to the outcrop. The section can be reached by car as well. In this case, drive to km 93.1, take an unpaved road that goes to the north along the western bank of the river. Leave the car before the road crosses the river and jump (beware of those rivers in winter!) to the eastern bank to visit the section.

In this location a not very well-exposed section of the Upper Tortonian Basal Unit is visible (Fig. 3-1 a). There is not a good exposure of the lower limit and the unconformity with the underlying substratum. This is made up of Paleozoic rocks of Late Devonian age.

The limit can be observed moving 350 m to the north, where an abrupt paleorelief made up of quartzites and shales is exposed in the canyon of the river. Neogene sands onlap that irregular surface but observation is far from perfect. The vertical relationship can also be guessed just north of a quarry (300 m to the east) where the Neogene sands are mined. There, almost horizontal Neogene deposits rest on top of an irregular surface limiting the Paleozoic rocks.

The base of the section is not exposed in the particular site where the section is visited. Several intervals (with descriptive value only) are visible. (Fig. 3-1 (b))

(1) *Ophiomorpha* sands: medium to fine burrowed sands. *Ophiomorpha* burrows occur everywhere. The lower half of this layer is poorly exposed here, but it yielded a large number of whale bones a few years ago, some 150 m to the north. Thin layers of finer, better sorted sands occur interbedded in the upper half. There is a layer of *Heterostegina* microconglomerate (fine gravel) which wedges out laterally to the south (cf. m 8). Mineralogical composition is quartz, rock fragments and some feldspars. This layer is covered, and laterally substituted by *Heterostegina* sands.

(2) Several small-scale fining upwards microsequences which, as a whole, integrate a coarsening up sequence topped by *Heterostegina* rich conglomerates (fine gravel).

(3) Burrowed medium to coarse sands. *Ophiomorpha* burrows in the loose sands and mostly horizontal galleries (probably the lower part of the *Ophiomorpha* complex) in the more cemented layers.

(4) Medium to coarse, poorly sorted sands. Siliciclastic fragments include quartz, quartzite and rock fragments; some glauconite is also recognized. There is a high content in Foraminifers.

This layer changes upwards to finer, Foraminifera rich sandy-silts and eventually to blue-grey marls (5).

The coarser grained layers (in particular the one described in m 8) contains a peculiar internal structure roughly visualized as an inverted cone. Common dimensions are about 40 cm high and 30 cm wide. We assume that these structures are burrows.

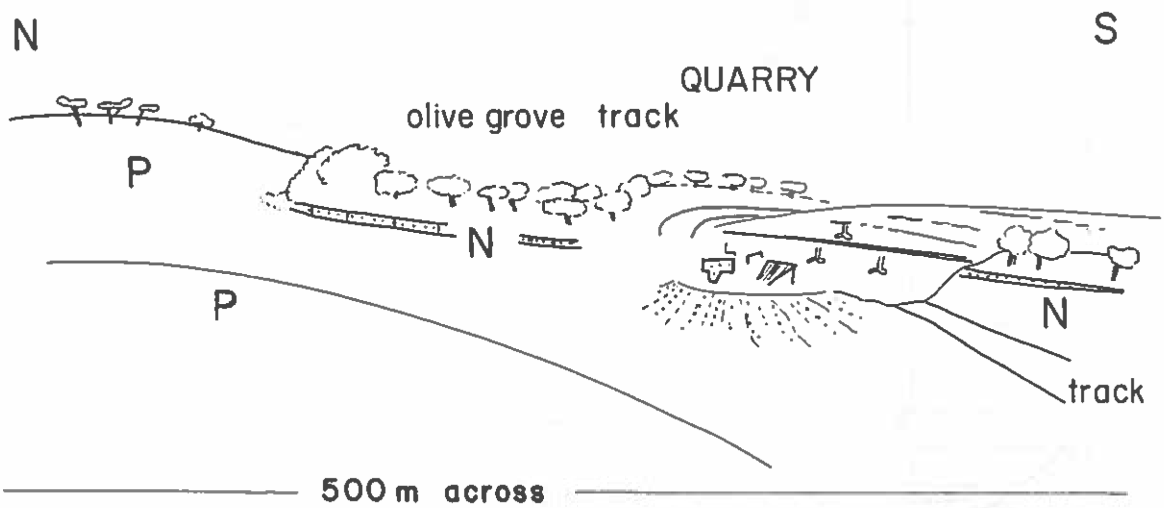

Fig. 3-1 (c). Panorama of the area of the quarry near Arroyo Galapagar section where the Neogene sediments (N) onlap Paleozoic rocks.

The marls are very poorly exposed along the A. Galapagar creek from this site to the Guadalquivir River, but a series of samples, which allowed us to recognize various calcareous plankton events, could be taken.

Event 1 and the increase of proportion in the small placoliths is situated approximately 2 m above the base of unit 4, whereas event 2 is found 3 m above event 1 in the roadcut near the bridge at Km. 92.5. Event 3 was found, in a very bad outcrop, some 300 m to the south of the bridge, on the right margin of the creek (SIERRO, *et al.* 1987, FLORES and SIERRO, 1987).

Event 3 has been correlated with the first record of *Globorotalia mediterranea* and *Globorotalia conomiozea* in the Mediterranean realm and so with the Tortonian /Messinian boundary (SIERRO 1985).

The more cemented layers (see Fig. 3-1 b) can be traced laterally to the northern end of the outcrop, where they can be seen to onlap the underlying paleorelief dug into the Paleozoic (Upper Devonian) rocks (see Fig. 3-1 a).

STOP 3-2. The Upper Tortonian Basal Unit in Villanueva del Río y Minas.

From Arroyo Galapagar drive to km 93.8 (C-431) and turn north for two kilometers along the road to Villanueva del Río y Minas and Constantina. Two outcrops are visited in the village of Villanueva del Río y Minas: STOP 3-2-A in the terrigenous Basal Unit and STOP 3-2-B in the transition from the basal to the marly unit.

STOP 3-2-A: the terrigenous Basal Unit

It is located in a hill (height 120 m) just opposite the market (Mercado de Abastos) of the village, near (southeast) the railway station. UTM coordinates: 261.2; 4171.6.

The substratum of these sediments is made up of Upper Devonian and Upper Carboniferous rocks. The latter were mined for coal until the early seventies.

The Neogene section is more than 45 m thick. Three intervals were distinguished for description.

(1) Intensely burrowed medium sands with thin layers of coarse to very coarse sands which usually are more cemented. There are also layers of microconglomerates (fine gravel). *Ophiomorpha* burrows are ubiquitous but horizontal galleries (most of the time related to *Ophiomorpha*) are dominant in the more cemented, coarser grained, layers (cf. m. 16 to 18). Marine fossils found in this interval include: Ostreids, Bivalves, abundant

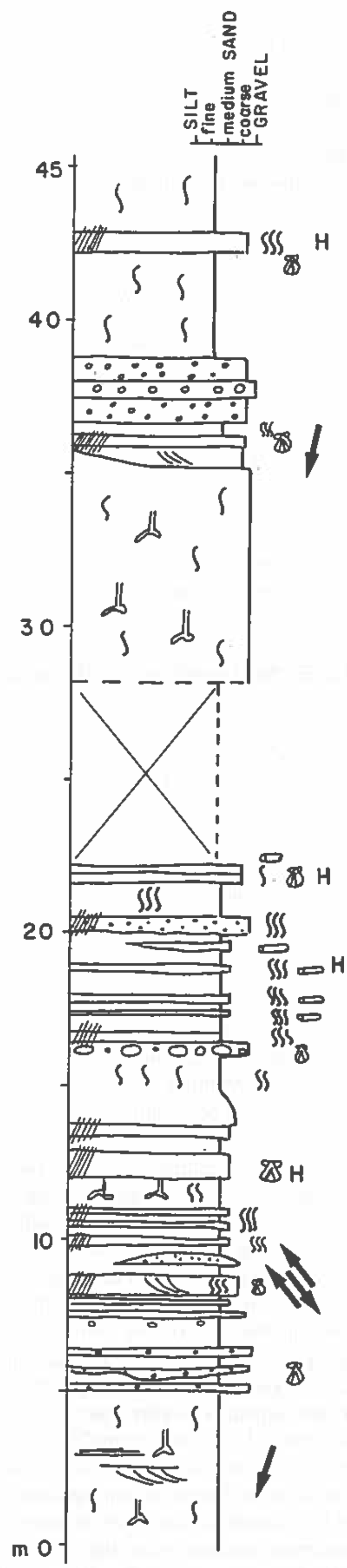

Fig. 3-2-A. Section of the Upper Tortonian Basal Unit in Villanueva del Río y Minas..

