

Neogene and Quaternary fan-delta deposits in southeastern Spain. Field Guide

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CONTENTS

INTRODUCTION

Towards a definition of fan delta

Do we actually know what a fan delta is?

Geodynamic aspects of fan-delta deposits: application to the Neogene Betic basins

Reactivation of the N 150° E faults as dextral faults

FIRST DAY: fan deltas of the Fortuna Basin

General

The Tortonian fan deltas of the Fortuna Basin

STOP 1-1: The Tortonian fan delta of La Umbría

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General

Purpose

Description

STOP 1-2: The fan delta of El Montañal

General

STOP 1-2-1: The quarry at Cerro Victor

Purpose

Description

STOP 1-2-2: Panorama from Canteras Hill

Purpose

Description

SECOND DAY: Late Tortonian fan deltas in the Basin of Murcia-Carrascoy

General

The tectonic control (first order megasequences)

Sedimentary model of fan deltas

Second order megasequences (decametric scale)

STOP 2 - 1: Panorama from Sierra del Puerto

Purpose

Description

STOP 2 - 2: the boundary of the basin and the lower megasequences

Purpose

Description

STOP 2 - 3: fan-delta front and slope facies

Purpose

Description

Facies associations

THIRD DAY: Pleistocene fan deltas in the Lower Segura River Basin

General

STOP 3 - 1 A: The Segura Conglomerates at La Zeneta

Purpose

Description

STOP 3 - 1 B: Observations in the way to Rojales (Section of Hurchillo)

STOP 3 - 2: The Segura Conglomerates at Rojales

Purpose

Description

FOURTH DAY: Pleistocene fan deltas in the Basin of Cope

General

Controls of sedimentation

Tectonics (fault movements)

Eustatic changes of sea level

Dynamics of fan deltas

STOP 4 - 1: Casa de Renco

Purpose

Description

Marine fan-delta deposits (coastal and sublittoral highstand deposits)

Subaerial facies (lowstand deposits)

STOP 4 - 2: Rambla del Garrotillo

Purpose

STOP 4 - 2 - 1

Description

Channelized conglomerate facies
Disorganized conglomerate facies
Sandstone facies
Red mudstone facies (M)

Facies relationships

STOP 4 - 2 - 2

Description

ABSTRACT

A guided field-trip through the basins of Fortuna, Carrascoy-Murcia, Lower Segura and Cope, with detailed sections, interpretation of rock bodies and sedimentary models.

Key words: Fan deltas, field guide, Neogene, Quaternary, Southeastern Spain

RESUMEN

Excursión guiada a las cuencas de Fortuna, Carrascoy-Murcia, Bajo Segura y Cope, con secciones detalladas, interpretación de los cuerpos rocosos y modelos sedimentarios.

Palabras clave: fan deltas, Guía de campo, Neógeno, Cuaternario, sureste de España.

INTRODUCTION

Towards a definition of fan delta

Holmes (1965) defined a fan delta as an alluvial fan prograding directly into a standing body of water from an adjacent highland.

After the discovery of hydrocarbons in sediments of assumed fan delta, or fan delta-related origin, a wave of interest was raised and a relatively large number of papers have been published about this subject. As it often happens, this generated much confusion about the precise meaning of the term fan delta.

Nemec & Steel (1988) proposed a revised terminology where a fan delta is «a coastal prism of sediments delivered by an alluvial-fan system and deposited, mainly or entirely subaqueously, at the interface between the active fan and a standing body of water. Fan deltas represent interaction between

heavily sediment-laden alluvial-fan systems and marine or lacustrine processes».

McPherson *et al.*, (1987) used the term fan delta in the original Holmes' (1965) way, introducing a new name (*braid deltas*) for gravel-rich deltas that form where a braided fluvial system progrades into a standing body of water. Braid deltas have no necessary relationship with alluvial fans.

Nemec (1990) revised the existing terminology, focusing on the concept of *delta*. According to him, a delta can be defined as a deposit built by a terrestrial feeder system, typically alluvial, into or against a body of standing water, either a lake or a sea. The result is a localized, often irregular progradation of the shoreline controlled directly by the terrestrial feeder system, with possible modification, by basinal processes, such as the action of waves or tides. It does not follow of course, that deltas are necessarily associated with an overall marine or lacustrine regression; many deltas have formed as elements of retreating shorelines, where the episodes of delta progradation accompanied an overall, longer term transgression of the sea or lake. Moreover, there are deltas that are totally subaqueous, lacking (as yet) the typical subaerial expression in the form of a prograding «delta plain».

After discussing some terminological problems, and reviewing the existing and newly suggested classification of alluvial deltas, with emphasis in their advantages and weakness, he suggested that several classifications schemes can be used in delta research but in a hierarchical way: a descriptive and relatively detailed scheme on the basic level of field research and the broadest genetic schemes on the highest level or more general considerations.

In particular, Nemec (1990) suggests to use alluvial deltas (which can be divided into: river deltas, braidplain deltas, alluvial-fan deltas and scree-cone or scree-apron delta) and non alluvial deltas (pyroclastic deltas and lava deltas). A term such as McPherson *et al.*'s (1987) *braid delta* should not be used because it is misleading, implying that we can use terms such as meander delta as well.

Postma (1990) stresses the depositional architecture and facies of river and fan deltas instead of the alluvial feeder system and the actual modifying basinal processes. The basis for a universal delta classification should consider: feeder system, depth ratio, river-mouth processes and diffusion processes due to waves, tides and gravity. In this way Postma (1990, p. 17) describes 12 major prototype deltas.

Do we actually know what a fan delta is?

It is obvious that such a discussion is not (only) of academic or personal interest; in fact it is motivated by the radically different points of view of authors faced with the task of developing sedimentary models able to describe and integrate many observations upon which sedimentary models of predictive value (with all kinds of conceptual and economic derivations) are built.

Deposits of a variety of sedimentary environments such as fan deltas, braidplain deltas and river deltas have been described from many places; however, it is not as easy to understand which are the precise meanings of these terms and the geological criteria used to define them. The problem reaches almost unsolvable proportions when a distinction of their coastal parts - which are supposed to be most important for defining type and dynamic behaviour of the delta- in the stratigraphic record is attempted.

This also provides a challenge to us because we decided to visit a series of *fan-delta deposits* during a *fan-delta workshop!* There are diverse answers to this question including not meeting at all. However, we feel that under these circumstances it is really important to communicate with researchers in the field, and to consider together several assumed fan-delta deposits with an open criterion and the common wish of sharing a large experience on fan-delta studies. Thus, the real questions are: can we do anything to clarify these concepts? and how can we use all this experience to improve our own research, finding some keys suitable for future work?

In the meantime we use Nemeč & Steel's (1988) concept of fan delta, keeping in mind that our goal is not defending a term or idea but looking for new ideas and developing a branch of science through careful research and constructive discussions. Thus, we feel that we are handling an useful concept as a working tool subject to improvements or even being rejected when a more powerful or adequate one is available. We hope that this workshop and field trip will help to promote an advance of our knowledge.

Geodynamic aspects of fan-delta deposits: application to the Neogene betic basins

Fan delta facies associations are likely to record very precisely the geological events that occurred along the basin-margin and especially the reciprocal effects of tectonics, climate, sea level changes, variations of alluvial sediment input and the marine or lacustrine processes.

As fan deltas occur in a wide range of tectonic and sedimentary contexts, it is assumed that they can produce a varied mosaic of sedimentary facies which are still poorly known. More information on these relationships is needed for future palaeogeographical reconstructions and the Betic basins can provide such a information because their high mobility in recent times.

The aim of this field guidebook is to help in extending the knowledge about fan delta sequences and facies patterns from the compilation of many data on fan deltas in several of the Late Neogene and Quaternary basins of the Eastern Betic Cordillera in southern Spain (Fig. 1). These basins display a variety of features which can illustrate several completely different geodynamic patterns and depositional behaviours.

The Late Neogene and Quaternary sedimentation in the eastern Betic

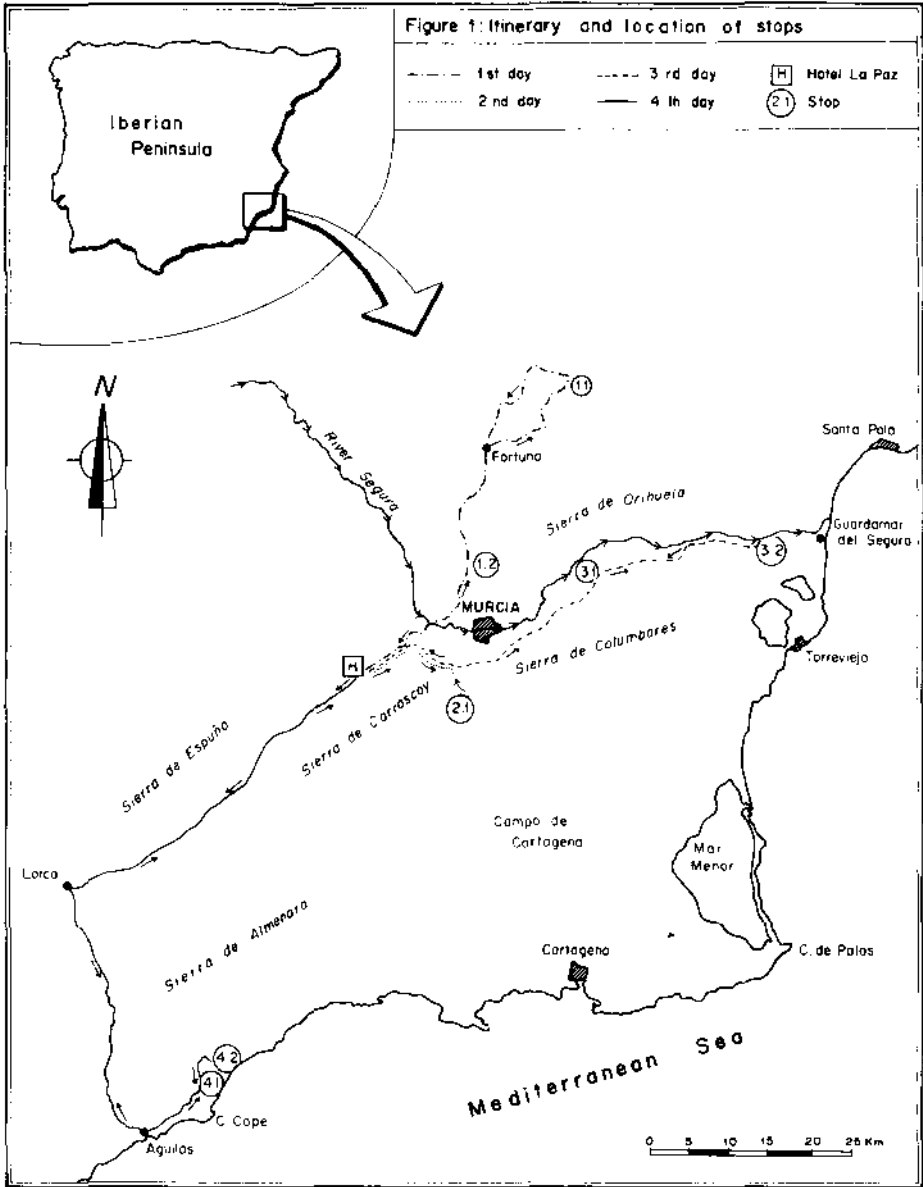


Fig. 1.—Sketch map of the region of Murcia with Itinerary and Stops. See detailed maps (Fig. 2, 4, 14 and 33) for precise location of stops. Hotel La Paz: site of the Workshop.

Fig. 1.—Mapa esquemático de la región de Murcia con el Itinerario y las Paradas. Ver los mapas de detalle (Figs 2, 14 y 33) para la localización precisa de las paradas. Hotel La Paz: sede del Workshop.

Cordillera (Fig. 2) took place in a complex tectonic and paleogeographic framework related to the Alpine Orogeny of large islands surrounded by interconnected depressions (Montenat, 1977). Most of these islands correspond to present-day mountainous ranges (*sierras*), but some others disappeared following tectonic subsidence even in very recent times. One of these lost massifs is the so called «Segura Massif», the one we will have the chance to observe during the field work.

The most recent papers dealing with the Eastern Betic Cordilleras (Montenat *et al.*, 1987; Ott d'Estevou, 1987; Coppier *et al.*, 1989; Larouzière *et al.*, 1988; Sanz de Galdeano, 1990; etc.) point out that Late Neogene basins (Tortonian to Pliocene, 10 M.Y.) of the Eastern Betic Ranges are located inside a wide left-lateral shear zone trending NE-SW. This system, mainly inherited from previous structural stages, was affected by a submeridian compression inducing a slight perpendicular extension resulting from the Iberia-Africa collision. During the Late Neogene, the stress field rotated with a direction of regional shortening shifting from NW-SE (Tortonian) to N-S (Late Tortonian to Pliocene) and again NW-SE (Late Pliocene to Holocene) (Fig. 2).

On the other hand, the left-lateral shear zone corresponds to a zone of high thermal anomaly, where diversified magmatic activity was concentrated and expressed mostly during the Late Tortonian times. Moreover, this lineament corresponds to an important lithospheric discontinuity

Coeval extensional and compressional deformation took place inside this wide shear zone. Thus no basin can be used as a single model to illustrate the geodynamic behaviour of the others.

Between Late Pliocene and Early Pleistocene, the change in the direction of the stress axis shifted towards more dextral directions (Rodríguez Estrella, 1986; Somoza, 1989; Goy *et al.*, 1989 a) triggered a change in the cinematics of the fractures originated during Neogene times: the union of the strike slips of Cabo de Gata-Palomares / Alhama (o. c. Baena, *Seminario de Neotectónica, U.C.M.*, 1979) with the Vélez Rubio-Alicante lineation (Somoza, 1989; Goy *et al.*, 1989 a & b) generated the large continuous structure of the «Eastern Betics left lateral shear zone» (Fig. 3).

Reactivation of the N 150° E faults as dextral faults

The geometry, spatial disposition, and sedimentary facies, of the Quaternary marine and continental deposits deduced from detailed geological mapping indicate that a more important tectonic activity took place in the transition from Early to Middle Pleistocene, in the Almería and Alicante littorals (Goy & Zazo, 1986, 1988, 1989). Likewise, the construction of isobase maps for the quaternary marine deposits, and more especially for the Tyrrhenian ones (180 - 95 Ka.) reveals that the area with greatest uplifting trend is located in the coast of Almería, the zone of Mar Menor constitutes the greatest subsiding

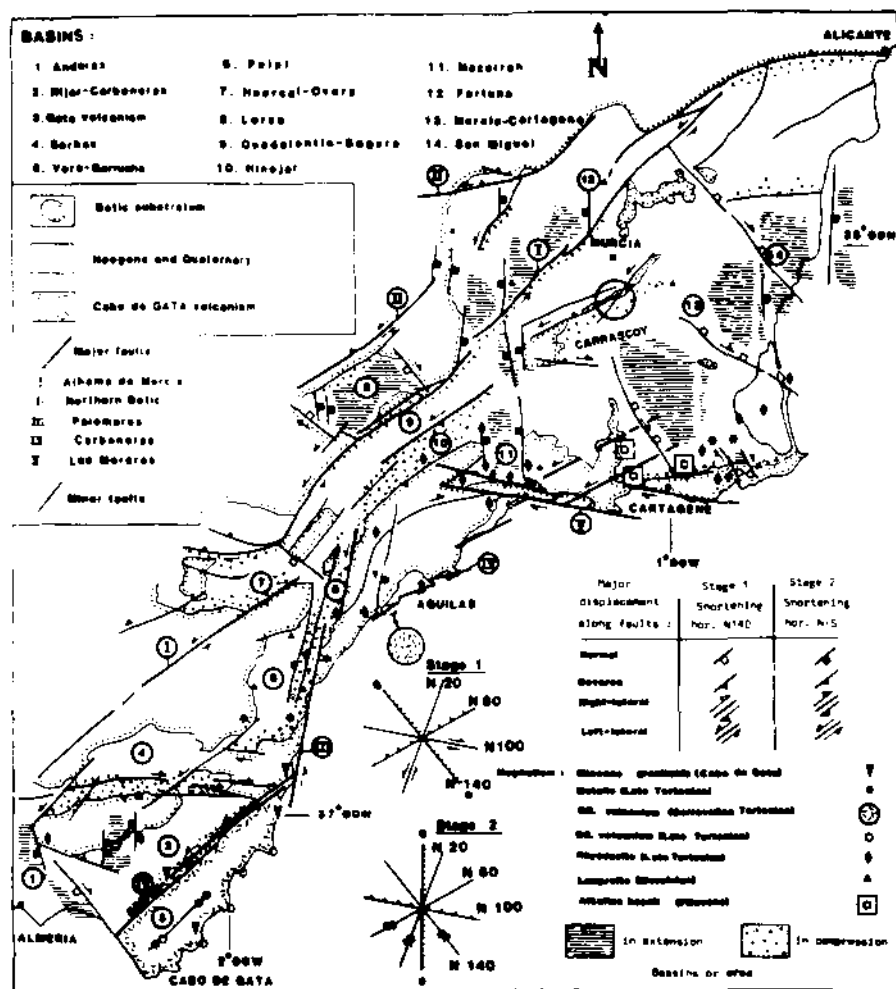


Fig. 2.—Synthetic sketch map of structural basinal and magmatic areas during the Upper Miocene (Structural Stages 1 and 2). After Montenat *et al.* (1987). Major faults: I: Alhama de Murcia; II North Betic; III: Palomares; IV: Carboneras; V: Las Moreras. Key to the poorly visible lower right part: Magmatism: Miocene granitoids (Cabo de Gata); Metallic (Late Tortonian); C.G. vulcanism (Serravallian-Tortonian) (C.G. means Cabo de Gata); C.G. vulcanism (Late Tortonian); Ryodacite (Late Tortonian); Lamproite (Messinian); Alkaline basalt (Pliocene).

Fig. 2.—Mapa sintético esquemático de las áreas estructurales de cuenca y magnéticas durante el Mioceno Superior (estadios estructurales 1 y 2). Según Montenat *et al.* (1987). Fallas principales: I: Alhama de Murcia; II Nord Bética; III: Palomares; IV: Carboneras; V: Las Moreras. Clave para la parte derecha que se lee mal: Magmatismo: granitoides miocenos (Cabo de Gata); Metalico (Tortonienne Superior); C.G. vulcanismo (Serravallienne-Tortonienne) del Cabo de Gata (C.G.); vulcanismo del Tortonienne Superior; Riodacitas (Tortonienne Superior); Lamproitas (Messiniense); basaltos alcalinos (Plioceno).