Cirripeds, and accumulations of *Heterostegina* (indicated by "H" in Fig. 3-2-A).

(2) Very coarse sands and conglomerates (fine gravel) with large *Ophiomorpha*. Shallow channels filled with cross-bedded coarse sands occur towards the top.

(3) The topmost part of the visible section is made up of intensely burrowed fine sands. A more cemented layer of coarse sand contains true accumulations of *Heterostegina*.

This section records deposition in shallow marine areas as demonstrated by the fossil content and *Ophiomorpha* burrows, with occasional input of terrestrial deposits in channels which are supposed to be subaqueous. Interval 2 represents a more important episode of continental (terrestrial) influx that was probably related to deposition in deltaic lobes of gravelly rivers. BORREGO & PENDON (1989) suggested that deltaic progradation took place in this area during Tortonian times based on the interpretation of such conglomerates as having been deposited by braided rivers.

STOP 3-2-B: the transition to the marly unit

It corresponds to a recent (1989-1990) excavation dug on the back side of the school. UTM coordinates: 261.2; 4170.9. The outcrop and the school are easily seen from a distance but going through the streets of the village is rather labyrinthine.

The obviously incomplete section allows us to visit just the uppermost part of the Basal Unit and the transition to the marls.

At the base, yellowish, burrowed fine to medium sands. Thin layers of dominantly glauconitic and siliciclastic grains alternate in these sands. There is an interbedded fine-grained conglomerate with Mollusk shells.

The limit between both units (cf m 3.9 to 4.1) is marked by a layer of glauconitic medium sands. A most characteristic feature is the existence of abundant bones of Vertebrates, Shark teeth, abundant Mollusk shells and many other fossil remains. Burrowing is very intense. There is some cross lamination pointing north and northwest.

The overlying marl unit extend up the slope of the hill behind the school for some meters. The lowermost part consists of rich glauconite and planktonic Foraminifera sandy-silts which gradually pass upwards to grey marls.

The described layer of accumulation of fossils is most typical of the transition between both units in the Guadalquivir Basin. In our opinion it might be related to a condensation layer generated after a widespread transgression above the shallow marine and nearshore deposits of the Basal Unit and before progradation of the deeper marine marls of

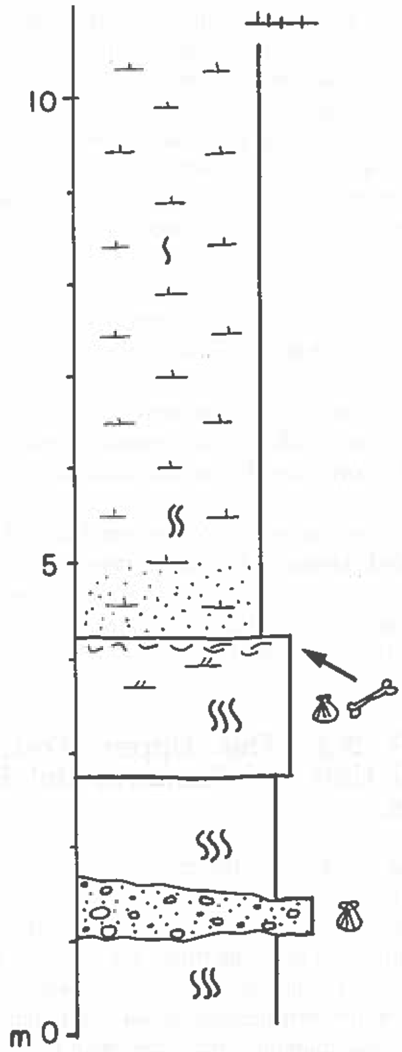

Fig. 3-2-B. The transition to the marly unit in the back of the School of Villanueva del Río y Minas.

Late Tortonian age (cf. STOP 2-2). Like in Montoro the age of maximum transgression is nearly 7 m.a. which strikingly coincides with a global sea level change (cycle 3.2 of HAQ *et al.*, op. cit.).

STOP 3-3. Upper Messinian marls and Calcarenites of Carmona.

There is no direct road from Villanueva del Río y Minas to Carmona. Thus, drive west along C-431 to Cantillana, Apeadero de Cantillana and Los Rosales; turn south. Total distance about 40 km. An easy alternative: drive east along C-431 to Lora del Río and turn south to C-432 in the direction of Carmona. Total distance about 46 km. Carmona is very close to the national road N-IV. Several exits around km 500 to 510 can be used to get to the city.

Several outcrops will be visited in Carmona along the Arroyo de Brenes and the cliffs of the calcarenite unit. All these locations are reached driving across Carmona to take the road to El Viso del Alcor. Leave the road at km 131.5 and go to an unpaved road heading towards the "Fábrica de Anisados La Purísima Concepción" and Cortijo de la Caridad. The rest of the STOPS are reached on foot.

STOP 3-3-A. Grey and blue marls of Late Messinian age in Arroyo de Brenes section.

Leave the car at the "Fábrica de Anisados" and follow the Brenes creek to the southeast. The exposure is very poor but along the thalveg of the creek, and also in some places of the margins, in situ marls are found. Consequently it is possible to sample a continuous section.

This section is interesting because it was proposed as the upper part of the stratotype for the Andalusian Stage (PERCONIG, 1974).

STOP 3-3-B. Fine sand and marls in the transition to the Carmona Calcarenite.

The exposure is located 100 m northwest of the "Fábrica de Anisados" and it can be recognized as the cliff separating the creek from the road Carmona - El Viso del Alcor.

A composite section was measured along the Arroyo de Brenes section including the top of the marls and the transition to the calcarenites (Fig. 3-3-B). Several informal, descriptive intervals were distinguished which will be described in ascending order.

(1) Grey and blue marls.

(2) Light yellow, calcareous *Ophiomorpha* sands. Abundant burrows of probable echinoids were recognized as well.

(3) Yellow calcarenites and grey-blue marls.

The upper part of the section was measured about 100 to 150 m to the south along the escarpment behind the "Fábrica de Anisados".

(4) Coarse to very coarse yellow calcarenites with crude parallel stratification. Large *Ophiomorpha* burrows (often more than 60 cm long).

(5) Alternating parallel-laminated layers (5 to 8 cm thick) and internally burrowed (mostly *Ophiomorpha*) decimetric layers (approximately 10 cm thick).

(6) Calcarenite. The internal structure, apart from the crude horizontal bedding, is hard to distinguish.

It is evident from regional dipping and topography that there is still a part of the section which was not measured in this particular place.