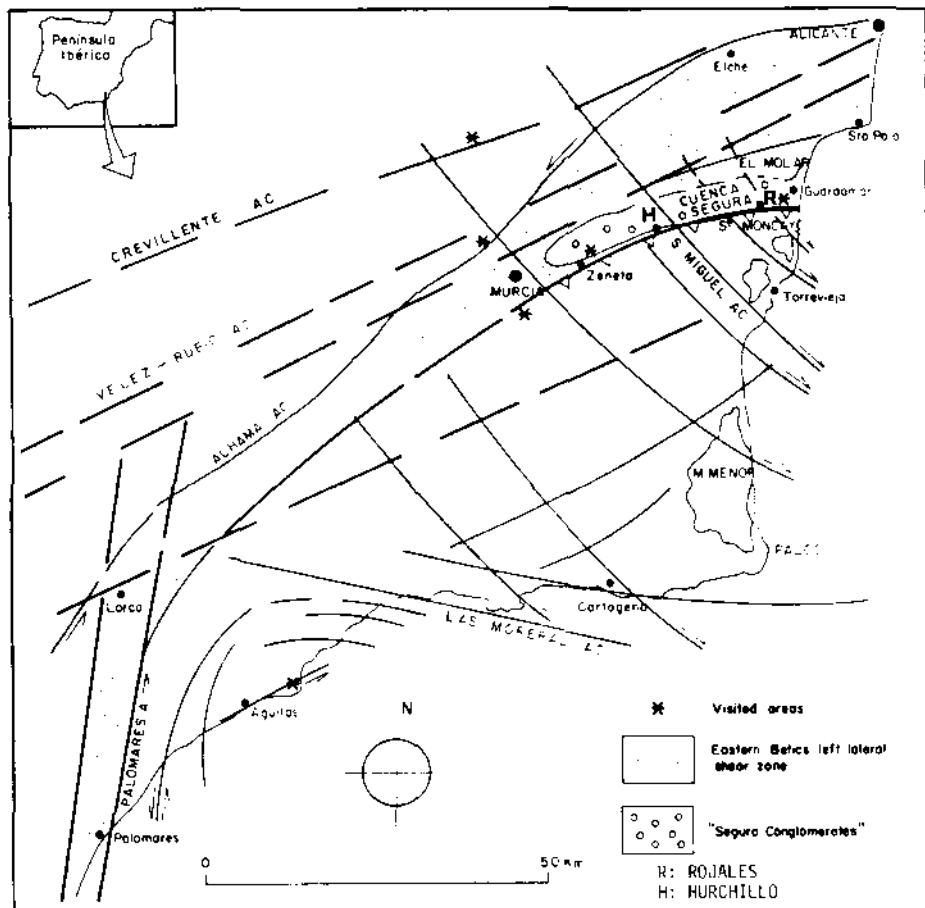


Fig. 3.—Location map of the area visited during the workshop inside the «left lateral shear zone» and main tectonic structures active during Quaternary (modified after Boccaletti *et al.*, 1987; Montecat *et al.*, 1987; Goy & Zazo, 1989 and Somoza, 1989).

Fig. 3.—Mapa de situación del área visitada durante el recorrido de campo dentro del corredor de desgarre sinistrorso y principales estructuras tectónicas activas durante el Cuaternario (modificado de Boccaletti *et al.*, 1987; Montecat *et al.*, 1987; Goy y Zazo, 1989 y Somoza, 1989).

area, and the coast of Alicante presents an uplifting trend again, although of a lesser intensity than in Almería. The movement rate in these Eastern Betic coasts is of around $+0.15$ m/K.A. (Somoza *et al.*, 1987; Zazo & Goy, 1989).

The high seismicity produced in historical times (Seismic Intensity X, Guardamar-Torreveja Area) is related both to the reactivation of ancient fractures (Estévez *et al.*, 1986), and with the wide range deformation axis (sinform and antiform).

FIRST DAY: FAN DELTAS OF THE FORTUNA BASIN

General

The city of Fortuna is located in the centre of a semiarid depression, 25 km north of the town of Murcia (Fig. 1). A sedimentary basin was located in this area (Fig. 2) during Late Neogene times, after the last main phases of folding of the Betic Cordillera (Serravallian).

The sedimentary record of the Basin comprises rocks of Tortonian, Messinian and Pliocene ages. Pliocene rocks were deposited only in the southern part of the basin in terrestrial environments; they were subsequently eroded during Quaternary times and are poorly represented in the basin.

The Late Miocene basin of Fortuna is placed near the Mediterranean side of the former North Betic Strait. It is one of the many basins, marginal to the Mediterranean Sea, where sedimentation was strongly influenced by the *Messinian Salinity Crisis*. Absolute falls of sea level up to 500 m took place during the crisis.

Most of the physiographic characteristics of the area of Fortuna are a direct inheritance of the original morphology of the basin during Tortonian and Messinian times. Its topographically-high margins are shelves related to deltaic plains and reefs. Taluses connected to these platforms are dipping surfaces which can be traced for distances representing differences of height up to 400 m (Santisteban, 1980).

Messinian deposits crop out in the central area of the basin, onlapping these Tortonian taluses. They consist of a 1200 metres-thick succession made up of shallow-marine and evaporitic deposits.

The Fortuna Basin is controlled by a system of folds and faults directed NE-SW and faults NW-SE, associated to a large strike-slip fault, the Crevillente Accident (Fig. 3), which, in deep layers, was correlated to the Azores fault by Jerez Mir (1979). The structures directed NE-SW are responsible of the morphologic features of the northern side of the basin, inducing the development of a series of smaller basins (El Rellano, La Hoya del Campo, Balonga, La Umbría, ...). These folds and faults developed during the late phase of folding (Serravallian). No major intra-Tortonian or intra-Messinian tectonic deformations have been recognized, excepted some places along the margins where synsedimentary unconformities were generated.

The effects of tectonic compression are recorded in the basin during the Pliocene: (1) diapiric extrusion of plastic Upper Triassic rocks (Keuper facies with evaporites) along axis of folds; (2) diapirism of Messinian evaporites, and (3) reactivation of the NW-SE fractures as strike-slip faults.

The tortonian fan deltas of the Fortuna basin

The larger accumulations of coarse clastic sediments of the Fortuna Basin

are related to fan-delta systems (Fig. 4). The only exception is the accumulation of Sierra de la Espada (Sword Range) which corresponds to a fluvial delta. Almost undisturbed Tortonian fan delta deposits are located in the northern and southern margins of the basin.

The aim of this excursion is to visit and study the deposits of La Umbría and El Montañal systems (Fig. 4) with particular emphasis on the transition from shelf to delta front deposits and colonization by coral reefs.

STOP 1 - 1: The tortonian fan delta of La Umbría

General

The fan-delta deposits of La Umbría are exposed in the northeastern side of the basin (Fig. 4). The outcrop is elongate (7 x 1.3 km), with a total surface of about 9 km².

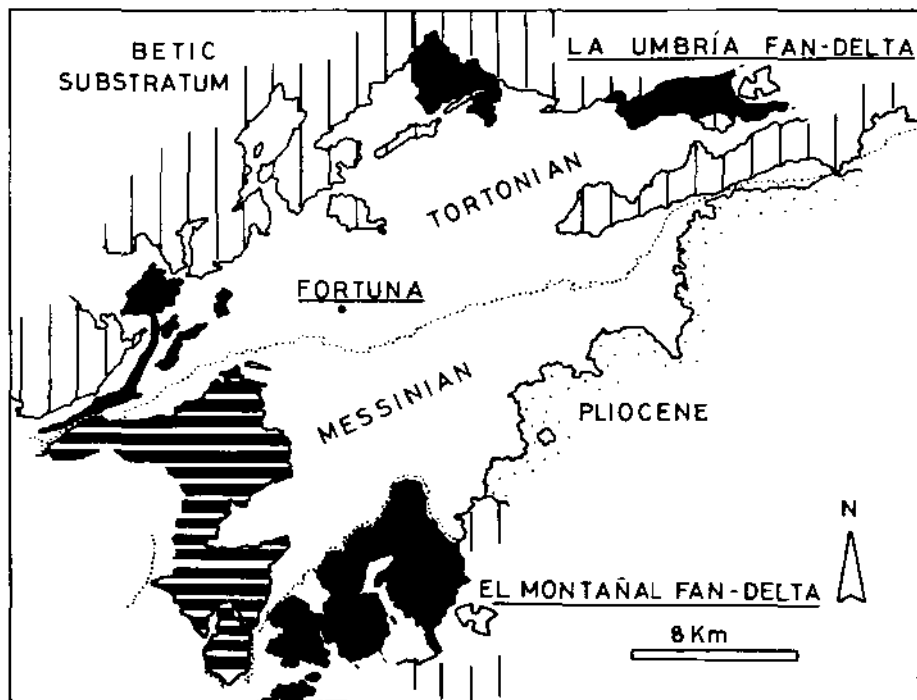


Fig. 4.—Geological sketch of the Fortuna Basin. Tortonian fan-delta systems are indicated in black. Messinian fan-delta systems are indicated by horizontal bars.

Fig. 4.—Esquema geológico de la Cuenca de Fortuna. Los sistemas de fan deltas tortonienses están en negro y los messinienses en líneas horizontales.

Most of the sediments of this system are conglomerates deposited at the northern margin of the basin, which prograded to the south forming an accumulation of depositional lobes.

In proximal areas (towards the north) these conglomerates are in contact with the Betic basement. The substratum is made up of alternating limestones and marlstones of the Internal Prebetic domain (the northern part of the External Zones of the Betics). The boundary between the conglomeratic units and the pre-Neogene substratum is a fault through which plastic Triassic rocks intruded diapirically until they reached the surface. In the areas close to the boundary, conglomerates are arranged in a geometric pattern of progressive unconformities which witness a synsedimentary tectonic instability.

In a distal direction, to the south, La Umbria conglomerates change gradually into sandstones which interfinger with the basinal marls of the Basin.

Purpose

To study the various facies associations of the fan delta of La Umbría following a section longitudinal to the whole system from deposits next to the coast to turbidites.

Description

Stop 1 - 1 is located along the riverbed of Rambla del Chicamo, between the localities of La Umbría and Barinas. The river has excavated a deep gorge oriented N-S and turns to the west near La Umbría, where good exposures are seen, along the right (north) margin.

There is a good panoramic view of the fan-delta deposits from the village of La Umbría. Note that all these rocks are gently inclined to the east. Around La Umbría a megasequence, formed by alternating marlstones and sandstones (base) and conglomerates (top) is observed. This panorama exposes a section of the fan delta in a direction at right angle to the progradation. The fan delta grew from the far end (north) and prograded to the south, i. e. to the observer. The deposits visible in this outcrop, from the observer's position, are the more distal of the system.

The basal part of the sequence consists of alternating marls and layers of sandstone and (or) conglomerates 10 to 70 cm thick. The sharp, erosional base of these beds loses definition laterally.

Moving into the gorge of rambla del Chicamo for about 1 km, the gradual transition from conglomerates into turbiditic layers in the direction of the measured paleocurrents (i.e., longitudinal to the system) is observed (Fig. 5).

Conglomerates integrate units up to 5 m thick, with large-scale, sigmoidal

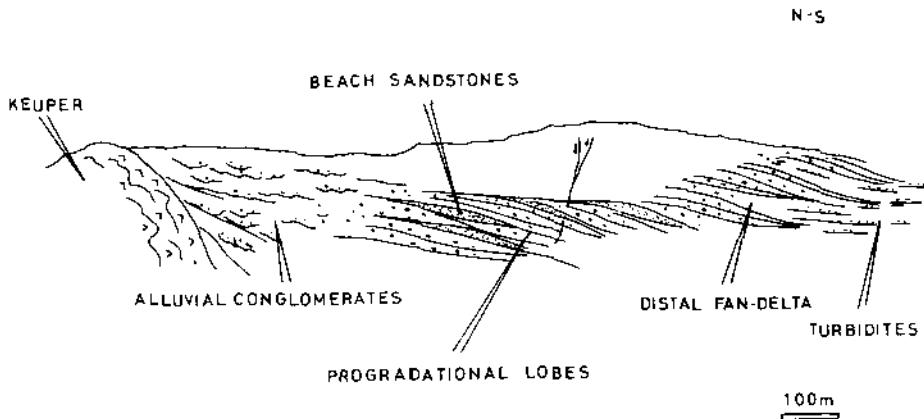


Fig. 5.—Schematic cross-section of the La Umbria fan delta, along the N-S section of the gorge of Rambla de Chicamo.

Fig. 5.—Corte esquemático del fan delta de la Umbría según la sección N-S de la garganta de la Rambla de Chicamo.

cross bedding inclined to the south. In this direction the layers of conglomerate wedge out and change gradually into sandstones (Figs. 6 and 7). In the zone of transition, marls and conglomerates are arranged into sequences of thickening and coarsening upward trend. The basal layers of any given sequence overlap the frontal slope of the underlying deposits (Fig. 6). Each sequence represents the development of a depositional unit (Fig. 8).

Moving to the north, the proximal facies are reached. They consist of conglomerates and, in a lesser proportion, sandstone. These deposits are organized in sequences between 1 and 7 m thick. Conglomerates predominate in the lower part and sandstones at the top. Values of the sandstone / conglomerate range between 1:3 and 1:10.

The conglomerates form tabular-shaped bodies with internal large-scale sigmoidal cross bedding. Many of the clasts forming the conglomerates are bored by *Lithophaga* and *Sponge*. Some layers include clasts with attached barnacles (*Balanus*) in life position. These layers are indicative of shallow marine conditions and also of hydrodynamic stability of sedimentation. Every unit of conglomerate is the result of the generation and progradation of a lobe of the fan-delta system.

The sandstone layer occurs at the top of the coarser grained units. Internal structures include hummocky cross stratification and cross lamination both of wave and climbing ripples. In our opinion these sandstone layers result from reworking by waves, of the upper parts of the conglomeratic lobes (Fig. 8).

Coral bioconstructions are also found topping some units, in a location similar to the described sandstones. One of these small reefs is observed in the section of Rambla de Chicamo (Fig. 9 A). The reef was built by the corals

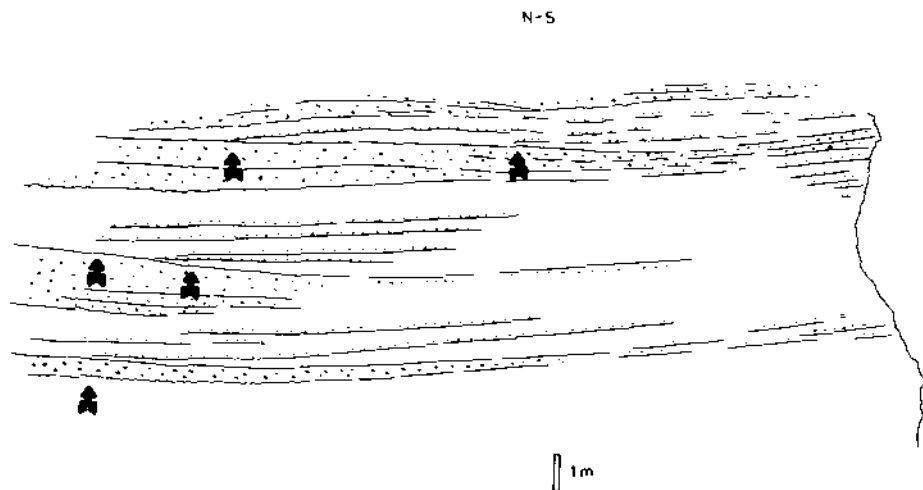


Fig. 6.—La Umbría fan delta. Transition from conglomerate lobes to turbidites. Distal-fan delta facies. Arrows indicate the adaptation of distal lobe facies to the morphology of the previous bar.

Fig. 6.—Fan delta de la Umbría. Transición de lóbulos de conglomerados a turbiditas. Facies de fan delta distal. Las flechas indican la adaptación de las facies delóbulo distal a la morfología de la barra previa.

Porites lobatosepta and *Tarbellastrea eggenburgensis*. The reef was partly eroded after deposition and it was subsequently covered by a younger conglomeratic unit (fan delta lobe). The existence of these small reefs indicates a shallow-marine environment and a certain sedimentary stability. In some cases they allow us to recognize the rhythm of development of the systems of fan deltas.

STOP 1 - 2: The Fan Delta of El Montañal

General

The fan delta of El Montañal is the largest of the Tortonian fan deltas in the Fortuna Basin (Fig. 10). It is located in the southern margin and covers an area of about 25 km². Santisteban (1981) described this system and pointed out the excellent preservation of most of the original physiographic characteristics and the horizontal position of these deposits.

The fan delta rests upon the palaeo-Segura Massif which is still partly surrounded by subaerial facies of the Tortonian fan-delta deposits. The rest of the system is made up of an accumulation of large conglomeratic units with well-preserved depositional lobes, visible both in air photographs and topographic maps (numbers 1 to 4 in Fig. 10). Reef growth on top of the

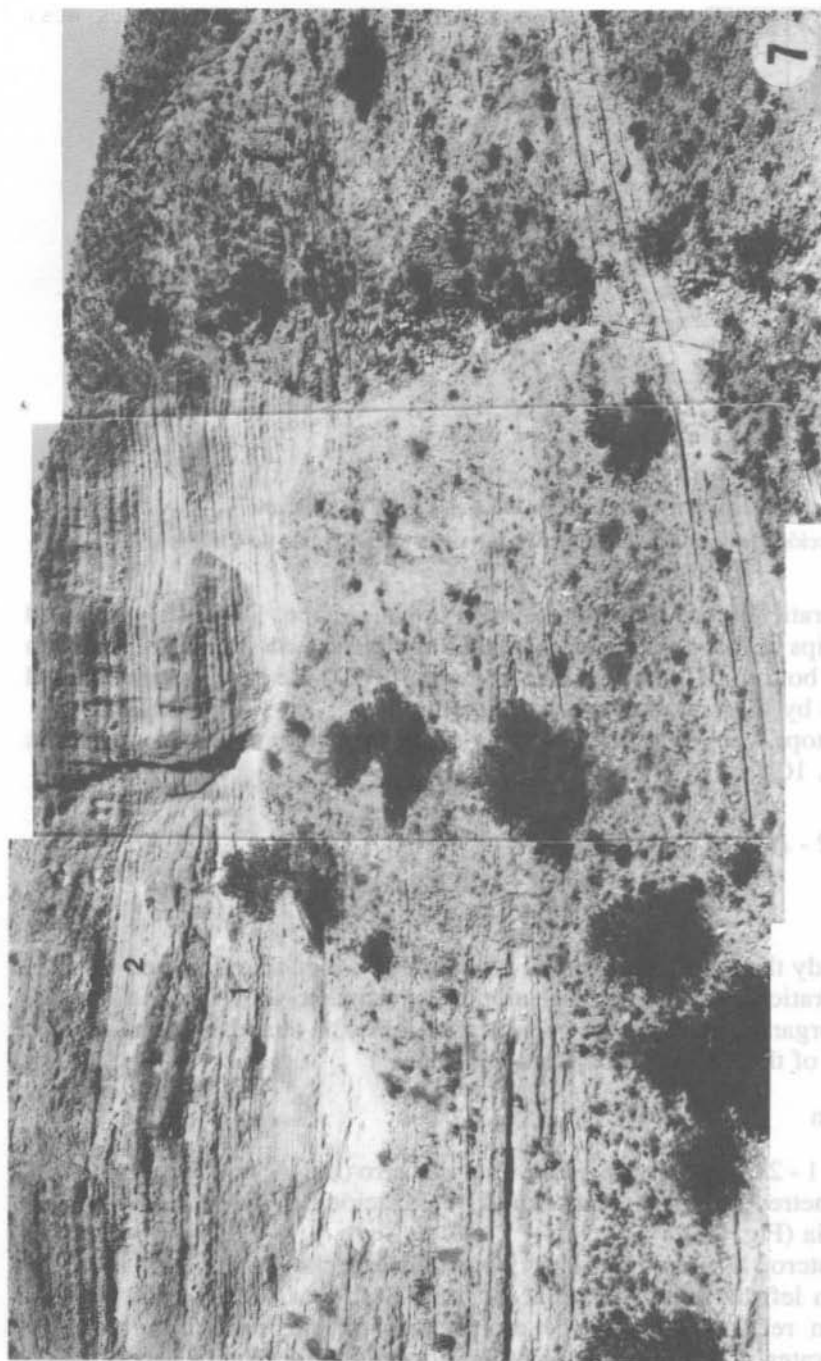


Fig. 7.—Longitudinal cross section to La Umbría fan-delta conglomerates. Detail of several thickening and coarsening upward sequences corresponding to subaqueous depositional lobes.

Fig. 7.—Sección longitudinal a los depósitos del sistema de fan delta de La Umbría. Se pueden observar varias secuencias negativas, en cuanto a la variación del tamaño de grano y el espesor de los estratos, correspondientes a lóbulos deposicionales.

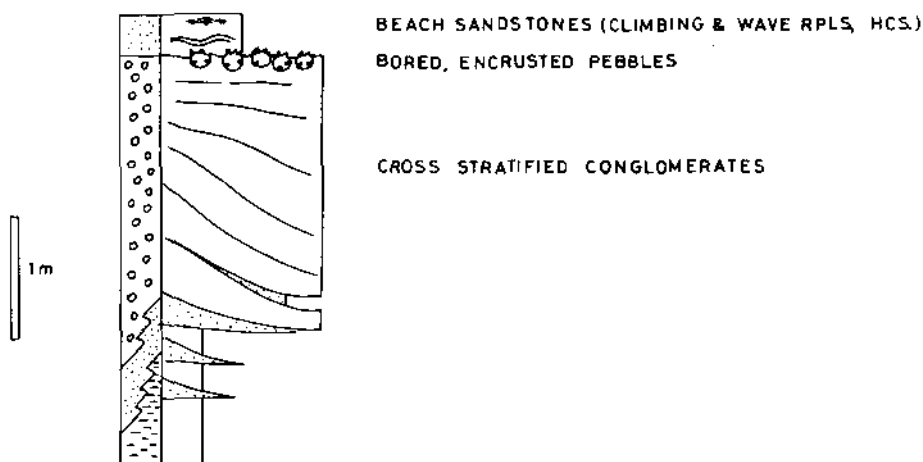


Fig. 8.—Idealized sequence of a fan-delta lobe in Rambla de Chicamo.

Fig. 8.—Sección idealizada de un lóbulo de fan delta en la Rambla de Chicamo.

conglomeratic bodies accentuates their lobate shape. The well-preserved original dips of slope facies indicate that the lobes were raised about 200 m above the bottom of the basin. The lower parts of these deposits are covered nowadays by Messinian evaporitic facies.

Two stops, very close to each other are described in the El Montañal fan delta (Fig. 10).

STOP 1 - 2 - 1: The Quarry at Cerro Victor

Purpose

To study the three dimensional structure of a reef developed on top of a conglomeratic fan-delta lobe. The aim of the visit is to show that the analysis of these organic deposits can help to recognize the shape, dimensions and dynamics of the system of depositional lobes.

Description

STOP 1 - 2 is located in a quarry dug in Cerro (hill) Victor, close to (a few hundred metres east of) the road from Urbanización La Alcayna to Espinardo and Murcia (Fig. 9B).

The outcrop is formed by a body of carbonate rocks which fills an irregular depression left between two adjacent fan-delta lobes. This means that the depression reflects the surface morphology of the underlying reddish conglomerates. The preservation of such topographic feature was possible

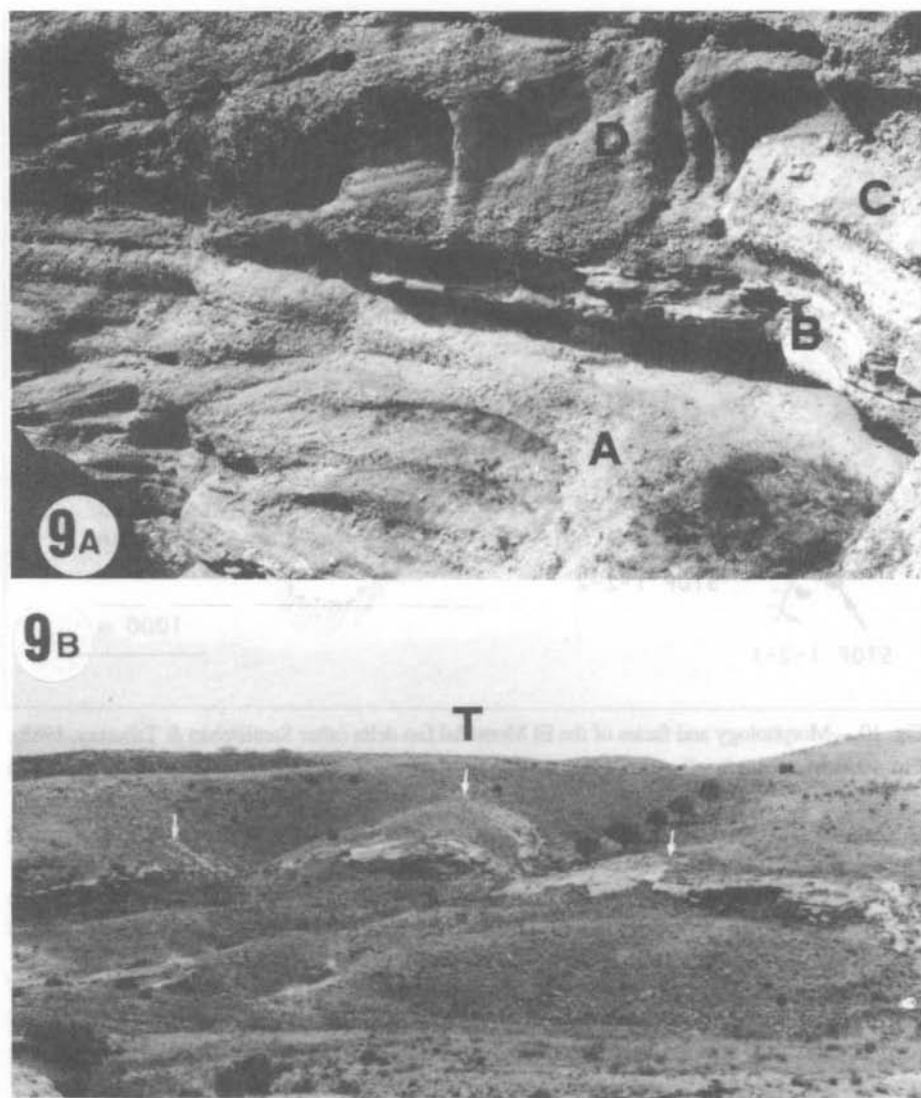


Fig. 9.—(9 A) La Umbría fan delta. Two superimposed fan-delta lobes. (A) Lower conglomerate lobe, (B) beach sandstone on top of the lower lobe, (C) partly eroded coral reef and (D) upper conglomerate lobe with large-scale cross stratification. (9 B) El Montañal fan delta, Cerro Victor. Reef-talus slopes, adapted to a group of fan-delta lobes.

Fig. 9.—(9 A) Fan delta de la Umbría. La fotografía muestra dos lóbulos deposicionales superpuestos. (A) lóbulo de conglomerados inferior, (B) depósitos de areniscas formadas en el ambiente de playa, (C) arrecife de coral parcialmente erosionado y (D) lóbulo de conglomerados superior en el que se aprecian superficies de estratificación cruzada a gran escala. (9 B) Fan delta de El Montañal, Cerro Victor. Depósitos de talud arrecifal adaptados a la pendiente frontal de un conjunto de lóbulos coalescentes de fan delta.

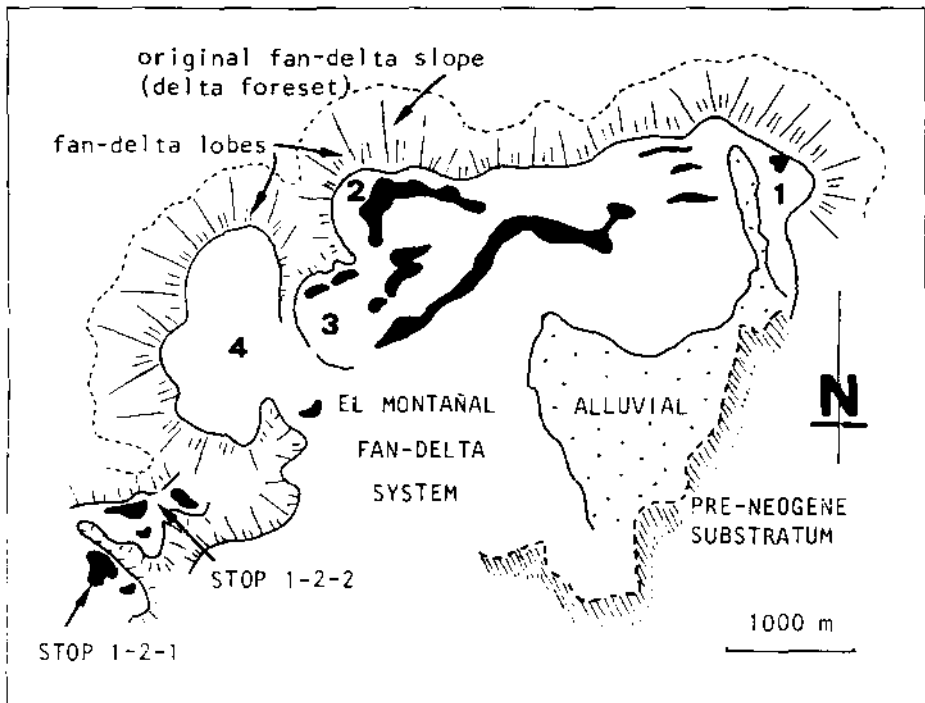


Fig. 10.—Morphology and facies of the El Montañal fan delta (after Santisteban & Taberner, 1988).
 Fig. 10.—Morfología y facies del fan delta de El Montañal (según Santisteban y Taberner, 1988)

thanks to the growth of a reef on the top of this part of the fan delta, after it became inactive or abandoned.

Pre-reef paleoslope dips to the north, according to the general progradation of the fan-delta system. Reef limestone also exhibit a large-scale cross bedding in the same direction indicative of reef progradation (Fig. 11).

Reef limestones are divided into two units: the lower one, at the base of the irregular depression, consists of skeletal calcarenites with fragments of reef limestone, mixed with scattered clasts removed from the substratum. It represents the reef talus slope.

The upper part of the carbonate section is the reef core made up of coral colonies. In the front sector, most of these colonies are of *Porites lobatosepta*, whereas in the upper platform the dominant specie is *Tarbellastrea eggenburgensis* (Fig. 11).

The colonies of *Porites* in the frontal part of the reef exhibit a marked morphological zonation resulting from the adaptation of these corals to the available light, nutrients, etc. Similar adaptations have been described in other Late Miocene reefs of the Betics (Esteban & Giner, 1977; Dabrio & Martín, 1978; Dabrio *et al.*, 1981 and Santisteban, 1981).

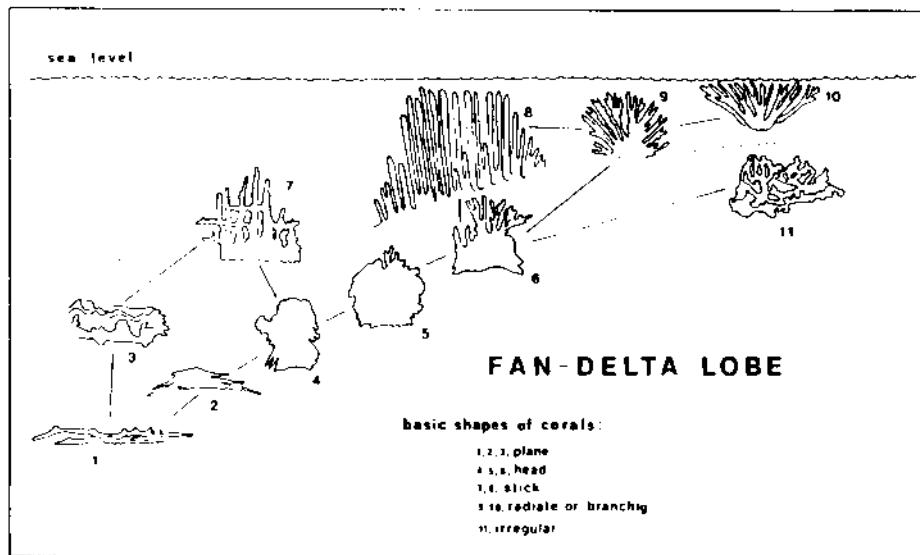


Fig. 11.—Morphologies of corals *Porites lobatosepta* and *Tarbellastrea eggenburgensis*, adapted to the frontal slope of a fan-delta lobe in Cerro Victor Quarry (after Santisteban & Taberner, 1988).

Fig. 11.—Morfologías de los corales *Porites lobatosepta* y *Tarbellastrea eggenburgensis*, adaptada a la pendiente frontal de un lóbulo de fan delta en la cantera de Cerro Victor (según Santisteban y Taberner, 1988).

The morphologic distribution of colonies, and the change of basic shapes of corals (plates → bells or heads → sticks → radiate or branching → irregular, Fig. 11) is assumed to be a response to a depositional slope in the fan-delta front on which the reef is placed (Fig. 12) (Santisteban & Taberner, 1988). The reef platform consists of large patch reefs of massive and digitate *Tarbellastrea*.

Consequently, the study of these reefs allows the recognition of some characteristics of the sedimentary systems they are associated with. In particular, morphology, dimensions and dynamics of fan-delta lobes acting as substratum are preserved and recognized.

STOP 1 - 2 - 2: Panorama from canteras hill

Purpose

Observation of a system of fan-delta lobes with interlayered reef growths.

Description

STOP 2 - 2 - 2 is placed in a hill called Canteras (height 200 m), about 400 m north of Victor.

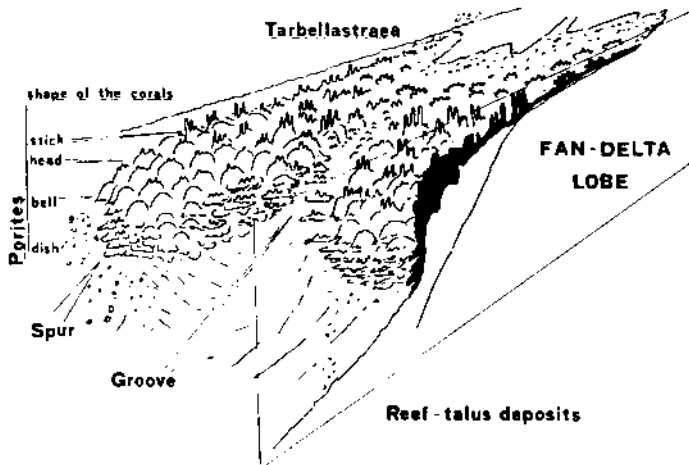


Fig. 12.—Reconstruction of the reef adapted to a fan-delta lobe in Cerro Victor (El Montañal fan delta). (After Santisteban & Taberner, 1988).

Fig. 12.—Reconstrucción del arrecife adaptado a un lóbulu de fan delta en Cerro Victor en el fan delta de El Montañal (según Santisteban y Taberner, 1988).

From this hill a system of interfingering conglomerates (fan-delta lobes) and reef carbonates is seen to the northwest (Fig. 13) resting upon distal marls. Conglomerate fan-delta lobes are recognized by the darker colour and the internal large-scale cross stratification. Lighter carbonate reef deposits cover the former, adapting to their depositional slope. The reef core is located between two conglomerate lobes, upon the frontal slope of the first. Reef-talus deposits (calcarenites) form a tabular unit which continues distally towards the basin interior, below the conglomeratic units.

The adaptation of a small reef to the morphology of a fan-delta lobe was studied in the previous stop (1-2-1). In Stop 1-2-2 it is clear that the reefs themselves are also dependant to the dynamics of the system. Detailed mapping of reef deposits allowed the recognition of several phases of the development of fan deltas (Fig. 10), their morphology, direction of progradation ..., etc.

SECOND DAY: LATE-TORTONIAN FAN DELTAS IN MURCIA-CARRASCOY BASIN

General

The complex of fan deltas of Sierra de Carrascoy (Fig. 14) is a part of the basin of Murcia which is placed on top of two sinistral strike-slip faults

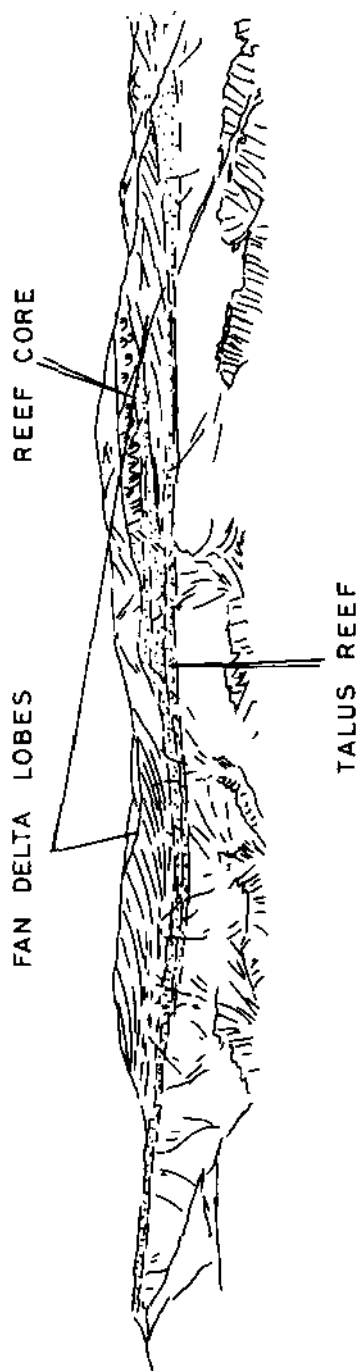


Fig. 13.—Panoramic view of reefs adapted to fan-delta lobes in Canteras hill.