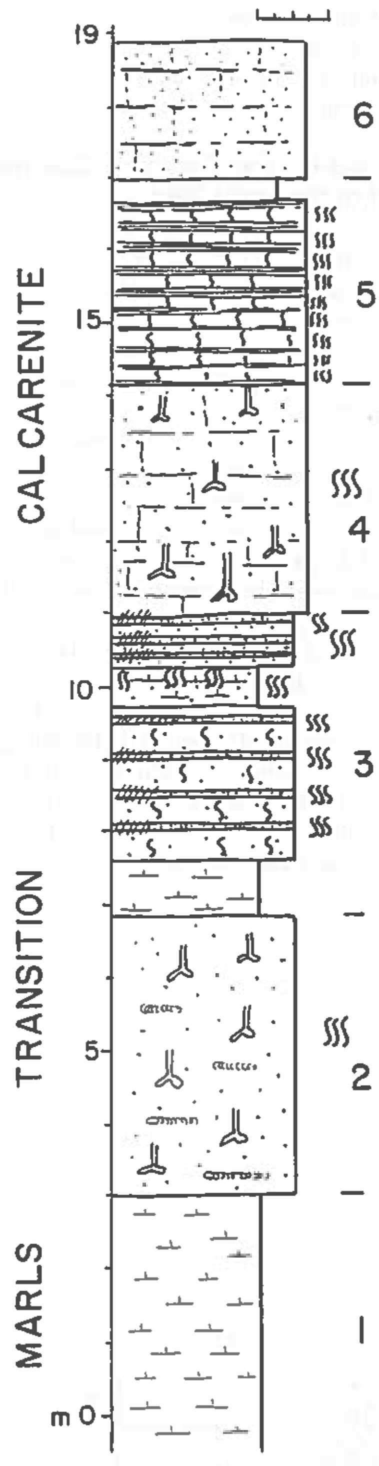

Fig. 3-3-B. Stratigraphic section of the uppermost marls (1) and the transition (2 and 3) to the calcarenite of Carmona (4, 5 and 6). Note that the section including 4, 5 and 6 was measured about 150 m to the south, in the escarpment behind the "Fábrica de Anisados".

Remains of these calcarenites are visible in some quarries located west of Carmona, but most of this unit is below the city. In the quarries, yellow calcarenites with Mollusk shells and foraminifers crop out.

The Carmona calcarenite is widely mined in quarries. It may be interesting to point out that these sands are used in bullfighting rings forming the arena which locals call albero.

STOP 3-3-C. The Carmona Calcarenite in the cliff of the sport field.

Following the cliff of the calcarenite to the southwest, there is a sport field near the Casas de Zabala. The Carmona Calcarenites are exposed along the escarpment where several sections were measured including the top of the previously described (Fig. 3-3-C).

Referring to the same number used in the previous outcrop, a brief description will follow.

(4) Coarse skeletal calcareous limestone (calcarenite). It is loosely cemented and intensely burrowed; large *Ophiomorpha* burrows, surpassing 40 cm, are most characteristic. Towards the upper part a faint parallel lamination is observed. The top is marked by a laterally continuous burrowed layer of Mollusk shells (*Ostrea*, etc).

(5) Coarse-grained calcarenite with abundant Molluscan remains. Crude parallel bedding marked by an alternation of burrowed and parallel-laminated layers. To the south, burrowing of a larger scale largely obliterates the internal structure. Such burrows are very similar to those found in Arroyo Galapagar, visible thanks to differential cementation. They occur as upside down cones with dimensions of 30 x 30 cm.

(6) Calcarenite layer. Usually they occur as massive looking but, in some places, the internal structure was seen to consist of horizontal bedding with a thickening upwards trend.

STOP 3-3-D. The Carmona Calcarenite along the cliff of Ermita de Santa Lucía and the radio aerials.

Following the escarpment to the northeast, until reaching a group of three high radio & telephone aerials, some additional observations of the Carmona calcarenite can be made (but unfortunately in a waste pool).

The previously described intervals are exposed.

(4) Yellowish, coarse calcarenite crudely bedded in layers 10 cm thick. Those layers integrate a large scale cross bedding gently dipping in direction N320E. Abundant large *Ophiomorpha* burrows strongly shade the internal structure. A faint coarsening upwards trend is observed.

(5) Yellowish, crudely bedded coarse calcarenite. Loose cementation except for the topmost layer which is cemented. Large scale cross bedding dipping to the west. Intense

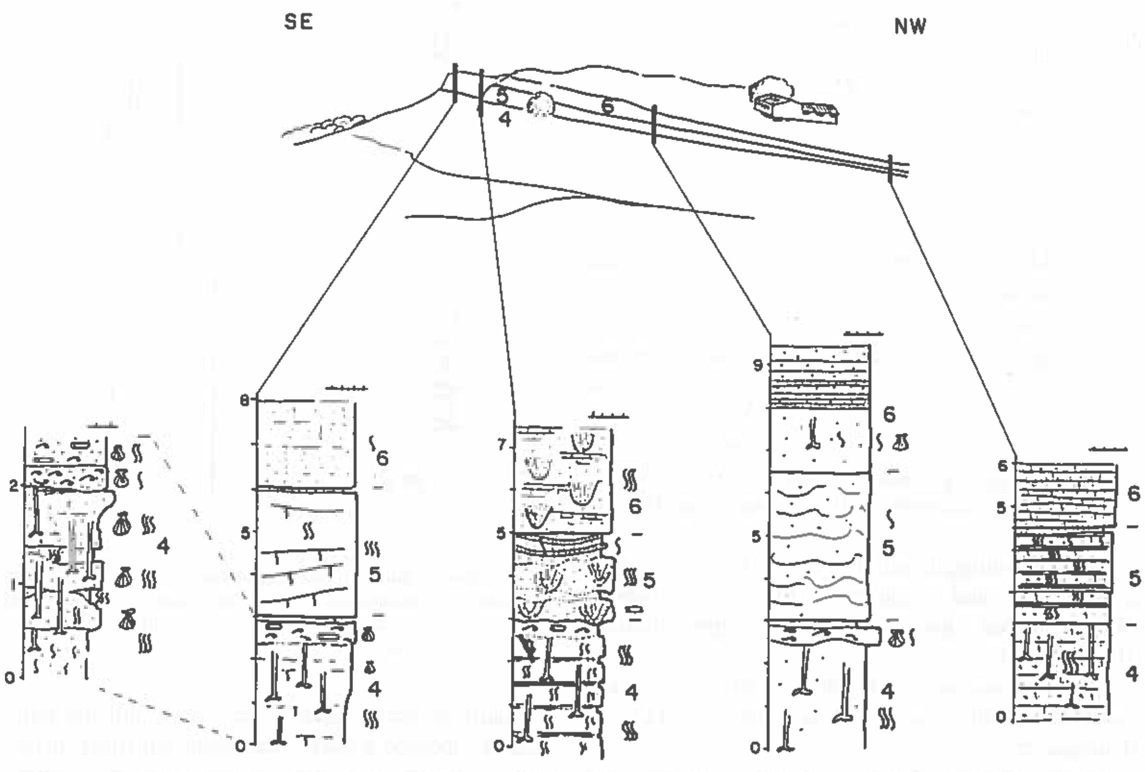

Fig. 3-3-C. Panorama of the escarpment near the sport field, with selected sections measured along it. Same numbers as in previous figure and text. Note that the detailed section pictured to the left of the figure corresponds to a spot located between the two sections located further to the south..

burrowing, mostly of the *Ophiomorpha* type, following the large scale structure.

(6) Yellowish, coarse calcarenite. Intense burrowing and deformation by water escape badly obliterate the internal structure of the lower half. However, a gentle cross bedding towards the west is appreciable.Locally there is some brecciation. In the upper part of this interval the layers are more defined, about 10 cm thick, with *Ophiomorpha* burrows.

Interval 6 was continued below the village but we could not make accurate observations.

Interpretation.

According to the previous data, we think that the Carmona Calcarenite records the progradation of a carbonate talus fed by mostly skeletal fragments derived from a carbonate shelf located to the east-southeast. In our opinion, this progradation directed to the north can be related to the growth and northward displacement of the thick olistrostrome rooted in the Betics at the southern margin of the basin (cf STOP 2-4).

Underlying the sands and calcarenites described here more than 130 m of marls were sampled for micropaleontological studies. This is a thick, very monotonous series of blue marls with abundant Benthic Foraminifera which constitute more than 80 percent of the Foraminifers. *Bolivina* and *Uvigerina* are very abundant. BERGGREN and HAQ (1976) studied the paleoecological and paleobathymetric characteristics of this microfauna finding that a gradual regression takes place from bottom to top.