Fig. 13.—Panorámica de los arrecifes adaptados a lóbulos de fan delta en el cerro Canteras.

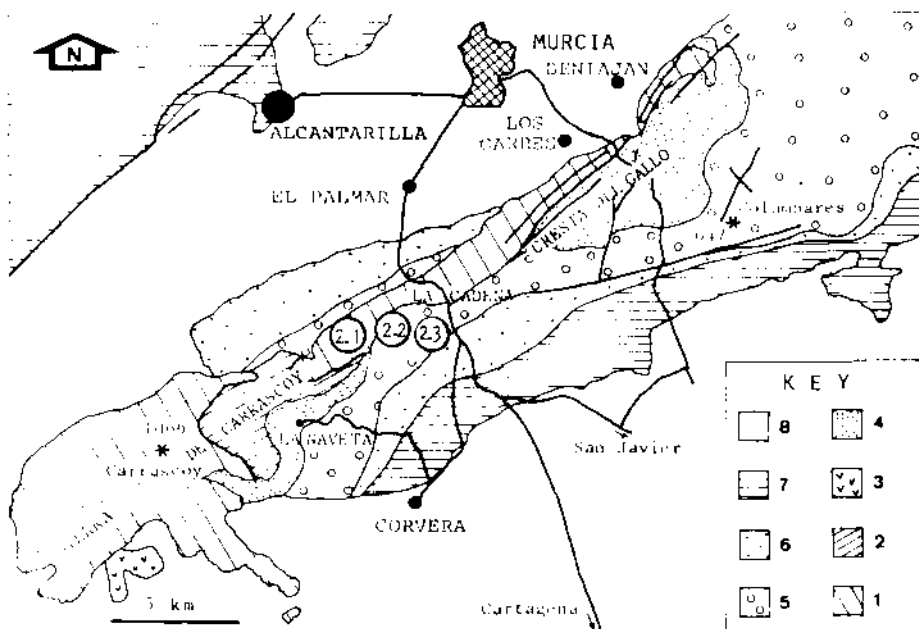


Fig. 14.—Schematic geological map of Sierra de Carrascoy (Murcia). Legend: (1): Alpujarride (grey phyllades) and Ballabona - Cucharón (red mudstones, limestones and dolostones) Complexes; (2): Maláguide Complex (red mudstones and quartzites, followed upwards by dark grey dolostones) (1 & 2, Betic substratum); (3): Volcanic rocks; (4): conglomerates and turbidites (Tortonian I); (5): «Puerto de la Cadena conglomerates» (fan deltas, Tortonian II to Messinian I); (6): basinal marls and turbidites («Torremendo marls») and La Virgen calcarenites (Tortonian II to Messinian I); (7): Mio - Pliocene marls and conglomerates (8): Plio - Quaternary rocks. Encircled: location of STOPS 2-1, 2-2 and 2-3.

Fig. 14.—Esquema geológico de los alrededores de la Sierra de Carrascoy (Murcia). Leyenda: (1) Materiales del Complejo Alpujarride; (2) Materiales del Complejo Maláguide ambos del sustrato bético; (3) Rocas volcánicas; (4) conglomerados y turbiditas (Tortonense I); (5) conglomerados del Puerto de la Cadena (fan deltas, Tortonense II- Messiniense I); (6) margas de cuenca y turbiditas («Margas de Torremendo») y calcarenitas de la Virgen (Tortonense II-Messiniense I); (7) margas y conglomerados mio-pliocenos; (8) materiales plio-cuaternarios. En círculos, localización de las paradas 2-1, 2-2 y 2-3.

oriented N40-50° E and N80° E, with a complex, syntectonic infill underlined by many unconformities and notable wedging outs (Montenat *et al.*, 1985; Montenat *et al.*, 1987).

One of the most prominent features is the complete wedging out of the approximately 1200 m thick «Tortonian I» (an informal way of designing the lower part of the Tortonian deposits with no precise implication of age) succession over less than 10 km measured parallel to the northern edge of the basin (Montenat, 1973).

We propose a regional stratigraphic framework for the Late Miocene of

Carrascoy (Fig. 15) which reflects the complex nature of the synsedimentary tectonic activity. The active sinistral strike-slip faults induced large horizontal displacement, but also triggered a prominent, rapid subsidence of the southern block. Transverse faults oriented N 150° E acted as dextral strike-slip faults and also as normal faults (Fig. 16) inducing lateral differences of behaviour which are also observed in the sedimentary successions.

These facies associations record deposition on a tectonically-active basin margin. Differential subsidence (accommodated along faults) is responsible of the asymmetry of sedimentary bodies in both sides of the Sierra de Carrascoy (Montenat, 1973): thin onlapping, proximal, mostly terrestrial deposits in the north and thick marine successions towards the southeast, which generated a coastal onlap following a relative rise of sea level (Fig. 15).

The Tectonic Control (first order megasequences)

Up to 12 to 14 km (measured stratigraphically) of fan delta deposits were deposited along the active margin of the basin. In detail, individual units of alluvial-fan and fan-delta deposits can be distinguished inside this huge accumulation of sediments (STOP 2 - 2). These units show sequences on various scales which are thought to record diverse controls of sedimentation. The existence of active wrench faults and the overall organization of deposits very much resembles the model of basin margin described in the Devonian Hornelen basin by Steel *et al.*, (1984). A similar mechanism is invoked in this paper: the relative movement of the blocks defining the active border of the basin forced the points of sediment input (i.e., the apical zones of fans next to the mountain valleys, but separated from them by the wrench fault) to move laterally. The lateral offset of units (mostly deposits of fan deltas having only radiuses of about 4 to 5 km) produced the huge stratigraphic thickness (Fig. 16).

Lateral movements along the fault displacement will be recorded in the sediments. We assume that the lateral migration of depocenters (related to the displacement of the shelf towards the northeast) generated various types of megasequences. Those areas placed to the southwest of the points of sediment supply experienced a movement to the northeast and progressively approached the points of sediment supply. This approach is recorded as coarsening and thickening upwards megasequences such as the one found in La Naveta area (Dabrio, 1990). However, fining and thinning upward megasequences developed as other areas progressively moved away from the emitting valleys (Fig. 16). Increased rates of deposition off these points favoured the progradation of fan delta complexes (including well-developed subaerial facies) that were subsequently drowned when subsidence prevailed over deposition once they moved away of the valleys. Sequences of smaller order (briefly described below) are found inside the former evidencing the diversity

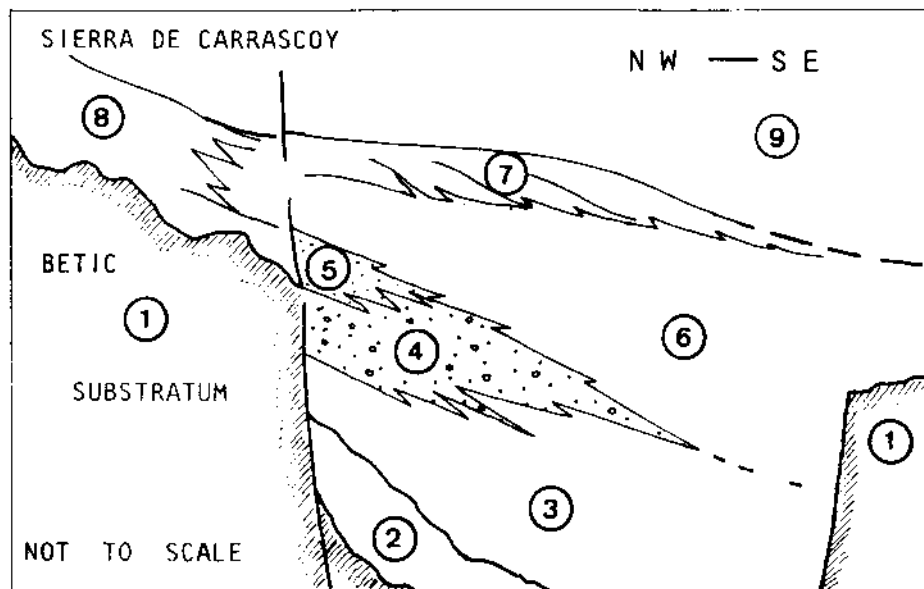


Fig. 15.—Lithostratigraphic framework of the Murcia (Carrascoy) basin. Key: (1): Betic substratum; (2): conglomerate (sedimentary breccia) and turbidite (Tortonian-I); (3 to 7): Tortonian-II to Messinian-I units, (3): marlstones, turbidites and megabreccia, («La Naveta marlstones»); (4): fan delta deposits («Puerto de la Cadena conglomerate»); (5): shelf conglomerates and calcarenites, lateral equivalent to fan delta deposits; (6): basinal marlstones and turbidites («Torremendo marlstones»); (7): shallow-marine calcarenites («La Virgen limestones»); (8): Uppermost Miocene to Pliocene terrestrial conglomerates; (9): Mio-Pliocene marlstones and conglomerates. Horizontal scale: about ten km; vertical scale: some hundreds of metres. See also Dabrio & Polo (*This volume*)

Fig. 15.—Esquema de unidades litoestratigráficas de la Cuenca de Murcia-Carrascoy. (1) sustrato bético; (2) conglomerados y turbiditas (Tortonense I); (3 a 7) unidades del Tortonense II- Messiniense I, con la siguiente clave: (3) Margas, turbiditas y megabrechas de la Naveta; (4) conglomerados del Puerto de la Cadena (fan deltas); (5) conglomerados y calcarenitas de plataforma que son equivalentes laterales de las anteriores; (6) margas de cuenca y turbiditas («Margas de Torremendo»; (7) calcarenitas (Calizas de la Virgen); (8) conglomerados continentales (Mioceno Superior-Plioceno); (9) margas y conglomerados mio-pliocénicos. Escala: horizontal, alrededor de diez kilómetros; vertical, unos cientos de metros. Véase también Dabrio y Polo (*este volumen*)

of the sedimentary processes involved and the repeated lateral migration of subenvironments.

A later relative rise of sea level resulted in a hemipelagic drape of several of the shallower water units (Fig. 15).

Morphologies inherited from former stages and differential subsidence controlled by transverse faults (which were very active during the Late Miocene, Núñez *et al.*, 1974) strongly influenced sedimentation during this displacement of sedimentary environments. This interpretation is supported by the progressive change of paleocurrent directions: in subaerial fans they

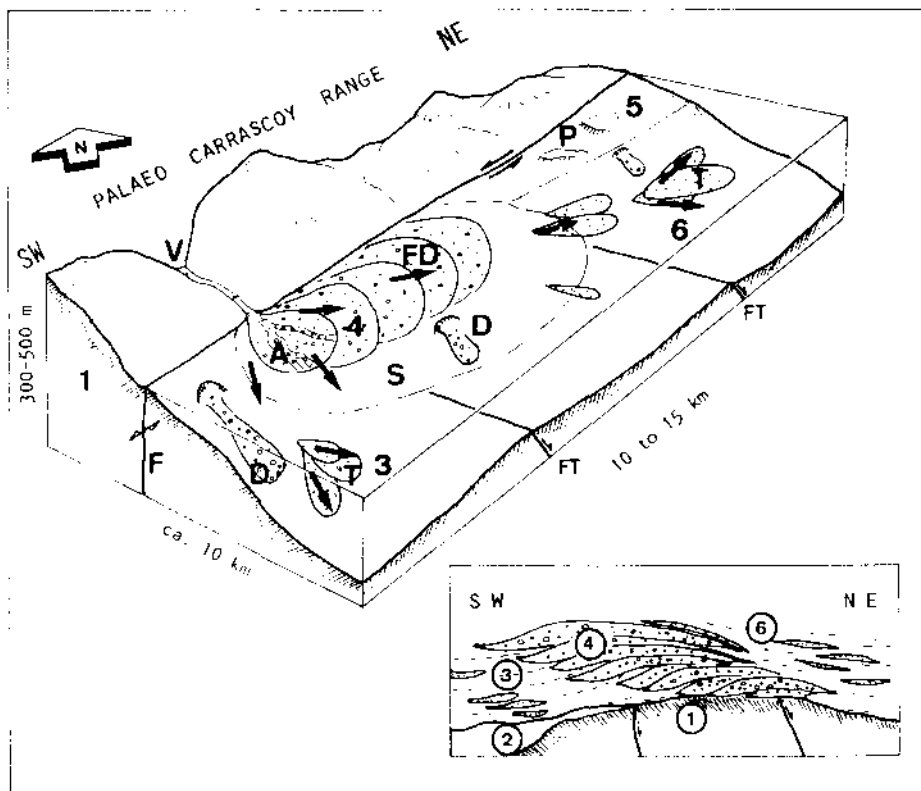


Fig. 16.—A simplified model of margin of basin related to a synsedimentary strike-slip fault (F) in Carrascoy range. Note that more than one fault was active and also that the directions of these were diverse (at least N 40 - 50° E and N 80° E). More than one point emitting sediment could be active. Below, dynamic interpretation of lithostratigraphic units distinguished in figure 15 (numbers have the same meaning). (FD): successive fan delta lobes having a channelized subaerial part (A); (D): debris flows; (S): prodelta and slope; (T): turbidite deposits (including channels); (FT): transverse faults generating additional subsidence in various zones of the basin margin (after Dabrio, 1990).

Fig. 16.—Modelo de margen de cuenca ligado a una falla de desgarre sinsedimentaria (F) en la Sierra de Carrascoy. Téngase en cuenta que podía haber más de una falla activa y que las direcciones de éstas eran diversas (por lo menos N50° E y N80° E). Además, podía haber más de un punto emisor de sedimentos activo. Abajo, en el recuadro, interpretación dinámica de las unidades litoestratigráficas distinguidas en la figura 15 (los números tienen el mismo significado que en ella). (FD) lóbulos sucesivos de fan delta que tienen una parte subaérea (A) canalizada; (D) flujos de derrubios (debris flow); (S) prodelta y talud; (T) turbiditas de lóbulos y canales; (FT) fallas transversales que producen subsidencia adicional en las distintas partes del margen de la cuenca (según Dabrio, 1990).

are consistently towards N 150-180° E, but they turn progressively towards the east in subaqueous fan delta deposits (N 120-130° E) and still more in turbidites (N 110-120° E in channel-fill deposits, N 30 to 100° E in overbank

turbidites). This is probably related to deflection of currents by the positive reliefs induced by underlying sedimentary bodies (Fig. 16).

The model of displacement of depocenters by strike-slip faults was proposed by Gloppen & Steel (1981) and Steel *et al.*, (1984) to explain the huge stratigraphic thicknesses (more than 25 km) of fan delta, fluvial and lacustrine sediments in the Devonian Hornelen basin (Norway). Steel (1988) documented the difficulty of distinguishing vertical motifs caused by progradation from those caused by offset faults.

Sedimentary model of Fan Deltas

The proposed sedimentary model (Fig. 17) consists of a basin margin with narrow, sloping shelf that was connected distally to an abrupt slope. Off the mouth of the mountain valleys draining the paleo Sierra de Carrascoy, fan deltas developed prograding upon the narrow shelf and slope system. Sedimentary processes in these fan deltas consisted of shifting, channelized flows and flash floods, including a component of mass-transport. Detailed mapping and correlation suggest that the radius of the coarse-grained facies generated by these fan deltas ranged from 4 to 5 km, but the sediment transportation at times surpassed this distance, mostly as sediment gravity flows fed by partial destruction of shallow water, shelf and fan-delta slope deposits. Well-rounded clasts suggest reworking of previous Neogene deposits, evidencing the cannibalistic nature of the basin.

Second-Order Megasequences (decametric scale)

Sequences of decametric scale are measured in the lenticular units that can be distinguished inside those hundreds of metres thick sediments cited above. In the area of La Naveta these second-order megasequences show coarsening and thickening upwards, interpreted as reflecting progradation of the delta front and alluvial fan environments of individual fan-delta lobes, inside the main complex of fan deltas. These lobes prograded or retrograded, adapting to previously formed morphologies, probably in response to relative sea-level changes (Dabrio, 1990).

Fan abandonment took place when subsidence did not compensate deposition, which is the case when lobes are moved away from the emitting valleys due to continued activity of the various strike-slip and normal faults involved. This is well represented in the area of Puerto de la Cadena.

Decimetric to metric third order sequences are found inside the previously described ones. They are interpreted in terms of diverse sedimentary processes: filling of channels, rapid deposition on the shelf after floods, settling of sediments after storms, etc. (see STOP 2-3).

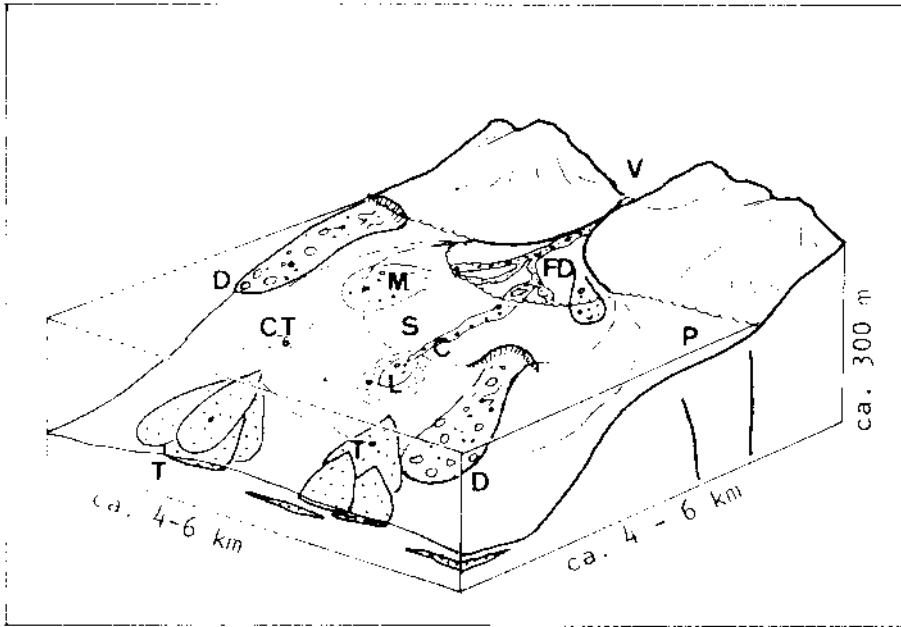


Fig. 17.—Model of a fan-delta lobe in El Puerto de la Cadena (STOP 2 - 3). Explanation in the text. Key: (V): fluvial valley; (FD): fan delta (letters on the subaerial zone); (P): narrow shelf; (S): prodelta and slope; (C): channel; (L): coarse grained lobe at the end of a submarine channel; (M): wave-winnowed gravels; (D): debris flows; (T): turbidites; (CT): turbidite channels (after Dabrio, 1990).

Fig. 17.—Modelo de un lóbulo de fan delta en el Puerto de la Cadena (PARADA 2 - 3). Explicación en el texto. Leyenda: (V) valle fluvial; (FD) fan delta; (P) plataforma estrecha; (S) prodelta y talud, (C) canal; (L) lóbulo de desembocadura de canal submarino; (M) gravas cernidas por las olas; (D) flujos de derrubios (debris flow); (T) lóbulos turbidíticos; (CT) canales turbidíticos (según Dabrio, 1990).

The Late Jurassic deposits of the Wollaston Forland (Greenland) have been interpreted as formed on slopes fed by fan deltas, related to large normal faults (Surlyk, 1978, 1984). The succession is 4 km thick and includes four fining upward megasequences (several hundred metres thick) thought to be related to tectonic activity. Smaller (second order) metric to decametric fining upwards sequences are interpreted as filling and abandonment of channels or surging flows, which were covered by hemipelagites afterwards. A close comparison of sequences and controls of sedimentation in this case-study and that of Carrascoy can be easily established, although the tectonic movements involved and the sedimentary processes interpreted are somewhat different.

Tectonically-active edges of basins usually result in association of fan deltas and submarine fans. This is the case of the Eocene-Oligocene deposits of the Santa Ynez Mountains (Van de Kamp *et al.*, 1974) where the so-called

episodes B (unstable slope with delta progradation) and D (unstable slope and fracturation of the margin of the basin) are similar to those invoked for Carrascoy.

Some aspects of the model of Carrascoy strongly resemble those of fractured slope aprons (Stow, 1985, 1986) with fan deltas building an active slope which feeds sediment gravity flows.

STOP 2 - 1: Panorama from Sierra del Puerto

Purpose

Panoramic view of the Murcia Depression, the faults running along its borders and the Basin of Mula.

Description

STOP 2 - 1 is located at the top of Sierra del Puerto (Fig. 14). UTM coordinates: 661.5; 4196 (Mapa General of Spain Serie L, Sheet 934). To reach such locality, drive from km 407.1 of N 301 to the west / southwest along an unpaved road for about 3 km ascending the mountain to a height of 500 m where the road opens to the north side of the sierra.

Looking northwest from STOP 2 - 1, the depression of Murcia can be seen. At the toe of the sierra there is a tectonic limit separating the pre-Neogene and Neogene rocks from the Late Pleistocene deposits inside the depression. Beyond the Alcantarilla airfield at the northern margin are the faults separating the almost flat, subsiding depression and the hilly landscape carved into the Late Neogene and Early Pleistocene sediments of Mula Basin (in the far end).

STOP 2 - 2: The Boundary of the basin and lower megasequences

Purpose

Observation of the faulted boundary between the pre-Neogene rocks of the Internal Zones of the Betics and the Late Neogene conglomerates which will be studied in detail in STOP 2 - 3.

General look at the transgressive megasequences of the conglomeratic alluvial fan and fan delta deposits (*Puerto de la Cadena conglomerate*).

Description

STOPS 2 - 2 and 2 - 3 are located along the same unpaved road but on the way back to N 301. STOP 2 - 2 is located some hundreds of metres southeast

of the former. There is a position from which a valley opens to the northeast and the prominent, isolate, flat-topped Cabezo del Puerto with the ruins of the castle is visible.

From this point a close-up, and a panoramic view of the limit is possible. Pre-Neogene rocks are made of phyllades and well-stratified carbonate rocks (mostly dolostones) along with some igneous rocks. The Late Neogene deposits are represented by the "Puerto de la Cadena conglomerate". Note that there are abundant clasts of igneous rocks in the conglomerates which are derived from rocks similar to those which form the substratum in the immediate vicinity of the fault as seen in the roadcut.

We continue walking along the road and a section of two terrestrial to marine sequences of conglomerates are observed. Pay also attention to the nice panoramas of these sequences, exposed in the neighbouring hills in both sides of the road.

The passage from the alluvial part of these megasequences to the marine deposits is gradual and it is indicated by a change in colour which turns yellow and the occurrence of marine fossils (*Ostreids* and *Pectinids*).

A close up of one of these layers cropping out in the road allows us to observe extensive deformation of the internal structure (Fig. 18).

STOP 2 - 3: Fan-Delta front and slope facies

Purpose

Study of the transition from alluvial fan to delta front and delta slope facies in the section of Puerto (pass through mountains) de la Cadena (Fig. 19).

Description

STOP 2 - 3 (Fig. 20) is placed in the southern side of Puerto de la Cadena, very near (west) km 403.3 (road N 301), between Casa Motor (pumping house) by the unpaved road used to reach the former STOPS, and a farm crowning a little hill (adjacent to the unpaved road and separating it from N 301). The upper parts of the section are best visited moving around the little hill and south of it (Fig 21).

The fining and thinning megasequences consist of three units (not always easy to distinguish) separated by sharp vertical changes (Fig. 19). The lower unit is channel-fill dominated conglomerate (C-1) with scattered remains of marine fossils. In the middle unit, alternations of fossiliferous calcarenites (roughly described as S-1 and S-3) and unconfined conglomerate (C-2) are thought to record the active fan delta front, with incised channels and poorly-developed sublittoral deposits which may be the result of rapid deposition. The upper unit consists of tabular to gently wedge-shaped layers of calcarenites

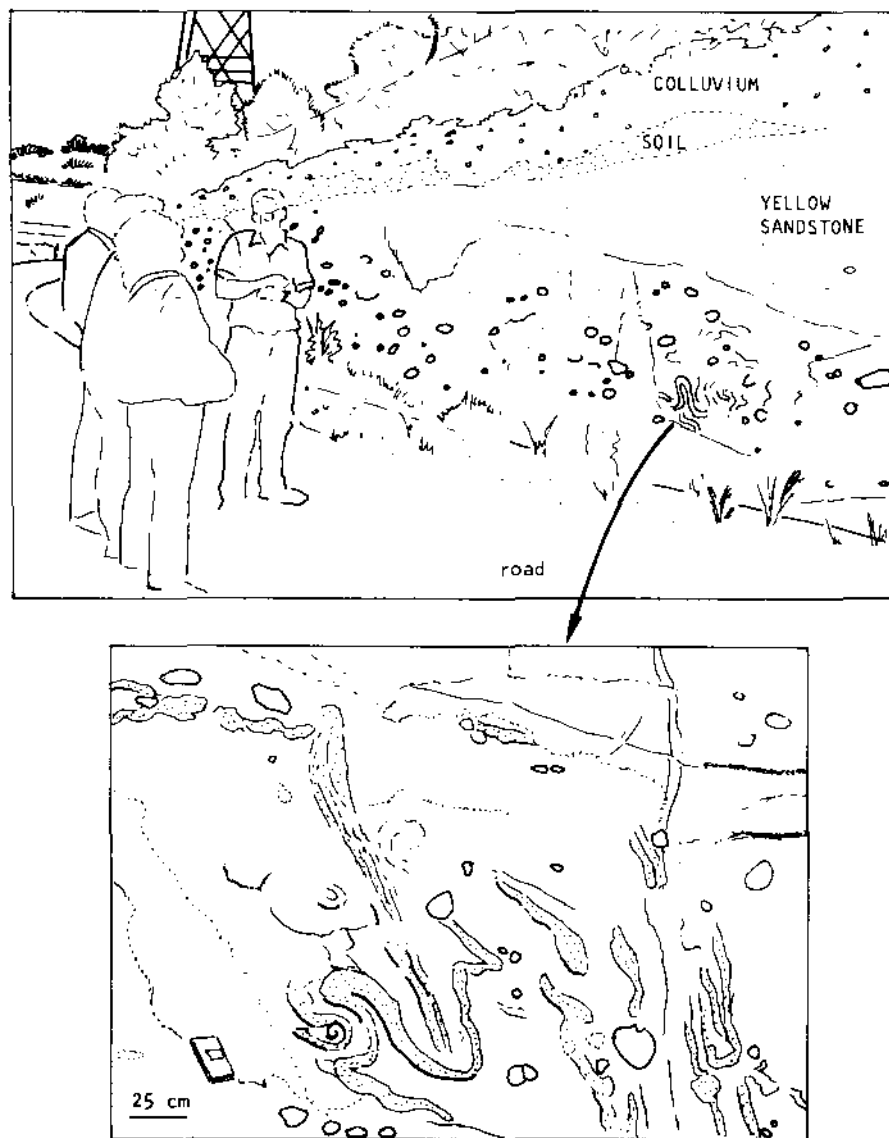


Fig. 18.—Above: a fossiliferous layer of yellow sandstones with scattered pebbles and water-escape deformation at the top of a transgressive sequence of fan-delta lobe. Note a thicker layer of conglomerates (facies C-2, see Table I) behind people standing on the road. Below: detail of deformation; dotted layers are more cemented sandstone layers.

Fig. 18.—Arriba: un nivel fosilífero de areniscas amarillentas con cantos dispersos y deformación por escape de agua sobre una secuencia transgresiva de lóbulo de fan delta. Obsérvese un nivel más grueso de conglomerados (facies C-2, ver Tabla I) sobre las personas que están en pie en la carretera. Abajo: detalle de la deformación; las capas punteadas son capas de arenisca más cementadas.

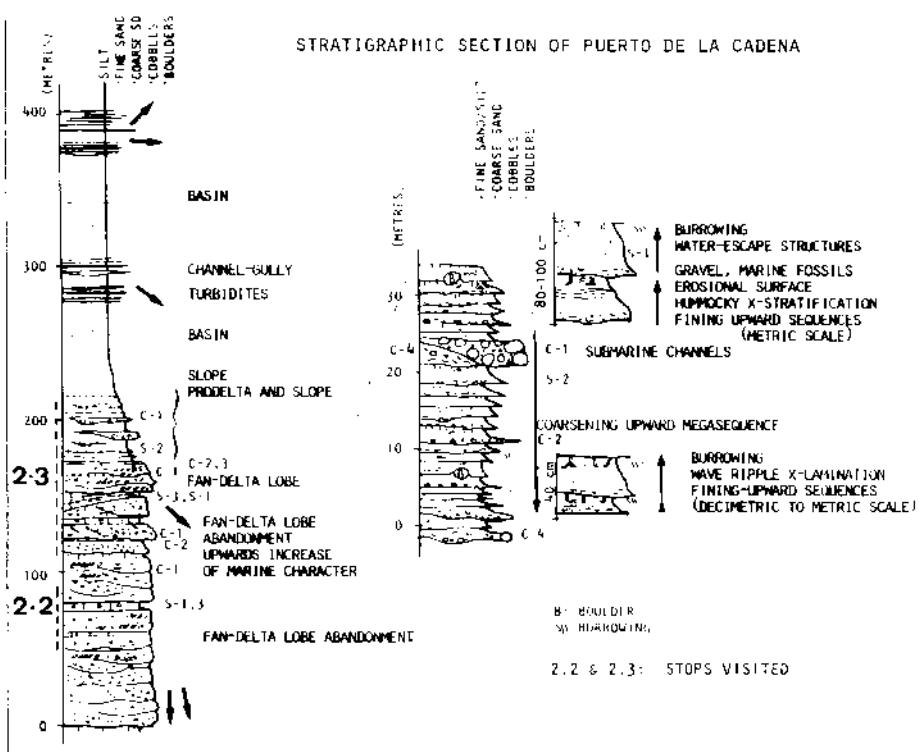


Fig. 19.—Stratigraphic succession of the Puerto de la Cadena Conglomerates near km 407.100 of road N 301 (Murcia-Cartagena) in the central part of the Carrascoy mountains. A detail of prodelta and slope facies is included. Note scattered boulders (B) in sandy deposits.

Fig. 19.—Serie estratigráfica de los Conglomerados del Puerto de la Cadena cerca del kilómetro 407,100 de la carretera Nacional 301 (Murcia-Cartagena) en la parte central de la Sierra de Carrascoy. Se incluye un detalle de las facies de prodelta y talud con bloques aislados caídos (B) en los sedimentos arenosos.

and conglomerate with various vertical structures (C-2, C-3 and C-4). They correspond to littoral and sublittoral deposits on the subsiding, transgressed fan delta lobe (Fig. 19).

Fan abandonment took place when subsidence did not compensate deposition, which is the case when lobes are moved away from the emitting valleys.

Facies Association

Dabrio & Polo's (1988) informal terminology may help to simplify descriptions.

C-1: conglomeratic channel-fills, marine fauna. Submarine channels and gullies.

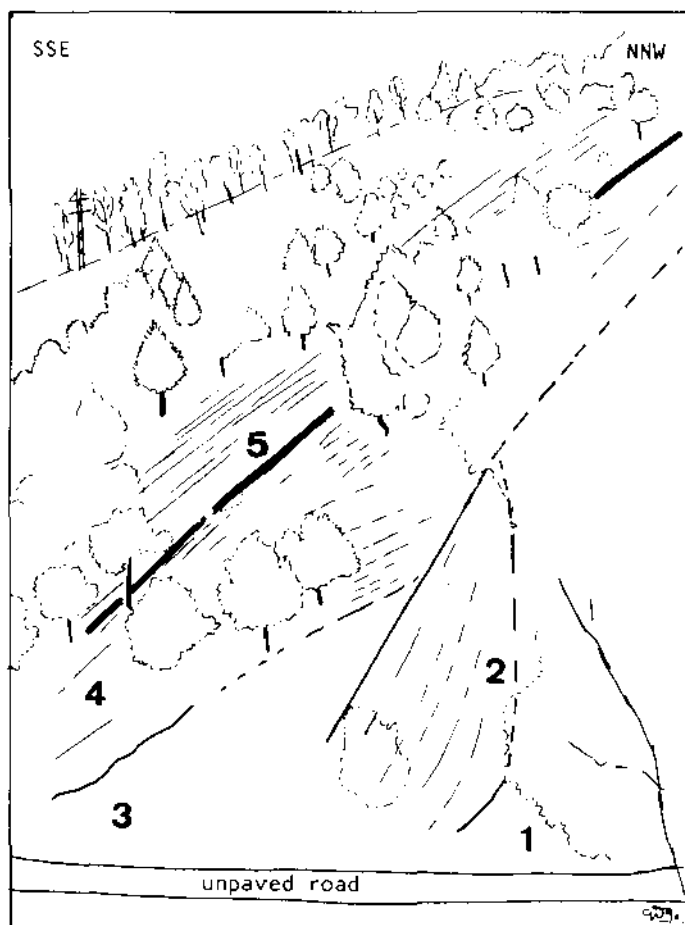


Fig. 20.—Panorama of the topmost part (transitional from terrestrial to marine) of a fan-delta lobe megasequence at STOP 2 - 3 (west of Puerto de la Cadena). Key: (1): conglomerates with thin layers of fossiliferous yellowish calcarenites (partly C-1); (2): channel-shaped body of conglomerate with channel-fill cross bedding: channel with marine influence, in the fan-delta front; (3): yellowish sandstone to calcarenites (S-1); (4): large channel-shaped body of conglomerate with channel-fill cross bedding (backset?, lateral accretion??); (5): sandstones and conglomerates (S-3 and S-1), passing upwards into parallel-laminated, fine-grained, micaceous sandstones (S-2) (see text for meaning of letters). Compare with Dabrio & Polo (*this volume p. 55*)

Fig. 20.—Panorama de la zona de superior (transición de continental a marino) de una megasecuencia de lóbulo de fan delta en la PARADA 1 (oeste de El Puerto de la Cadena). Leyenda: (1): conglomerados con niveles finos de calcarenitas fosilíferas amarillentas (parcialmente C-1); (2): cuerpo canalizado de conglomerados con estratificación cruzada de relleno de canal: canal con influencia marina en el frente deltaico; (3): calcarenitas a areniscas amarillentas (S-1); (4): gran cuerpo de conglomerados de morfología canalizada y estratificación cruzada de gran escala de relleno de canal (backset? acreción lateral??); (5): areniscas y conglomerados (S-3 and S-1), que pasan hacia arriba a areniscas micáceas con laminación paralela (S-2). El significado de las siglas se indica en el texto. Compárese con Dabrio y Polo (*este volumen* pág. 55).

C-2: conglomeratic layers with marine fauna. (a) Wave-produced lag deposits after fan-derived gravels; (b) reworking of shallow marine (shoreface) sediments.

C-3: Parallel-stratified, clast-supported conglomerates, imbricated clasts, marine fauna. Coastal to sublittoral deposits.

C-4: Unstratified, matrix-supported conglomerates. Subaqueous debris-flow deposits.

S-1: Parallel-stratified, coarse sandstones to fine pebble conglomerates, marine fauna. Reworking of fan-derived sediments by waves and (or) currents in shallow-marine and shoreface / foreshore zones of fan deltas.

S-2: Parallel-laminated, fine-grained, micaceous sandstones to siltstones. Suspensional settling of fines on shallow-marine fan-delta front and slope, near or below fair-weather wave-base.

S-3: Parallel-laminated, cross-bedded and wave-ripple cross-laminated sandstones to micaceous siltstones. Lower foreshore to transition zones of shallow-marine fan deltas.

M: Massive, red sandy mudstone, scattered clasts. Settling of fines after flooding.

Several sedimentary facies have been distinguished.