The marls probably were deposited on a steep slope at high sedimentation rates according to the short time interval recorded in the section. The base of the section is later than event 4 (change from sinistral to dextral in the *N. acostaensis* group) and 5 (reduction of the *Globorotalia miotumida* group) and typical sinistral

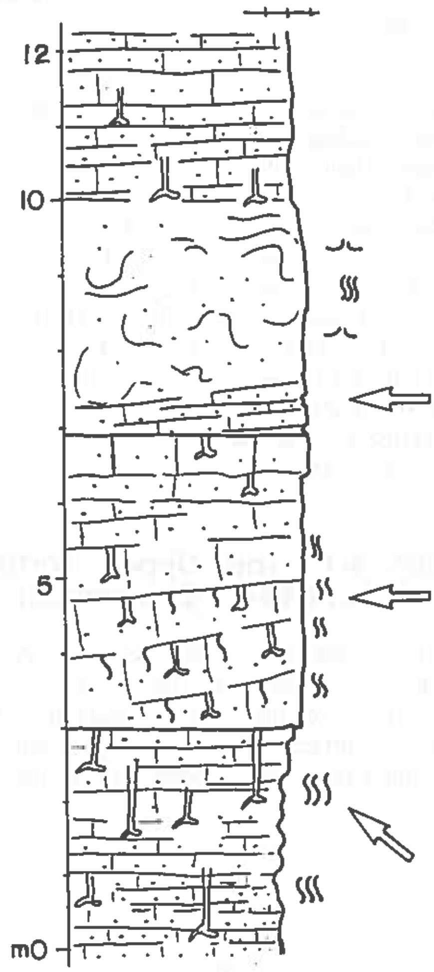

Fig. 3-3-D. Section of the Carmona Calcarenite in the escarpment, below the group of aerials.

Globorotalia margaritae is first recorded towards the uppermost part of marls. The absence of *E. berggrenii* in the upper sands and calcarenite layers is not significant because of its coincidence with the lithological change.

FOURTH DAY

A cross-section of the Upper Neogene deposits of the Guadalquivir Basin between Niebla and Moguer (Huelva Province) is presented in four stops (Fig. 4-1).

The Upper Tortonian Niebla Calcarenite (Basal Unit) is visited in STOP 4-1. The Upper Tortonian and Messinian Gibraleón Clays are partly seen in STOPS 4-2 and 4-4. The Pliocene Huelva Sands are found in STOPS 4- 2, 4-3 and 4-4.

STOPS 4-1 (Niebla) and 4-3 are located on map 10-40 (982) of the MTN.

STOPS 4-2 and 4-4 are located on map 10-41 (1000) of the MTN.

STOP 4-1. The Upper Tortonian Basal Unit (Niebla Calcarenite)

Drive to km 60.1 of highway A-49 (Autopista del Quinto Centenario) and take the exit to Niebla. Go to km 1.1 of that road and leave the car in a large, flat surface between a group of eucalyptus trees and a large quarry. Several interesting points are visited in STOP 4-1.

STOP 4-1-A. General.

This stop is in the same place where you left the car. A general picture and panoramic view of the various units present in the area of Niebla is shown from this point. From the panorama looking south one can see STOP 4-2. STOP 4-3 is located behind the Cabezo (hill) de San Cristóbal.

The observer is standing on a flat, horizontal surface at the top of the Upper Tortonian Niebla Calcarenite. This lithostratigraphic unit, as the general stratigraphy of the region, was initially described by VIGUIER (1974), and was formally defined by CIVIS *et al.* (1987), completed by MAYORAL & PENDO

The Niebla Calcarenite is paraconformably covered by the bluish marls of the Gibraleón Clays (also a lithostratigraphic unit formally defined by CIVIS *et al.*, 1987). The oldest deposits of the Gibraleón Clays in the present section could be of Latest Messinian or Earliest Pliocene age. However, in many other sections measured in the

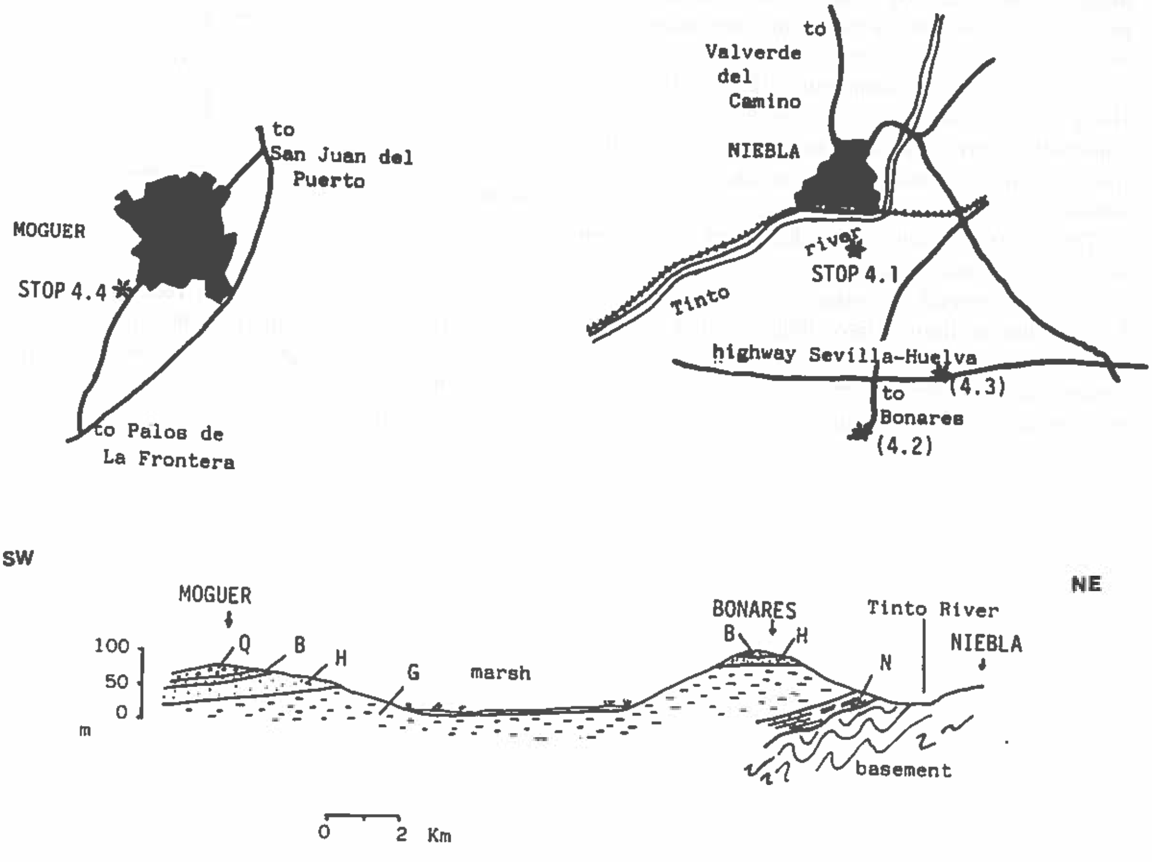

Fig. 4-1.- Location map of stops near Niebla and Moguer. Below, geological cross-section between these localities. Significant abbreviations: (N), Niebla Calcarenite; (G), Gibraleón Clays; (H), Huelva Sands; (B), Bonares Sands; (Q), Plio-Quaternary materials.