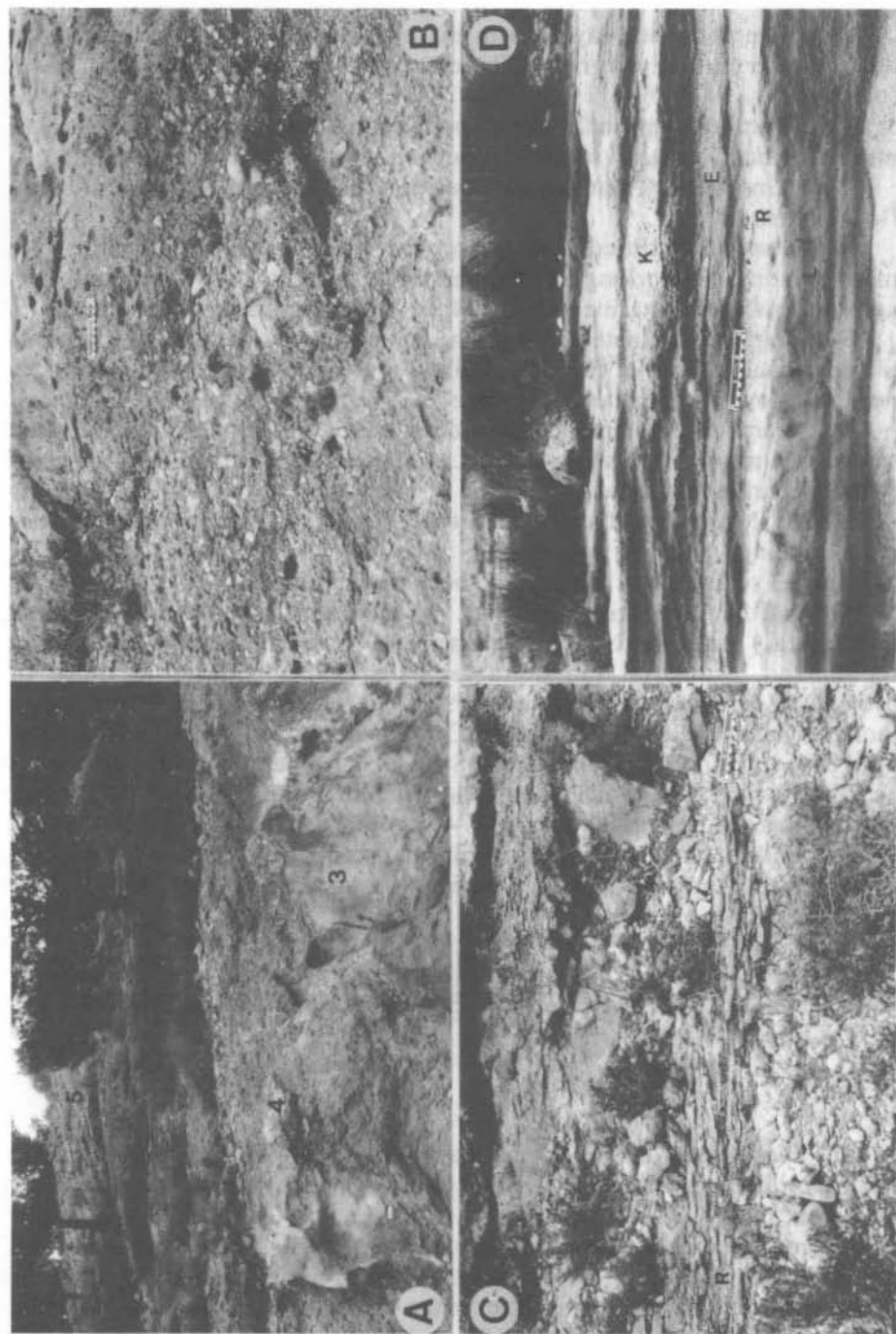
Alluvial fan (subaerial fan delta), subaqueous fan delta (both proximal and distal) and distal talus-slope and basinal facies have been recognized. Subaerial fan delta facies are very similar to those of previously-described alluvial fans. Proximal subaqueous fan delta facies include channelized conglomerates (C-1), disorganized conglomerate (C-2, C-3, C-4) and laminated sandstones (S-1). Distal subaqueous fan delta facies are marked by yellowish sandstone and siltstones (S-1 to S-2) with interbedded conglomerate (C-1 and C-4) layers. Distal talus-slope and basinal facies include hemipelagic light-grey silty marlstones and decametric sequences of turbidites. A more complete description is given in Dabrio & Polo (*this volume*).

THIRD DAY: PLEISTOCENE FAN DELTAS IN THE LOWER SEGURA RIVER BASIN

General

The Elche Basin-Lower Segura Basin is located in the eastern end of the Betic Cordillera at the northern end of the «left lateral shear zone» defined by Montenat *et al.* (1987).

Geomorphological and sedimentological analysis of the area show that the present configuration of this coastal segment is intimately related to the neotectonic activity of the final tract of the «left lateral shear zone» along the Quaternary (Goy *et al.*, 1989 a).



During Late Pliocene (Fig. 22) the sea occupied a large area extending to the toe of the Sierra (range) de Crevillente, Segura Massif, Sierra de Carrascosy and Sierra de Cartagena reliefs evidenced by yellow, fossiliferous calcarenites deposited in the shallow marine shelf which opened towards the southeast. Lower Pleistocene uplift of the previously cited reliefs triggered a widespread regression and the shoreline came to rest much closer to the present position. Barrier island and lagoonal marine facies (Fig. 23) forming the so-called «El Moncayo - El Molar Transitional Unit» (Somoza, 1989; Goy *et al.*, 1989 a) witness this marine-terrestrial limit along Sierra del Molar, Sierra del Moncayo, Rojales, Puerto de San Pedro, etc. Progradation towards the southeast is visible in this Unit.

The uplift of the surrounding reliefs favoured the deposition of alluvial fans as well. Distal facies of these alluvial fans overly the «El Moncayo-El Molar Transitional Unit» in the area of El Moncayo, El Molar and Sierra de Columbares.

A reactivation of the final (eastern) tract of the «left lateral shear zone» during Lower-Middle Pleistocene occurred due to the welding of the Palomeras-Alhama and Vélez Rubio faults together with movements along the N120-130° E fault systems. As a consequence a sudden palaeogeographical change took place across the whole area with change of lithologies and direction of progradation of marine units.

In this time, the Lower Segura Basin was generated in a zone of strong subsidence (Fig. 22, 23 and 24). The Segura River brought up quartzitic, Betic-derived, sediments from the west to the new basin which formed fan deltas, known as the «Segura Conglomerates» (Goy *et al.*, 1989 b). In Rojales and La Zeneta outcrops only the most coastal facies of the «Segura Conglomerates» can be observed forming fossil beaches which prograded towards the north and east.

The generation of the Elche and the Lower Segura Basins is responsible for the separation of the proximal and the distal facies of the older alluvial fans (Goy & Zazo, 1989).

Fig. 21.—(A) Close up of figure 20 with same meaning of numbers; note large scale cross bedding (U) with pine trees for scale. (B) gradual transition from conglomerates to sandstones in a position equivalent to 4 but to the east of the unpaved road. (C) lenticular lamination, probably related to wave ripples, a few metres to the east of the previous picture. (D) Typical normal-graded, yellowish sandstones overlaying Puerto de la Cadena Conglomerate. (L) parallel lamination; (R) burrowing; (E) erosional base of sequence; (K) coarse sandstone to fine gravel. Ruler is 15 cm long. Compare with Polo & Dabrio (*this volume*).

Fig. 21.—(A) detalle de la figura 20 con el mismo significado de los números; obsérvese la estratificación cruzada (U) con los pinos como escala. (B) tránsito gradual de conglomerados a arenas en una posición equivalente a 4 (ver figura 21) pero al este del carril. (C) laminación lenticular relacionada probablemente con ripples de oscilación, unos metros al este de la anterior. (D) secuencia granodereciente típica en las areniscas amarillas sobre los Conglomerados del Puerto de la Cadena. (L) laminación paralela; (R) bioturbación; (E) base erosiva de la secuencia; (K) arenisca gruesa a grava fina. La regla mide 15 cm. Compárese con Dabrio y Polo (*este volumen*).

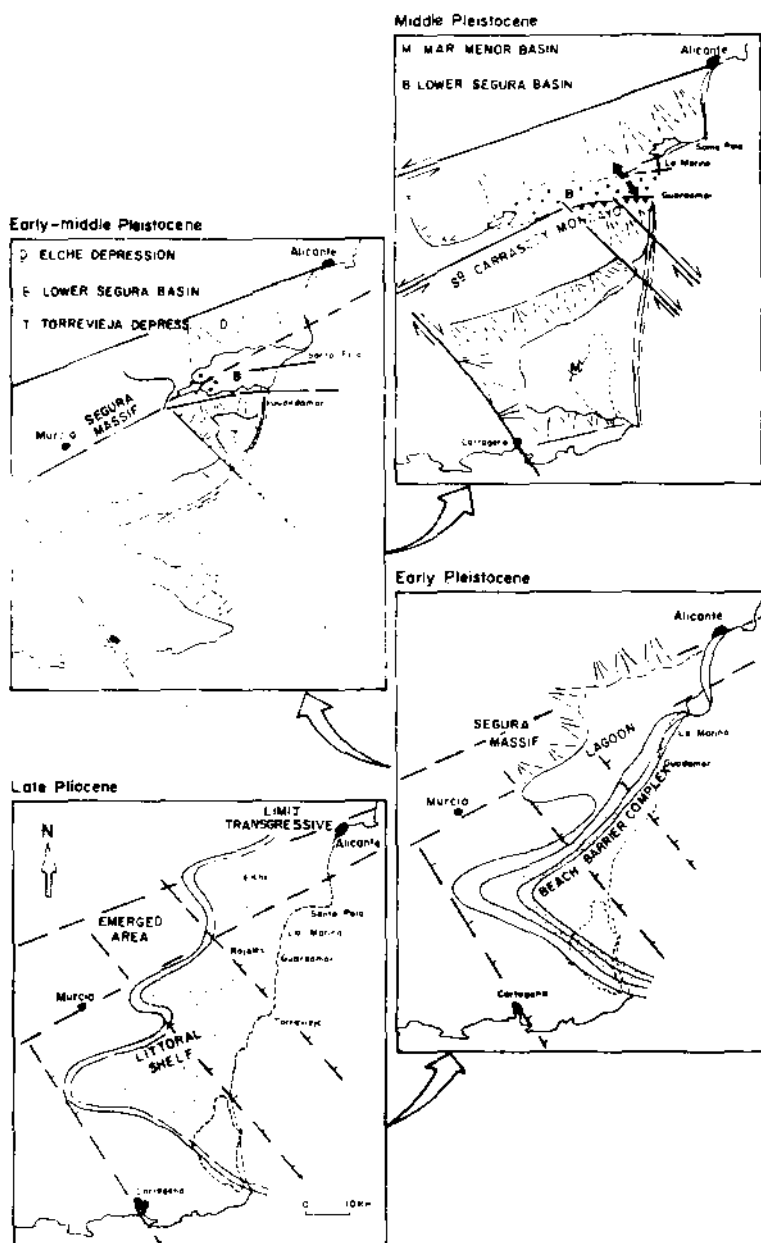


Fig. 22.—Schematic paleogeographical evolution of the Elche, Lower Segura and Mar Menor Basins during Late Pliocene to Middle Pleistocene (after Goy *et al.*, 1990).

Fig. 22.—Evolución paleogeográfica esquemática de las cuencas de Elche, Bajo Segura y Mar Menor durante el Plioceno Superior al Pleistoceno Medio (según Goy *et al.*, 1990).

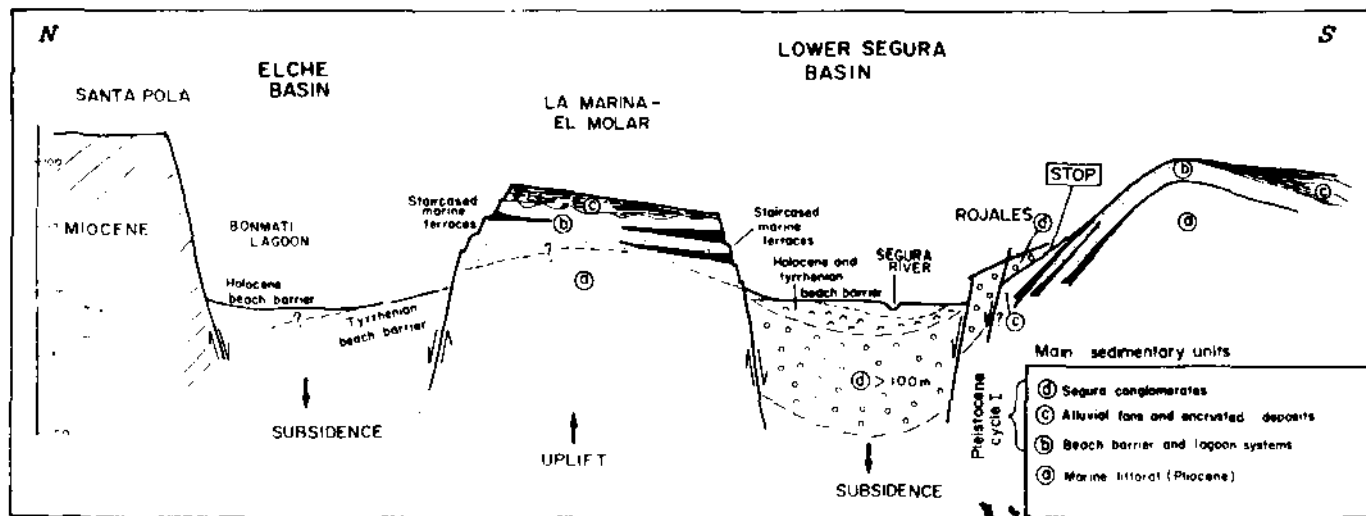


Fig. 23.—Schematic section of the Plio-Quaternary episodes between the «Elche Depression and the Lower Segura Basin» (after Goy *et al.*, 1989 a, and Somoza, 1989). Location of STOP 3 - 2 near the village of Rojales is indicated.

Fig. 23.—Corte esquemático de los episodios Plio-Cuaternarios entre la Depresión de Elche y la Cuenca del Bajo Segura (según Goy *et al.*, 1989 a, y Somoza, 1989). Se indica la posición de la PARADA 3 - 2 cerca de Rojales.

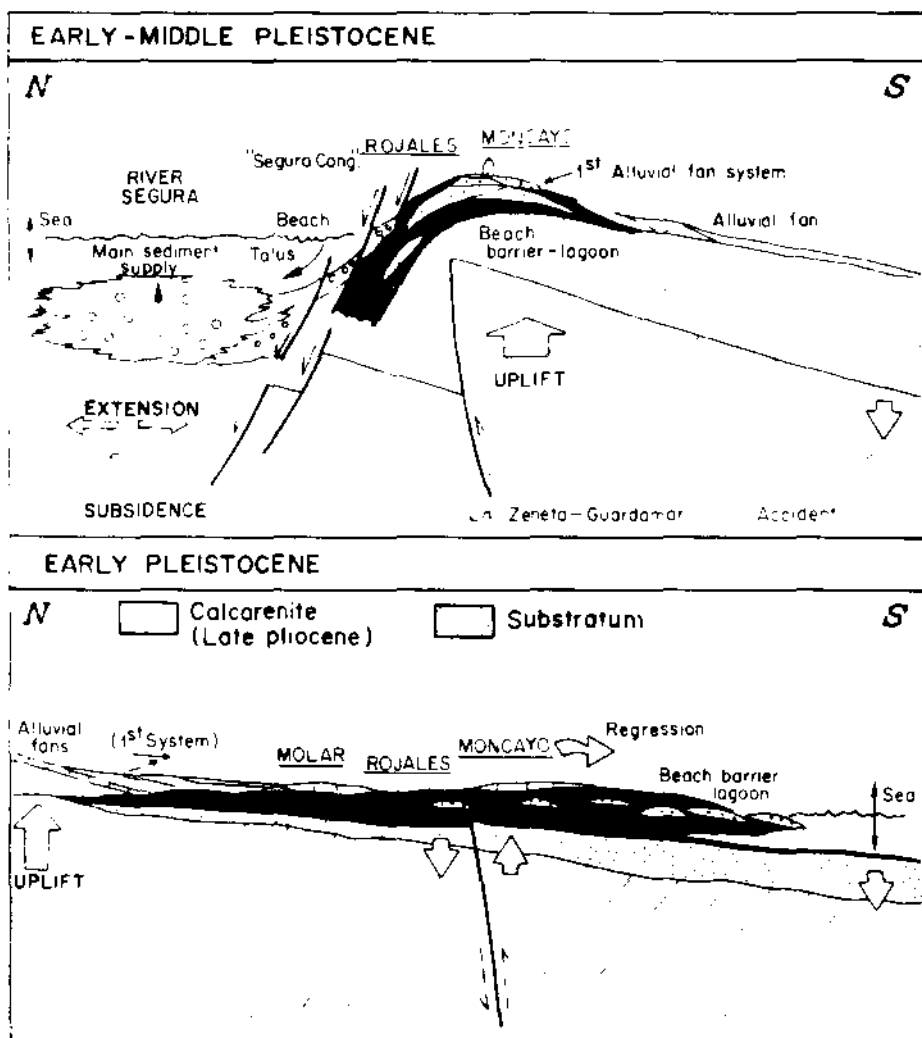


Fig. 24—Evolution of marine and terrestrial sedimentary facies in the tectonic framework of the Elche - Lower Segura Basin during Early Pleistocene and Early-Middle Pleistocene (after Goy *et al.*, 1990).

Fig. 24.—Evolución de las facies sedimentarias marinas y continentales en el marco tectónico de la Cuenca de Elche-Bajo Segura durante el Pleistoceno Inferior y el Pleistoceno Inferior-Medio (según Goy *et al.*, 1990).

This arrangement of facies can be envisaged as a long, but narrow (3 to 6 km wide), trough limited by faults from the positive topographic reliefs. Two major rivers, the Segura flowing from the north and the Guadalentín from the west, joined at the western extremity and supplied sediment to the

basin. At the other end (east) of this corridor-like basin, opened the Mediterranean sea.

Secondary accumulations of sediments, generated by lateral inputs (normal to the edge of the basin) favoured by alluvial streams which followed transverse (NW-SE) faults. Illustrations of this are the cases of La Zeneta and Jacarilla deltas (Fig. 25).

The large, mostly-longitudinal input of sediment was faced with a very restricted capacity of the marine dynamic agents to redistribute or rework the continuously-growing accumulation of sediments. Both factors coupled to produce a huge prism of sediments which rapidly filled the more-than-50-km-long basin.

Thus, the «Segura Conglomerates» are fan-delta deposits (Goy *et al.*, 1989) which filled a deep basin (more than 200 m of this unit have been drilled in places nearby, Gauyau, 1977) with development of fan deltas and beaches, similar to those of Rojales, along the edges.

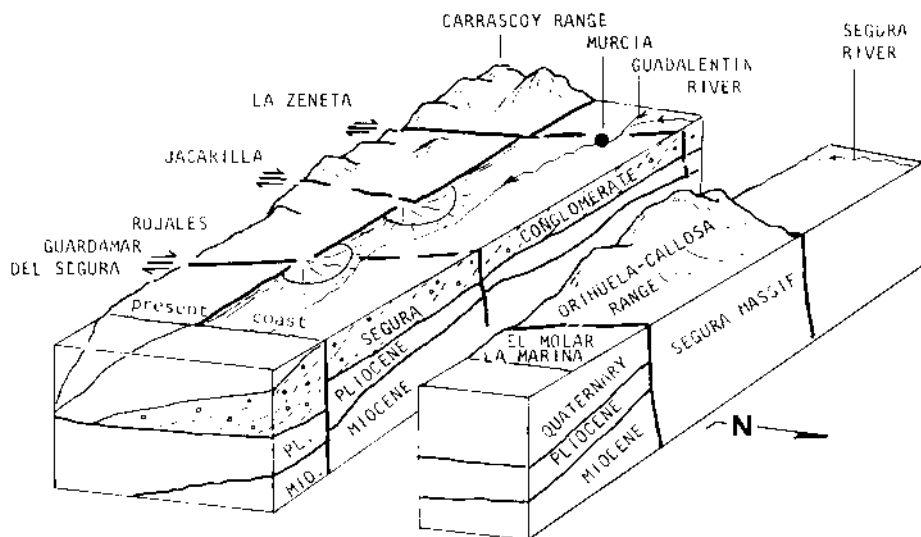


Fig. 25.—Ideal diagrammatic block to show the geometric relationships of units in the Lower Segura Basin area and the sedimentary filling of the basin. Note that the block has been divided into two parts along the northern fault limiting the basin. The names of some localities have been incorporated to facilitate a rapid comprehension. No precise scales involved but the area pictured is about 50 km long and 15 km wide.