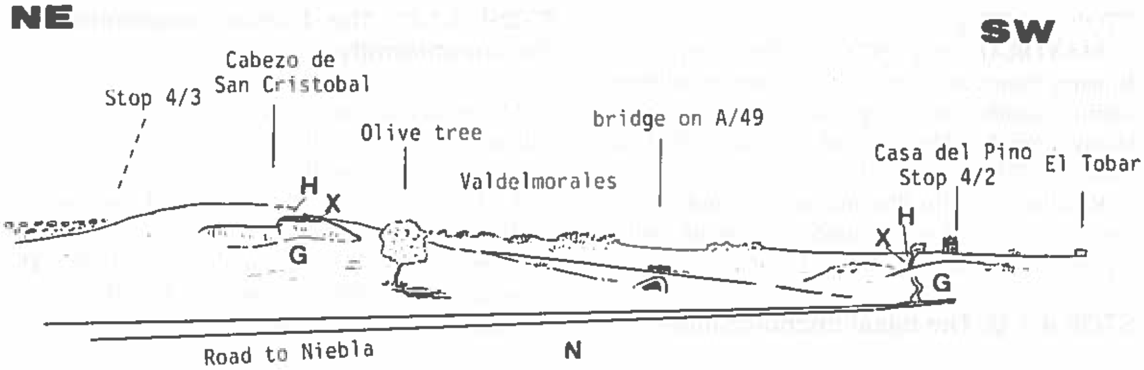

Fig. 4-1-A. Panoramic view looking south from km 1.1 on the road Niebla-Bonares. Significant abbreviations: (N), Niebla Calcarenite; (G), Gibraleón Clays; (X), Glauconite silts; (H), Huelva Sands. STOP 4-2 is situated below the farm Casa del Pino. STOP 4-3 lays behind San Cristóbal hill.

region of Huelva (Gibraleón, Trigueros...), even to the north of Niebla, the marls were dated as Late Tortonian and Messinian (SIERRO, 1984, 1985; FLORES, 1985; FLORES & SIERRO, 1987) although a break in sedimentation has been widely acknowledged inside the Gibraleón Clays (VIGUIER, 1974; MARTINEZ DEL OLMO *et al.*, 1984). This implies that in the section of Niebla-San Cristóbal hill there is a major hiatus separating the Niebla Calcarenites and the topmost part of the Gibraleón Clays. The hiatus is not well observed due to poor outcrops. The only proof is the absence of Niebla calcarenite and the occurrence of ferruginous surfaces between the pre-Neogene substratum and the blue marls in the Piedra del Rayo Quarry (STOP 4-1-F).

Above the blue marls a fossiliferous sandy unit appears. It was defined by CIVIS *et al.* (1987) as Huelva Sands and dated as Lower Pliocene. The limit of Gibraleón Clays and Huelva Sands is easily recognized by a prominent 2 to 3 m thick layer of glauconite silts visible at the top of the quarry of San Cristóbal Hill and below Casa del Pino (see also STOP 4-2). These silts are a good guide-layer in the region. It is interesting to note that the glauconite silts probably were deposited near the Mio-Pliocene boundary. A more detailed account of this glauconite-rich layer is presented in

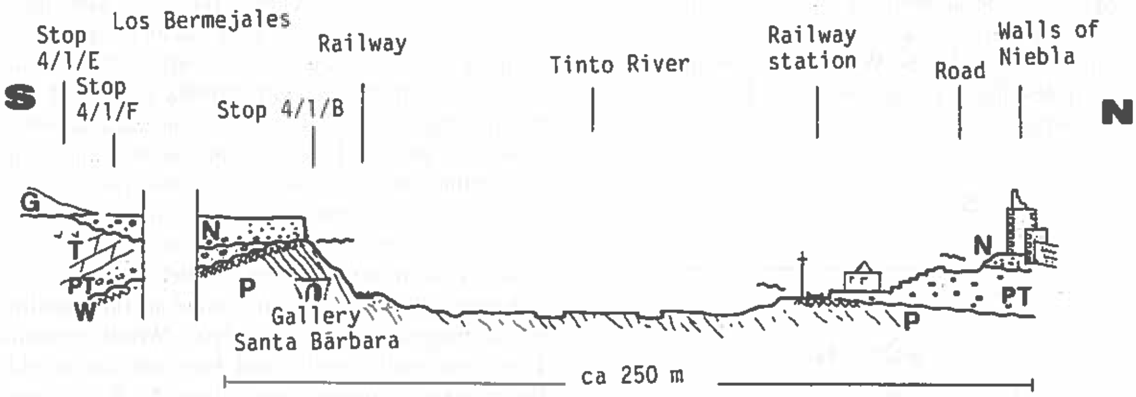

Fig. 4-1-B. (a) Cross section across the Tinto River at Niebla. (P), Paleozoic shales and quartzites; (PT), Permo-Triassic conglomerates and shales; (T), Triassic dolostones and volcanic rocks; (N), Niebla Calcarenite. The section has been completed by adding a sketch of the mutual relationships of units in the area of Los Bermejales (about 300 m to the south, see STOPS 4-1-E and 4-1-F). Needless to say this extended section is not visible from our present location in STOP 4-1- B.

STOP 4- 4 (Moguer).

MAYORAL & PENDON (1987) defined the Bonares Sands as a unit of fine, poor fossilifeorus, marine sands overlying the rich fossiliferous Huelva Sands. The age of this unit is Lower Pliocene (SIERRO, 1984).

Reddish Plio-Pleistocene sands and conglomerates of well-rounded quartzite pebbles top most of the hills in the background.

STOP 4-1-B. The basal unconformities.

Walk about 300 m to the west, passing the far end of the quarry and the mine gallery "Pozo Santa Bárbara, 1959. Río Tinto".

You can see that the Niebla Calcarenite is thinning down and that it rests unconformably on top of almost vertical strata of Carboniferous age (the so-called Culm Group). Proceeding farther west, a conglomeratic unit of Permo-Triassic age appears in between.

From this location, a panoramic view across the Tinto River allows us to distinguish the steep-inclined Paleozoic shales and quartzites (turbidite) beds, the almost-horizontal (Permo?-) Triassic conglomerates and the horizontal (actually it dips a few degrees to the south) Niebla Calcarenite. These units are easily recognized in the right bank of the Tinto River, below the walls of Niebla.

In detail, a close up of the unconformity displays the weathered top of the irregular surface of the Paleozoic rocks and the basal conglomerate of the Neogene Units. Walking further to the west a well developed conglomerate of Triassic age can be observed.

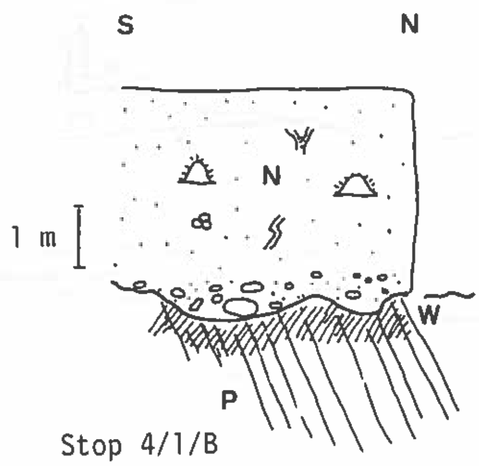

Fig. 4-1-B. (b) Detail of the unconformity below the Niebla Calcarenite (N). The erosional surface of the Paleozoic rocks (P) was affected by intense pre-Neogene weathering (W). Note the conglomeratic nature of the lower part of the Niebla Calcarenite.

STOP 4-1-C. The Niebla calcarenite near the unconformity.

Move back to the east via the top of the Niebla calcarenite until finding the steep cliff of the quarry. There, locate the small stairs carved in the rock. Go down and you will find the ancient roofless dome-shaped quarry.

Here the Niebla calcarenite is visible. The exposure is equivalent to interval 3 of the section recorded in STOP 4-3-D. Note the large *Clypeaster*.

It must be emphasized that this outcrop is essentially at the same height as the Paleozoic rock visited in 4-1-B. This means that the Niebla Calcarenite lies on top of an irregular erosional surface and also that the essentially flat intervals distinguished inside it wedge out laterally against the paleorelief.

STOP 4-1-D. A section of the Niebla calcarenite in the eastern side of the quarry.

Walk towards stop 4-1-A along the large quarry; when you reach the eastern end you will find a major depression in the wall. Here, a detailed section was measured.

Observation of the weathered wall is not very good due to present day cementation triggered by settling and wetting of "portland" cement dust escaping from the factory. By now you have probably noted the large grey factory, approx. 2 hundred meters away to the north, which is in complete disharmony with Niebla's aura of the Middle Ages. Thus we have concentrated on a newly dug profile. Five intervals are recognized in the section. They are traced along the wall.

The bottom of the section does not expose the basal unconformity; however we believe that it is probably not more than 2 or 3 m below.

Almost all the sediments found in this locality are of biogenic (skeletal) origin. Whole remains (Bryozoan balls, shells) and bioclasts are found. These rocks contain less than 5 % of non carbonate grains: fragments of shale and igneous rocks, quartz and glauconite were recognized.

The dominant grain size is coarse sand and gravel depending on the size of the accumulated skeletal debris. Some layers are easily traced because they are cemented and protrude from the wall.

Interval 1 consists of skeletal calcarenites, very rich in Red Algae, both encrusting and branching Rhodoliths, Bryozoans, fragmented large and small Ostreids, *Spondylus* and Sponge-bored Pectinids (*Chlamys latissima*).

The more cemented interval 2 is marked by an increase of red algae.

Interval 3, about 5 m thick, is made up of loosely cemented, coarse, bioclastic calcarenite. A most peculiar feature of this interval is the existence of vertical veins of calcite cement. Towards the upper part (meter 8.5 to 10) Bryozoan balls concentrate in layers. The lowermost of these (meter 8.5) includes balls of Bryozoans, more than 5 cm in diameter. There is also a gradual increase of algae and cementation towards the upper part.

Macrofossils include abundant *Clypeaster*, large Pectinids, Ostreids and fragments of many other Bivalves.

Interval 4 is characterized by an alternation of irregular layers of loosely cemented coarse bioclastic calcarenites and layers of algal limestone. These more cemented limestone layers contain Red Algae and Bryozoans (often forming Bryozoan balls), *Clypeaster* and Bivalves.

In addition to these general features, the more continuous limestone layers (which are those found at the bottom and towards the top of interval 4) yielded Cirripeds encrusted by red algae, *Lutraria* and *Modiolus*. The more irregular middle layer of limestone is characterized by an accumulation of gastropods (only molds preserved) and several families of Bivalves.

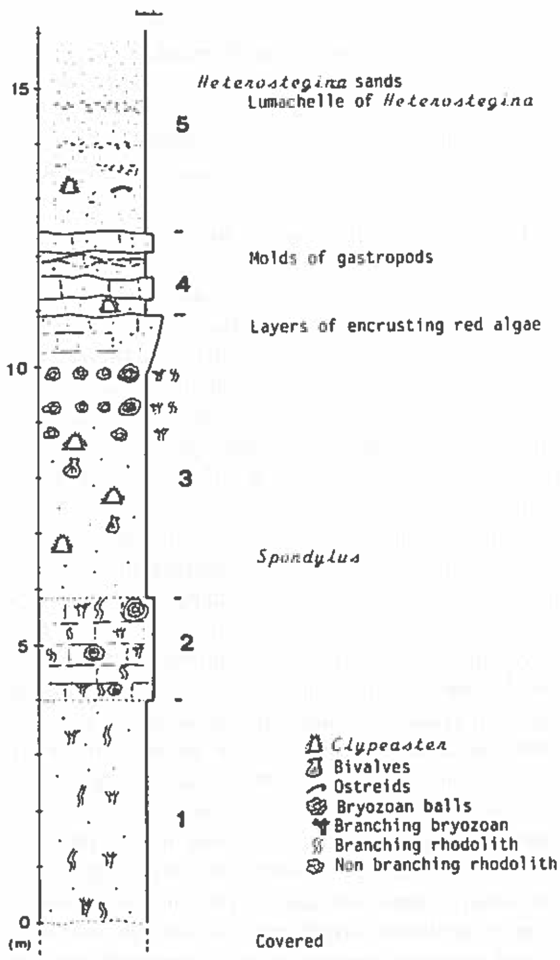

Fig. 4-1-D. Stratigraphic section of the Niebla calcarenite on the eastern side of the quarry south of the Tinto River. Figures indicate intervals described in text.

Interval 5 consists of coarse grained calcarenite with *Heterostegina*.

Some layers of accumulation of *Heterostegina* (cf. m 14 and 14.8) are real lumachelles.

The described section records deposition on a shallow sea with waves and currents able to move and accumulate skeletal sands.

Further information.

Complementary data can be drawn from the quarries dug north of Niebla. To reach these points drive 1.5 km on the road from Niebla to Valverde del Camino; after passing the cemetery the entrances to the quarries are found east and west of the road; only the western quarry is always open. There, intervals 1, 2, 3, and parts of 4 are recognized, but 3 and 4 are poorly exposed due to intense karstification and development of solution pipes filled by the overlying red deposits.

The lowermost part of the section, exposed at the floor of the quarry and also visible in large blocks left behind, is made up of calcarenites with plenty of molds of large articulated *Isognomon* and a rich accompanying fauna of Ostreids, Pectinids (*Pecten* spp., *Chlamys multistriata*, *Ch. latissima*), *Modiolus* and molds of Cardiids, Venerids, *Lutraria*, large *Glycymeris*, Scaphopods, Vermetid gastropods and Turritellids. Several branching, encrusting and Bryozoa balls, *Clypeaster*, Cirripeds and Clionid boring Sponge are also present. We assume that the layers of *Isognomon* represent the lowermost part of the Niebla Calcarenite and that the basal unconformity is immediately below the floor of the quarry. This assumption is supported by the fact that these quarries are dug as deep as possible to extract calcarenite, because the underlying substratum is unsuitable for the cement factory.

STOP 4-1-E. Los Bermejales.

From STOP 4-1-D. move towards the South around 500 m in the direction of the olive grove, about 100 to 150 m west of the second (southern) pole supporting electric wires. We keep to the west side of the Niebla-Bonares road. UTM coordinates: 705.5; 4136.7.

Here the unpaved road runs over conglomeratic calcarenites. Note boring by lithophagous Bivalves and *Cliona* in boulders and pebbles of the conglomerates. Encrusting serpulids were found in one of the trenches found here, a short distance to the northeast, forming encrusting laminae several decimeters long and about 1 cm thick.

Proceed further (about 200 m) to the west along

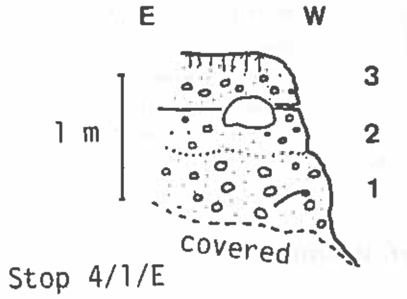

Fig. 4-1-E. Stratigraphic section of the Niebla calcarenite south of Los Bermejales. Note the conglomeratic nature of these deposits. Figures indicate intervals described in text.

the track, just north of the olive trees. Look around and you will find some minor trenches and small quarries.

These excavations allow us to observe the conglomeratic nature (mean grain size 4 to 5 cm) of the Niebla calcarenite and the coarse grained pebbles, boulders and large Ostreids.

Three layers with Ostreid remains can be distinguished. From bottom to top:

(1) Fine grained conglomerate; maximum diameter of pebbles 15 cm. Large Ostreids. (2) Matrix supported bimodal conglomerates. The coarser population includes small boulders up to 30 cm in diameter. The finer population, forming the matrix, is very fine gravel. Many of these clasts are bored. (3) Fine grained conglomerate with matrix of coarse sand; maximum grain size of pebbles: 6 cm.

STOP 4-1-F. The quarry of Piedra del Rayo (Arroyo de Carrascales).

In this location the abrupt paleorelief topping the Middle-Upper Triassic carbonate and volcanic rocks (with nice pillow-lavas) is exposed. Here the absence of calcarenites should be noted. Laterally, marls overlie the Triassic rocks. An interesting remark is the existence of a ferruginous surface (hard ground) with shallow-water fauna of *Lithophaga*, *Spondylus crassicosta*, *Ostrea lamellosa*, *Pecten*, *Chlamys multistriata*, *Ch. scabrella*, and *Ch. latissima*. In the marls immediately above this surface a deeper macrofauna characterized by abundant *Neopycnodonte cochlear* is found (SIERRO *et al.*, 1983). The abundant presence of typical *Globorotalia margaritae* without other keeled Globorotaliids, and the dextral coiling of the *Neogloboquadrina acostaensis* group suggests a Latest Messinian or Earliest Pliocene age for the basal part of the marls.

STOP 4-2. The Pliocene Huelva Sands in Casa del Pino.