Fig. 25.—Bloque diagrama ideal que ilustra las relaciones geométricas de las unidades de la Cuenca del Bajo Segura y el relleno sedimentario de la cuenca. Se ha dividido el bloque en dos partes según la falla que limita la cuenca por el norte. Se han incorporado los nombres de algunas localidades para facilitar la comprensión. No hay escalas definidas pero el área recogida en la figura abarca unos 50 km de longitud por 15 de anchura.

STOP 3 - 1 A: The Segura conglomerates at La Zeneta

Purpose

Observation of the facies of the Pleistocene Segura Conglomerates at one of the more internal (western) outcrops preserved.

Description

The studied section is one of the outcrops of the «Segura Conglomerates», placed more to the western part of the basin (Fig. 3). The section is located in a group of quarries, 200 m to the north of a filling station built on Km 2.5 of the road Arneva-El Mojón.

STOP 3 - 1 A is the almost vertical face of a quarry (Figs. 26, 27, 28 A and 28 B), a few metres to the east of the unpaved road going to a electric transformator and into the *huerta* (irrigated land with orange and lemon trees).

A most prominent feature of deposits of Segura Conglomerates in this outcrop is the steep inclination of layers to the north, which is related to very active subsidence in recent times along the faults limiting the Lower Segura Basin.

These rocks exhibit most of the characteristics of the Segura Conglomerate (Fig. 27 & 28). A very important feature is the massive occurrence of clasts of quartz and quartzite, in addition to the more common clasts of dolostones and metamorphic rocks, supplied by the (adjacent) sierras where these rocks of the Internal Zones of the Betics crop out, and those derived from erosion of the Neogene rocks (fossiliferous limestones, calcarenites and sandstones).

There are also conglomeratic layers with a marked yellow colouration (*cf.* metres 5 to 8) which also is consistently related to this unit (Fig. 27A & 28 A).

Grain sizes change abruptly along the section. Conglomerates with sandy matrix (matrix is medium to coarse sand), sandstones and mudstones are present. It is very unusual to find layers with well rounded clasts with sizes of about 2 to 3 cm (median diameter), but there are coarser clasts (pebbles and boulders). These larger sized clasts occur both at the base and to the top of certain layers. Coarse-tail direct and inverse granoselection (coarsening and fining upwards sequence) are observed in several layers. At least one layer exhibits both types (*cf.* metre 17).

In the uppermost part (Fig. 27B & 28 B), channels with steep walls are filled up with fine sands. Parallel lamination and small slumps are visible. Note root horizons below conglomeratic layers (metre 42).

All these conglomerates lay upon a reddish unit of clays with interlayered channel-shaped units of sandstone and conglomerates. These materials are poorly visible in the upper quarry to the south of figure 26, but they are better exposed in the southern side of the residual pieces of hill between two quarries

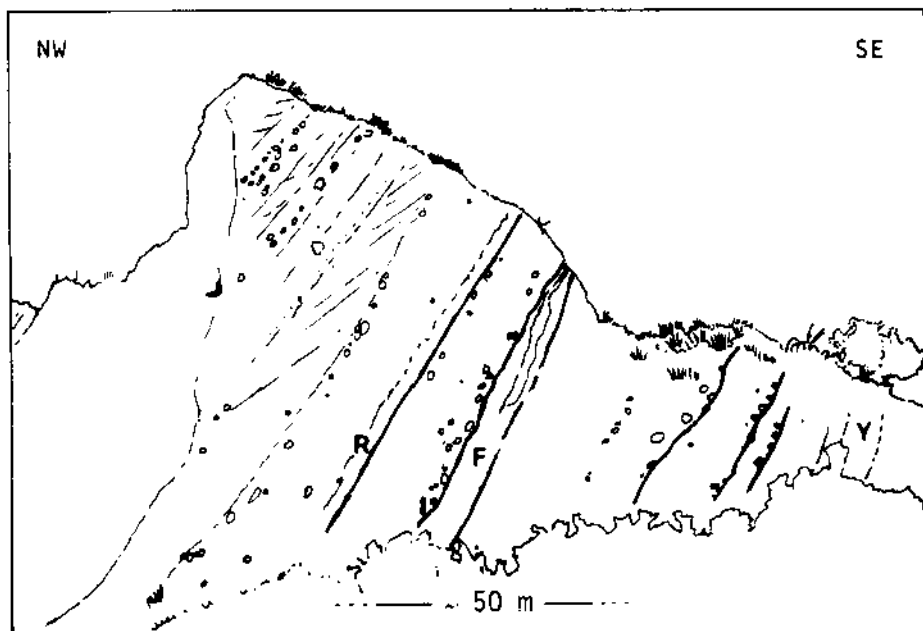


Fig. 26.—Panorama of STOP 3 - 1 A with the Segura Conglomerates exposed in a quarry behind the lemon trees which partly block the view of the lower part. Note two olive trees standing to the right for approximate scale. Same letters as in figures 27 and 28. Top of the section to the north (left of the observer).

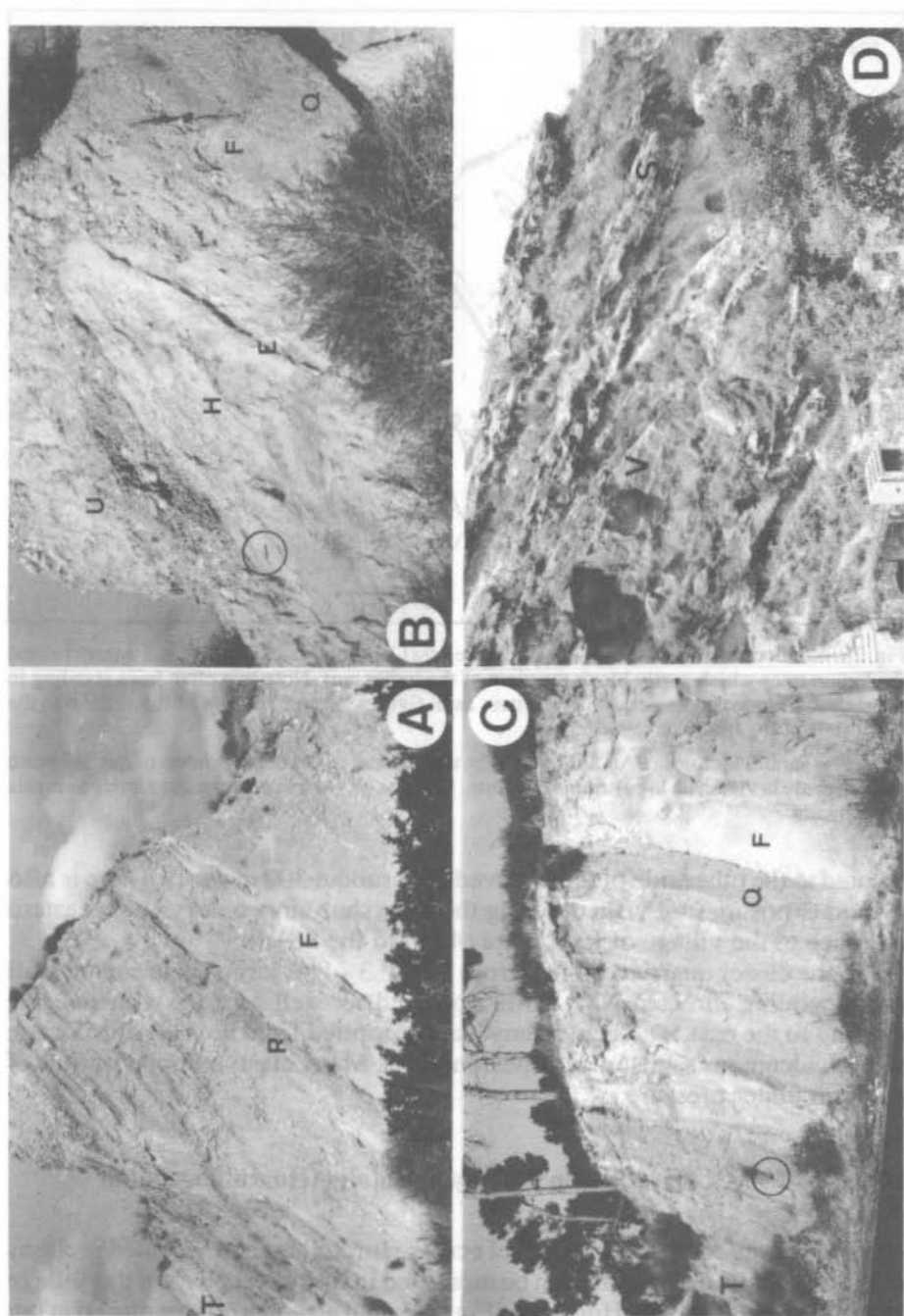
Fig. 26.—Panorámica de la PARADA 3 - 1 A en una cantera detrás de los limoneros que bloquean parcialmente la visión de la parte baja del corte. Hay dos olivos a la derecha que sirven de escala aproximada.

located to the other side of the unpaved road (about 300 m west). There is also a good exposure (not visited during the workshop) in a quarry at the eastern entrance to the village of La Zeneta (4 km to the SSW).

In the closer quarries, visible from STOP 3 - 1 A, large-scale channel-fill cross-bedding directed NW-SE is observed as well as bars with foresets dipping to the east. There are many clasts supplied from erosion of Miocene rocks (calcareous sandstones, limestones, ...). Many clasts exhibit imprints of solution under pressure.

STOP 3 - 1 B: Observations in the way to Rojas (Hurchillo section)

On the way to Rojas we travel across Hurchillo where detailed sections of the Segura Conglomerate can be measured in the roadcut east of the village along the road Bigastro-Hurchillo (Fig. 29), and also in a quarry placed at km 1 on the same road. These sections are similar to the one studied in STOP 3



1 on the same road. These sections are similar to the one studied in STOP 3

- 1 A and are not considered in detail for logistic reasons during the workshop.

The Segura Conglomerates are vertical and, even, overturned to the north in the roadcut of Hurchillo (Figs. 27 C and 29, where top is to the left of the observer). This indicates a prominent subsidence along the faults limiting the Lower Segura Basin.

The 40 m-thick exposed section displays fluvio-lacustrine deposits with successive incised channels filled up with gravel and sands. Most paleocurrents point to northeast and southeast but we found almost opposite measurements, probably related to high variability of channel orientations.

STOP 3 - 2: The Segura conglomerates at Rojasles

Purpose

Observation of the palaeogeographical and lithological change, produced during the Early Pleistocene in the Elche Basin, by the generation of the Lower Segura Basin as an result of the tectonic activity of the final (eastern) part of the sinistral Alhama fault.

Description

Several unconformable units can be distinguished in the outcrop visible just south of the village of Rojasles (Fig. 30 & 31). Fault systems running N50° E, N120°-130° E and E-W cut the rocks of the section.

In ascending order, the measured section (Fig. 31) consists of several descriptive intervals:

Interval (a) is made up of fine to medium yellow sands with lumachellic layers of Ostreids and Pectinids. Sedimentary interpretation suggests wave-dominated shallow marine to sublittoral environments. The age of these

Fig. 27.—(A) The quarry at STOP 3 - 1 A. Same letters as in figures 26 and 28 (T: top). (B) Upper part of the section in STOP 3 - 1 A, just to the left of the former photograph. Note erosional base (E) of channel cutting conglomerates (Q) and sands (F) filled with fine sediments (H) with small slumps. Conglomerates (U) covering both deposits. Encircled ruler for scale is 15 cm long. (C) Upper half of section in Hurchillo; Q: conglomerates; F: sands and silts; T: top. Encircled hammer for scale is 30 cm long. (D) Southeastern side of the hill in Rojasles (STOP 3 - 2) and the Segura Conglomerate (S). Note wedging out of the upper unit d (V) of figure 31.

Fig. 27.—(A) La cantera de la PARADA 3 - 1 A con la mismas letras que en las figuras 26 y 28 (T: techo). (B) Parte superior de la sección de la PARADA 3 - 1 A, justo a la izquierda de la fotografía anterior. Obsérvese la superficie erosiva (E) de un canal que corta conglomerados (Q) y arenas (F), relleno de sedimentos finos (H) con pequeños desplomes. Una capa de conglomerado (U) cubre ambos depósitos. La regla (círculo) mide 15 cm. (C) Mitad superior del corte de Hurchillo; Q: conglomerados; F: arenas y limos; T: techo. El martillo del círculo mide 30 cm. (D) Ladera sureste de la colina de Rojasles (PARADA 3 - 2) y el Conglomerado del (S). La parte superior de la Unidad de la figura 31 se acuña lateralmente (V).

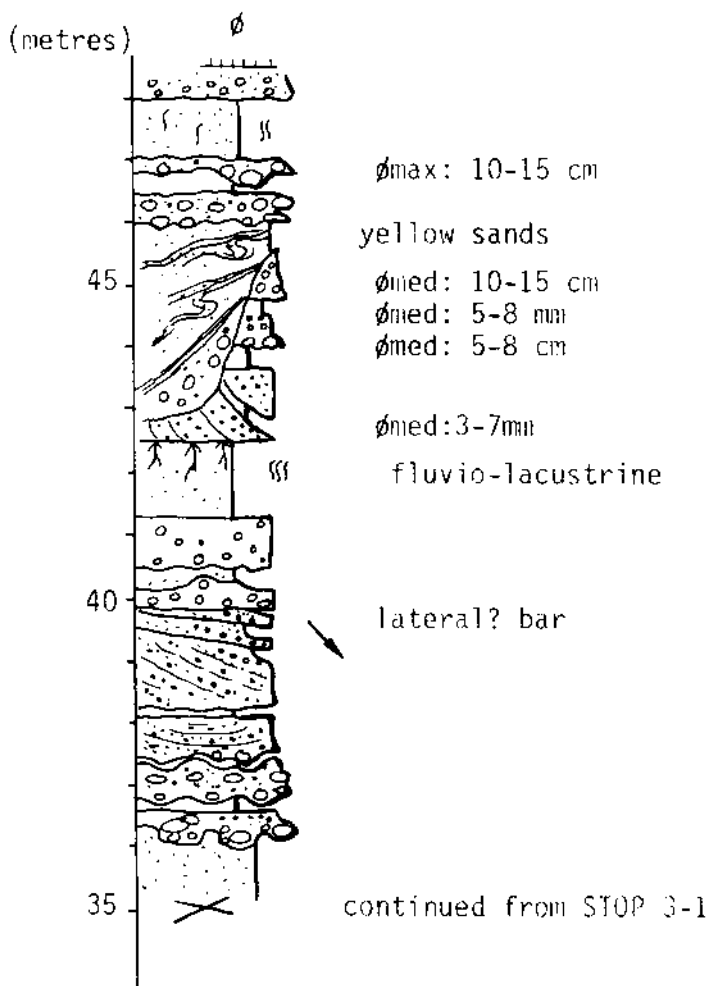


Fig. 28.—Stratigraphic section of the Segura Conglomerates at STOP 3 - 1 A. (A, left): section depicted in figure 27 A. (B, right): The upper part of the section in the northern side of the quarry. Letters Y (yellow), F (fines) and R (reddish) are inserted also in figures 26 and 27 A for correlation.

Fig. 28.—(A, a la izquierda) Columna estratigráfica de los Conglomerados del Segura en la PARADA 3 - 1 A que aparece en la figura 27 A. (B, a la derecha) parte superior de la sucesión en el extremo norte de la cantera. Las letras Y (amarillo), F (finos) y R (rojizo) son las que aparecen también en la figuras 26 y 27 para comparación.

deposits is Late Pliocene, although micropaleontological precision does not go beyond the *Globorotalia crassaformis* biozone.

Interval (b): variegated clays interpreted as lagoon sediments, resting unconformably on top of the former.

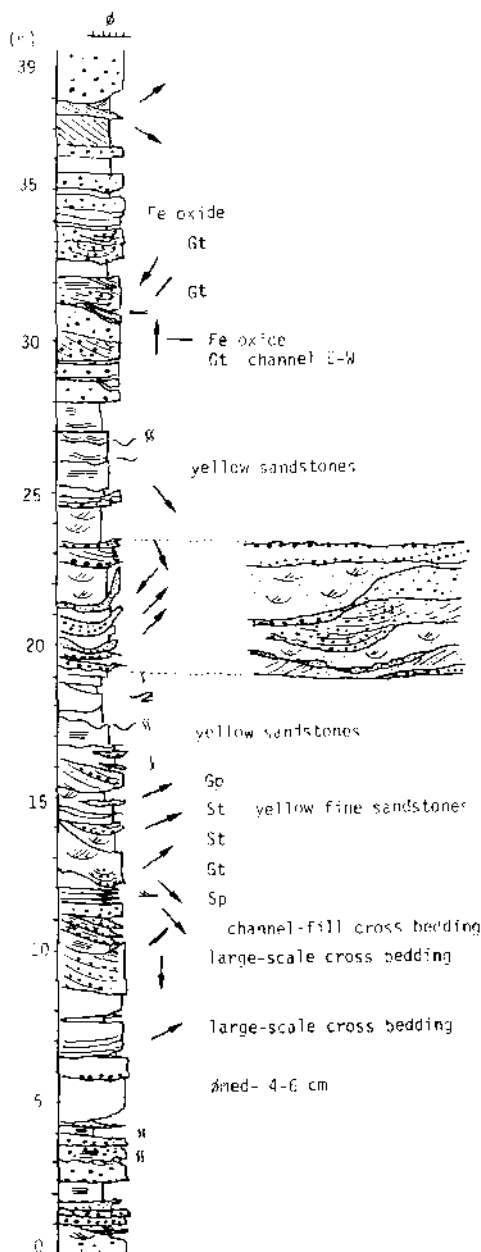


Fig. 29.—STOP 3 - 1 B: Section in the curve of the road Hurchillo-Bigastro, near km 1.

Fig. 29.—PARADA 3 - 1 B: sucesión del talud de la carretera de Hurchillo a Bigastro en la curva cercana al kilómetro 1.