Drive along the Niebla-Bonares road to the top of the hill (height 131 m) and the Casa del Pino (Pine tree house) already seen in the background of the panoramic view (STOP 4-1-A). Leave the car in the entrance to the unpaved road leading to the house (about km 4) and walk 100 m to km 3.9 along the road to reach the section.

The stratigraphic section allows you to observe the silty upper part of the Gibraleón Clays, the glauconite silts and the Huelva Sands. These are supposed to be of shallow marine origin due to the coarse grain size, fossil content and burrowing.

Additional proof for a shallow marine origin of the glauconite are: (a) presence of shallow marine Benthic Foraminifers; (b) coarsening of grain size as compared to the underlying clay and silts; (c) abundance of large sized *Ophiomorpha* with galleries more than 2 to 4 cm wide; (d) abundance of *Venus* and *Pelecyora* which are typical of shallow waters; (e) abundance of large Cirripeds.

Focusing the observation in the Huelva Sands, several layers of accumulation of Mollusk shells are seen along the walls of the roadcut, separated by thicker burrowed layers of fine sand (the so-called "interlayers") where only scarce shells are found. Intense burrowing completely obliterated the original hydrodynamic primary sedimentary structures.

If layers and interlayers are considered as a whole, they integrate fining upwards sequences separated by erosive surfaces located at the bottom of the fossiliferous beds. Burrowing increases upwards; in our opinion the diffuse galleries and "spreiten" of the middle part of the sequence can be related to Echinoid burrows, whereas the intense burrowing of the upper part is clearly of the *Ophiomorpha* type with local fish-made depressions (cf. STOP 4-4).

Although little variation in the abundance of the marine groups exists, the fossiliferous layers include very abundant remains of Bivalves (Ostreids, Pectinids, Venerids, Cardiids and Glycymerids), Gastropods (Naticids, Ringiculids and Nassarids) and Scaphopods (Dentalids). Shells are well preserved with various stages of growth, showing delicate structures, not abraded; however they occur in a disorganized and disarticulate manner. Some of the shells have been clearly reworked but others occur almost in life position with both valves closed. All the arguments previously mentioned and the presence of the same type of sediment inside and outside the articulate closed Bivalves suggest a short transport for the Mollusca shells. Layers I, II and III (cf. meters 1, 3.8 and 6.6 respectively, Fig. 4-2) were sampled for detailed paleontological and statistical studies.

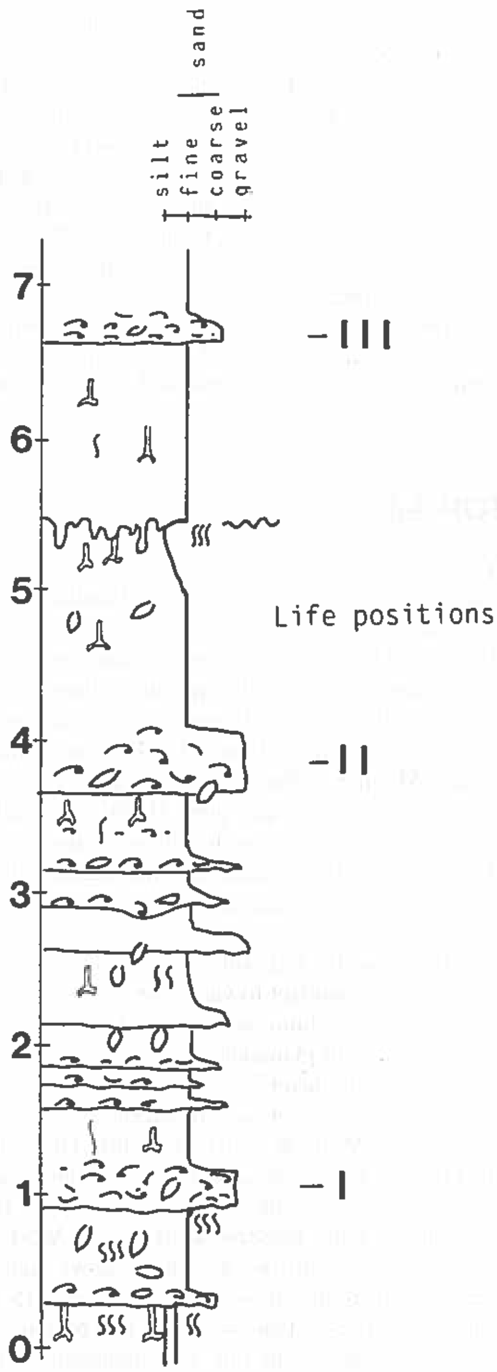

Fig. 4-2. Stratigraphic section of Casa del Pino (km 4, road Niebla - Bonares) the silty upper part of the Gibraleón Clays, the glauconite sands and the Huelva Sands. Layers I, II and III (cf. meters 1, 3.8 and 6.6 respectively) were sampled for detailed paleontologic and statistic studies.

The so-called interlayers overlie the former with a gradual transition in between. These are fine-grained yellowish sands with scattered remains of usually large-sized Mollusks (*Panopea*, *Lutraria*, *Pelecyora*...) which typically have their valves closed and appear in life position or only slightly removed. Delicate shells of *Amussium* are frequent. Accumulations of fragmented Mollusk shells are found in the uppermost part of these sandy interlayers in association with burrows attributed to echinoids and fishes (cf. m 3 and 5, Fig. 4-2). These punctual accumulations appear in the immediate vicinity of delicate well-preserved Mollusk shells. In our opinion this is due to the activity of the shell-fragmenting predators and necrophagous.

Interpretation

All the described features can be integrated in a single sedimentary model deduced from detailed sedimentological and paleoecological studies (DABRIO *et al.*, 1988). These layers are due to erosional modifications of a sandy-silty bottom colonized by diverse communities of life forms, under the high energy conditions related to repeated storm surges entering the broad shallow-marine Guadalquivir bay during the Pliocene era. → the bottom was below the (normal) wave base level, and above the storm base level

The essential variables of the sedimentary model are:

(a) The existence of various populations characteristic of sandy-silty bottoms living next to each other according to their characteristic microenvironments, extended to some distance under the water-sediment interface. There, various types of organisms lived according to their particular capacity of adaptation. Those microenvironments occupy different places in the studied sequences and they can be recognized from the ecologic features of their inhabitants. Generally, infaunal Bivalves are more abundant than the epifaunal ones.

(b) The changing position of the wave base in response to the energy conditions imposed by alternating fair and stormy weather. Fair weather means essentially quiet, tranquil sea bottom. Stormy weather represents remotion to a variable degree (and depth below the interface) according to the intensity of the wave-induced surges on the bottom. In some instances a large part of the bottom, the uppermost part of the underlying sediments, and the living communities included in these uppermost centimeters, or even decimeters of sediment, can be removed and redeposited under high-energy conditions.

(c) Erosion by waves extends some distance below the water-sediment interface, destroying a part of the sedimentary profile (generated during fair weather or gentler storms) and also the populations which colonized these deposits. Accumulation of these removed remains will generate layers, whereas the preserved horizons of colonizations will remain as interlayers. It is obvious that the preservation potential for a particular deposit, or in situ fossil, depends on how far it is placed below the water-sediment interface as compared to the depth reached by wave-induced erosion.

The proposed succession of events is: colonization and peaceful life → storm (local catastrophe) → redeposit, rapid sedimentation after storm and escape from the removed mass (readaptation means success and life; failure means death) → burrowing and necrophagous activity → recolonization and peaceful life.

The biocoenoses SFBC of PERES & PICARD (1964) is the best represented: *Glycymeris insubricus*, *Tellina planata*, *Neverita josephinia* and *Acteon tornatilis*, exclusive species of this biocoenoses, are present. Most of Bivalves are endobiont-suspension feeders. Carnivorous Naticidae (note the "O" bored Bivalve and Gastropod shells), Crustaceans (note the probable Decapod-attack signals in Mollusks), Echinoids and remains of fish (vertebra, otoliths and *Isurus* and *Rhinoptera* teeth) are frequent.

STOP 4-3.

The Pliocene Huelva Sands in the highway roadcut (Cabezo de la Costilla).

There are two ways to this stop. Drive to km 56.6 of highway A-49 and look for the northern roadcut. As stopping there might be dangerous (in addition to illegal), an alternative way is offered using the road Niebla-Rociana del Condado. The road leaves from a cross road below the eucalyptus trees cited in STOP 4-1 (km 0.9 of the road Niebla- Bonares-Moguer). Drive to km 14.4 and turn northeast via an unpaved road which goes to the side of the highway where you can leave the car and, carefully, cross the highway. UTM coordinates: 709.6; 4135.8.

This is a wonderful outcrop submitted to rapid decaying by solution due to acid rain after exposure of the roadcut to open air and forced growth of vegetation aimed to stop erosion of the slope. The aim of the stop is to observe: (a) burrowing both *Ophiomorpha* and caused by the infaunal benthic communities of Bivalves (and Echinoids?); (b) various types of more or less specific-dominated accumulations of shells.

Mollusk shells are abundant: 1200 Bivalves (47 species) and 850 Gastropods (42 species) were collected from 4 Kg. of sediment from the most fossiliferous levels. In other locations of the same formation certain variations in the abundance of Mollusks were found: in the "Palma del Condado" (northeast of Niebla) 3380 Bivalves (68 species), 820 Gastropods (71 species) and 115 Scaphopods (3 species) were collected from 18 Kg. of sediment. Whereas for the same weight of sediment 7150 Bivalves (71 species), 1952 Gastropods (67 species) and 520 Scaphopods (4 species) were found in Moguer (southwest of Niebla) (CASTAÑO *et al.*, 1988).

This section is probably a shallower facies than that of Casa del Pino, and the "layers" are often amalgamated. There are some "layers" which consist almost exclusively of *Acanthocardia paucicostata*, or *Glycymeris insubricus* or *Spisula subtruncata*. Note the life position of *Panopea glycymeris* and *Pelecyora brochii*. In the lower part, fine-grained grey sands with abundant Scaphopods and *Venus multilamella* can be seen.

Additional data on these Mollusks can be found in ANDRES (1982) and GONZALEZ DELGADO (1983).

STOP 4-4.

The top of the Gibraleón Clays and the glauconitic sands at the base of the Huelva Sands in Moguer.

Drive to Moguer via Bonares (about 20 km to the southwest) and pass through the village along the road to Palos de la Frontera to the southern entrance to the village (km 7.5). Turn north and approach Moguer. After crossing a creek (Arroyo de Montemayor) the road goes slightly upwards. Locate a roadcut just before reaching the houses.

The ten meter-thick succession has been divided into four descriptive intervals. In ascending order, these are:

(1) Fine sands and silts with *Ophiomorpha* burrows, more abundant towards the top.

(2) Fine to medium sand with *Ophiomorpha burrows* filled with glauconitic silts clearly derived from the overlying layer 3.

(3) After a layer of accumulation of skeletal debris (mostly Mollusk shells) including large and small *Ostrea*, *Amussium* and molds of Veneridae, there are greenish, glauconite silts. Many of the large *Amussium* still preserve both valves. Most of the abundant burrowing are bowl-shaped depressions of about 20 to 30 cm wide and 15 to 25 cm deep. These depressions at the bottom of the shallow sea were filled up with glauconite silts. Avalanching from the edges of the small pit dug by the animal produced a sort of cross bedding or cross lamination which has nothing to do with "true" current-induced bedforms. We think that these holes were dug by fish, thus we assume that they represent dwelling places.

There are two layers of accumulation of shells towards the top. The lower one yielded small *Ostrea*, *Amussium* and molds of Veneridae. However the upper layer (located at the limit with interval 4) only yielded *Amussium*.

(4) Yellowish, calcareous, skeletal fine sands. Accumulation of carbonate nodules which we assume to be the remainders of layers of

accumulation of shells destroyed after subaerial exposure and solution. No glauconite was observed.

The described section provides you with a detailed observation of the uppermost part of the grey-blue Gibraleón clays (1 and 2), the glauconite silts (3) and the base of the Huelva Sands (4).

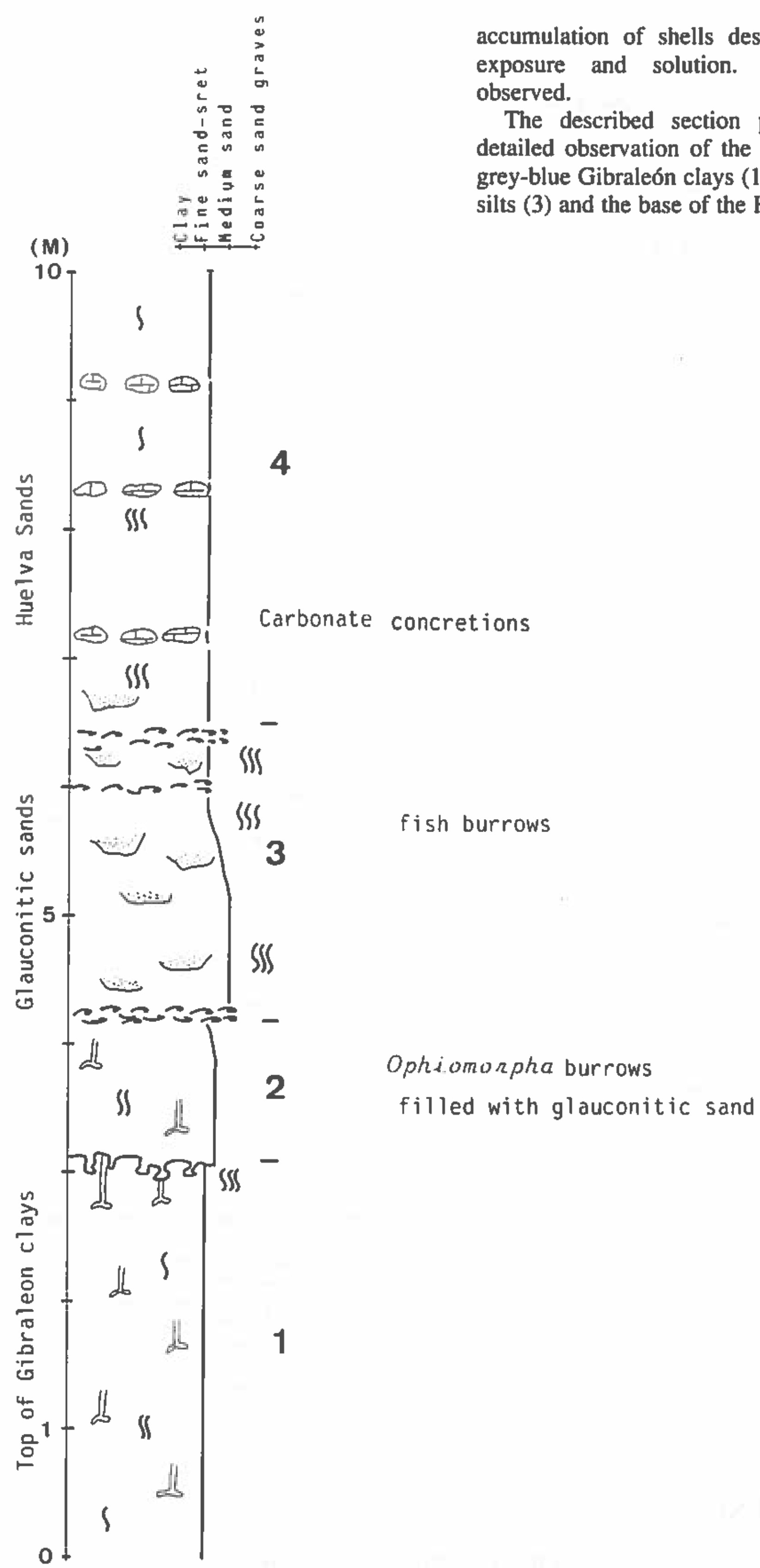

Fig. 4-4.- Stratigraphic section of Moguer. The uppermost silty to sandy part of the Gibraleón Clays 1 & 2), the whole Glauconite silts (3) and the lowermost part of the Huelva sands (4) are exposed.

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