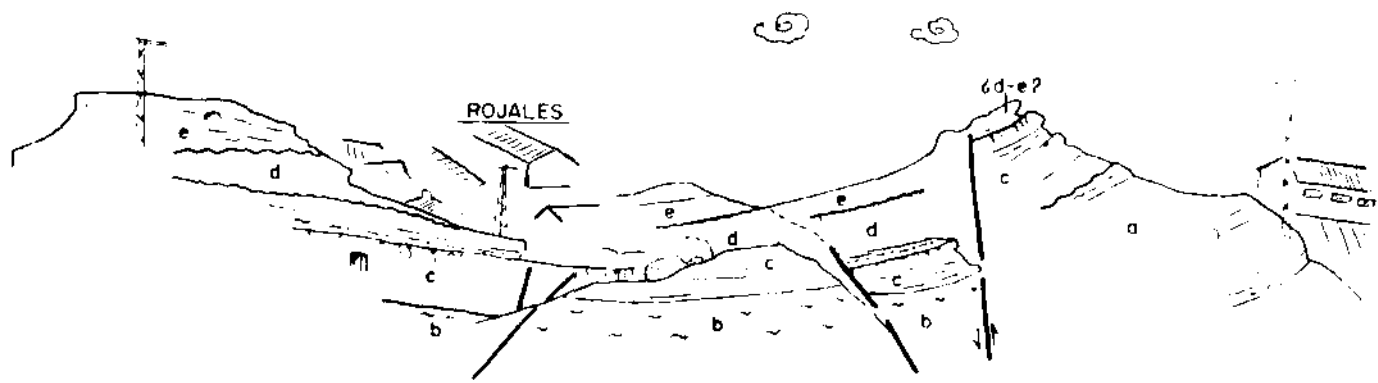


Fig. 30.—Outcrop of the Plio-Pleistocene continental and marine deposits in Rojas (Lower Segura Basin). a, b, c, d, e: are Units described in figure 31 (After Goy *et al.*, 1990).

Fig. 30.—Afloramiento de depósitos marinos y continentales plio-pleistocénicos en Rojas (Cuenca del Bajo Segura). a, b, c, d, e: unidades descritas en la figura 31 (según Goy *et al.*, 1990).

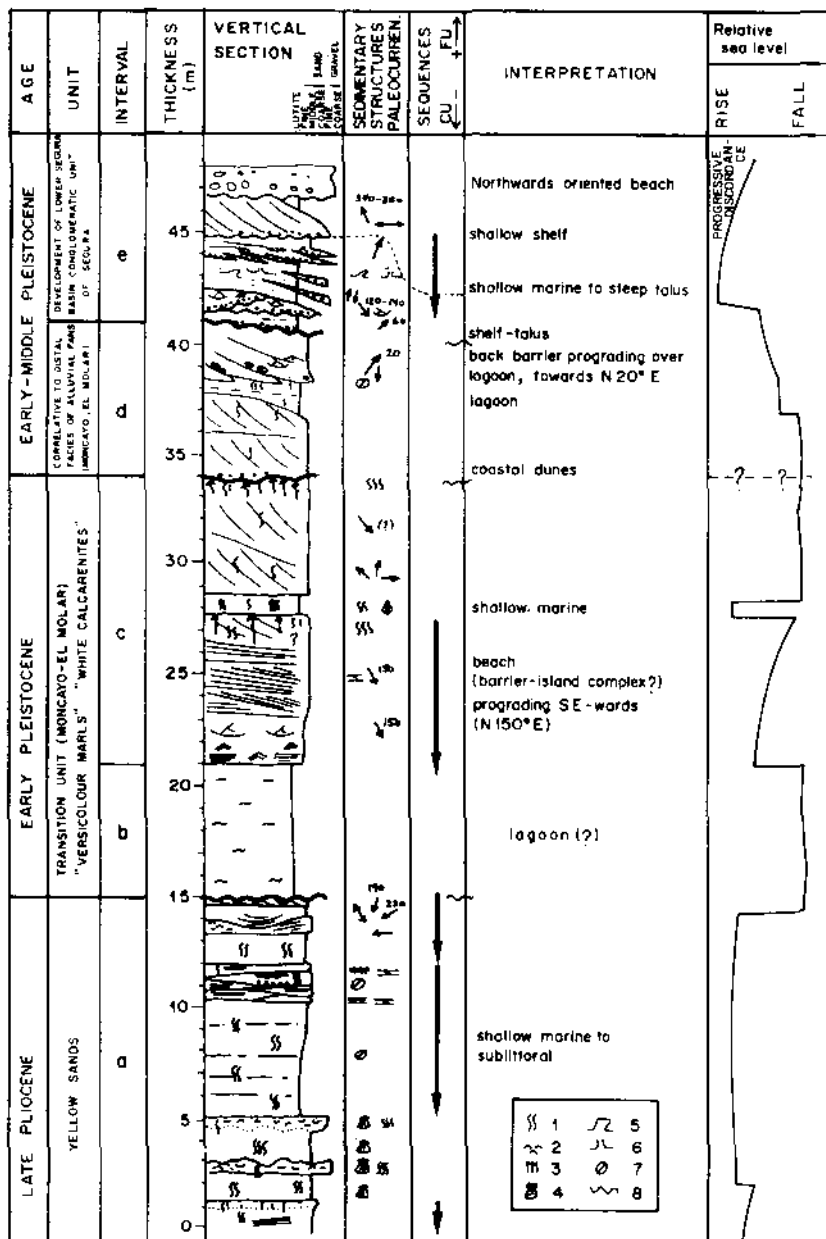


Fig. 31.—Section of Rojales. Sequence of Plio-Pleistocene marine and terrestrial deposits (after Goy *et al.*, 1990).

Fig. 31.—Columna de Rojales. Secuencia de depósitos marinos y continentales plio-pleistocénicos (según Goy *et al.*, 1990).

Interval (c): it is a complex unit mostly composed of white calcarenite (Fig. 32A)

The lower calcarenitic layer (visible in the outcrop along a line of caves corresponding to meters 21 to 28 in Fig. 31) has been interpreted as deposited in a beach prograding to the SE (N150° E) topped by vegetated aeolian dunes. The hydromorphic nature of the root layers suggest that this beach was a part of a barrier island which closed a lagoon placed to the north.

This layer is followed by 70 to 90 cm of burrowed, yellowish fine sands with marine fossils (gastropods). It represents a minor positive oscillation of the relative sea level.

The top of the unit is a new well-sorted calcarenitic layer with large-scale trough cross-bedding. The top is strongly burrowed. We have identified this unit as (aeolian) dunes.

Intervals b and c are included in the so-called El Moncayo-El Molar transition Unit (Unidad de transición El Moncayo-El Molar) deposited during Early Pleistocene.

Interval (d): rests upon an erosional surface. It is made up of white-greyish calcarenites with large-scale cross-bedding. Note that the lowermost 3 to 4 meters are partly covered and the internal structure is not always obvious.

White silts with grey patches, interpreted as lagoon sediments, lay upon the former.

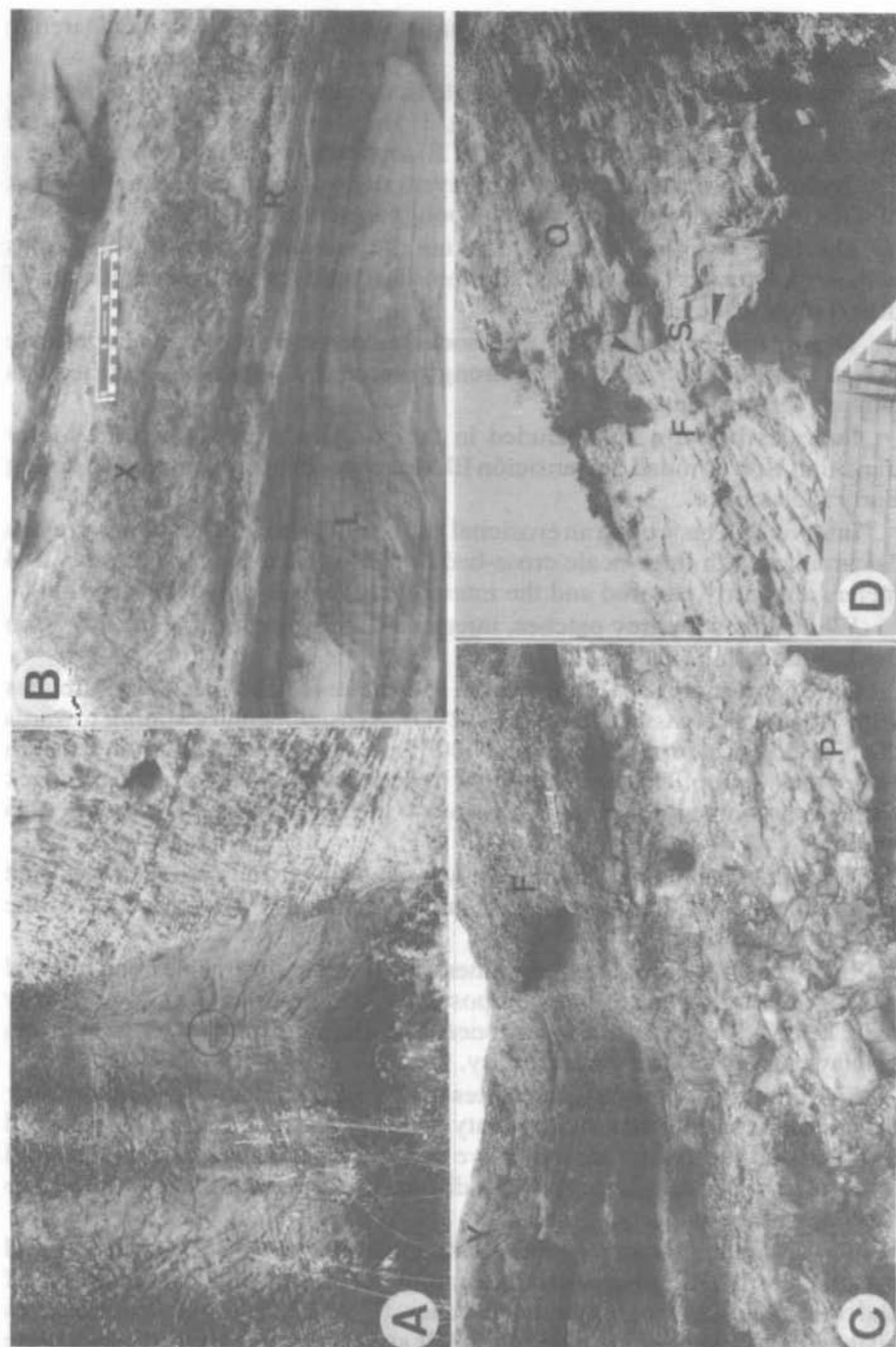
The topmost part of Unit d is a 2.5 to 3 meters thick layer of calcarenites with large-scale cross-bedding (Fig. 27D). Synsedimentary sliding towards the NE and paleocurrents directed N 20° E are visible at the far northeastern end of the outcrop. This unit is thought to represent the progradation of a back barrier environment into a lagoon placed to the north. However, some doubts remain.

We think that these features may represent an indication of the first subsiding trend of the lower Segura area, precursor of the generation of the Lower Segura Basin.

Interval (e): the «Segura Conglomerates» lay unconformable upon Interval d. These conglomerates are composed of wedge-shaped yellow, locally reddish, conglomerates and sandstones. The internal structure of these layers displays a progressive unconformity.

The lithology of the conglomerates marks a major change in composition: these are siliciclastic rocks with plenty of quartz and quartzite clasts. It should be noted that such clasts are indicative of a source area located in the Internal Zone of the Betics which strongly differs from the dominantly carbonate lithology of the underlying units.

The internal structure of these conglomerates (Fig. 32B) is planar and trough cross bedding generated in a rapidly subsiding shallow-marine shelf and the adjacent conglomeratic beaches (Fig. 32C). Small-scale slumps visible in the southeastern side of the hill and large scale slump scars visible



in the back wall of the cemetery (Fig. 32D), evidence instability associated with subsidence to the north in the transition from the narrow shelf to the talus slope.

Regional transport of conglomerates was from west to east as demonstrated by cross bedding in that direction.

FOURTH DAY: PLEISTOCENE FAN DELTAS IN THE BASIN OF COPE

General

The basin of Cope is located inside the «Aguilas Arc» also associated to the left-lateral shear zone of the Eastern Betic Cordilleras (Fig. 3). Two large shear zones N 20° E, sinistral (Palomares and Terreros faults) and N 100° E, dextral (Las Moreras fault) controlled the deformation of the Aguilas Arc within a compressive stress field which tensor axis oscillated between NW-SE and N-S (Coppier *et al.*, 1989).

The Cope Basin, placed in the «sea side» zone of the Arc was filled with shallow marine deposits until Late Pliocene (as demonstrated by the occurrence of *Strombus coronatus*). The transgression of the Pliocene sea on the previously emerged and uplifted Aguilas structure can not be related to simple eustatic changes. It results from an important breaking down of the margin. Such vertical movements are evidenced by seismic profiles carried out in the offshore near Aguilas (Coppier *et al.*, 1989).

The tectonic instability of this area during Quaternary is manifested in the distribution of the marine and terrestrial layers in Cope (Fig. 33) as discussed below.

The basement of the basin and the adjacent mountain ranges (sierras) is made up of metamorphic and metasedimentary rocks of the Alpujarride

Fig. 32.—(A) Sequence of calcarenitic beach in Rojales (interval c in figure 31); ruler (15 cm long) separating foreshore (up) and shoreface (down) facies. (B) laminated sandstones (L) and cross-bedded coarse sandstone (X) with regressive ripples (R) in the protruding layer following (upward) V in figure 27 D (interval e). (C) Vertical facies associations of conglomeratic beach in the upper part of the Segura Conglomerate (interval e). Boulders accumulate both in the lower (P: plunge step) and higher (Y: berm) parts of the foreshore (F). (D) slump scar (S and arrows) separating the Segura Conglomerate (Q) from the equivalent fine facies (F) deposited in the local steep slope.

Fig. 32.—(A) Perfil de playa calcarenítica en Rojales (intervalo c de la figura 31); la regla (15 cm) separa la facies de foreshore (arriba) y shoreface (abajo). (B) arenas laminadas (L) y arenas gruesas con estratificación cruzada (X) y ripples regresivos (R) en el nivel siguiente al V de la figura 27 D (intervalo e). (C) perfil de playa conglomerática en la parte alta de los Conglomerados del Segura (intervalo e). Los bloques se acumulan en la parte baja (P: escalón) y alta (Y: berma) del foreshore (F). (D) cicatriz de desplome (S y flechas) separando los Conglomerados del Segura (Q) de las facies finas (F) equivalentes laterales depositadas en el talud local.

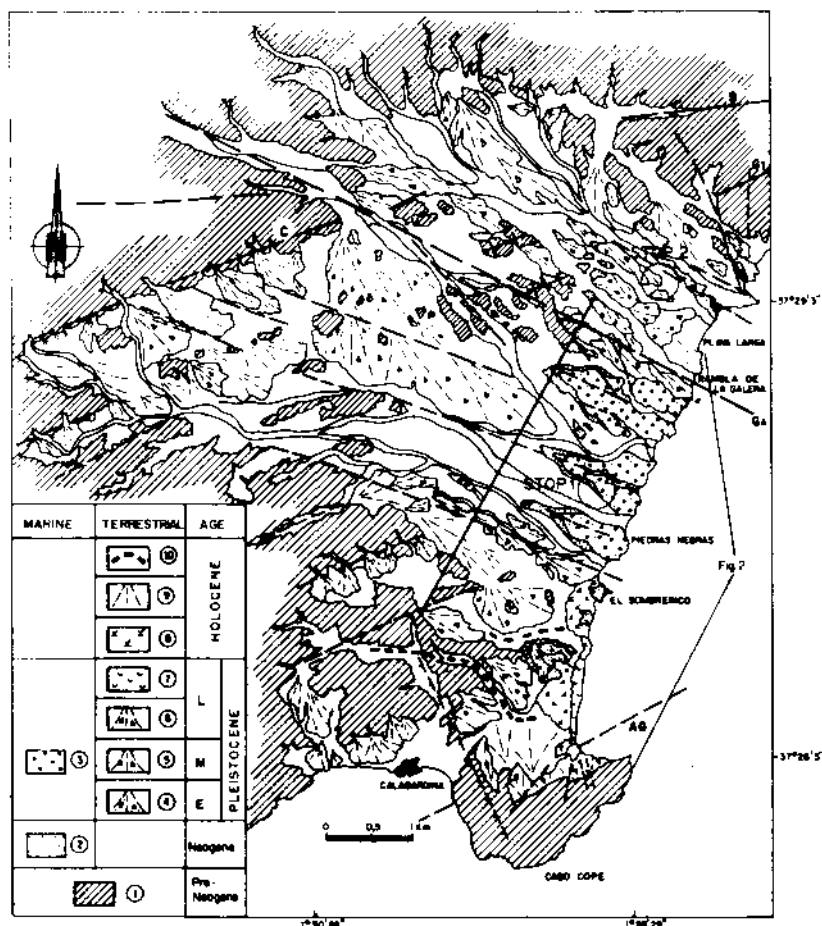


Fig. 33.—Morpho-structural scheme of Quaternary deposits in the Cope region with indication of STOPS 4 - 1 and 4 - 2. (1): phyllades and dolostones (Internal Zones of Betic Cordillera); (2): Pliocene fossiliferous sands and marls; (3): Pleistocene fan-delta deposits (prograding wedges of conglomerates and sands); (4), (5), (6), (9): alluvial fans; (7): oolitic and siliciclastic aeolian dunes; (8): fine-grained lagoon deposits; (10): abandoned river-beds. (F) faults (S: Siscal fault; C: Cantal fault; AG: Aguilas fault; GA: Galera fault; GI: Ginés fault); (— —): assumed fault; (- - -): supposed normal fault; (———): anticline axis (after Bardají *et al.*, 1986 and Goy *et al.*, 1989 a).

Fig. 33.—Mapa morfoestructural de la Cuenca de Cope con indicación de las paradas 4 - 1 y 4 - 2. Leyenda: (1) rocas metamórficas de las zonas internas béticas; (2) arenas y margas arenosas fosilíferas; (3) Fan deltas pleistocénicas (cuñas progradantes de conglomerados y areniscas); (4, 5, 6 y 9) depósitos de abanicos aluviales; (7) dunas eólicas siliciclásticas y oolíticas; (8) depósitos de grano fino de lagoon; (10) canales abandonados; (F) fallas (S: falla del Siscal; C: falla del Cantal; AG: falla de Aguilas; GA: falla de la Galera; GI: falla de Ginés); (— —): falla supuesta; (- - -): falla supuesta normal; (———): eje anticlinal (modificado de Bardají *et al.*, 1986 y Goy *et al.*, 1989 a)

Complex of the Internal Zones of the Betic Cordillera: Paleozoic graphitic micaschists, quartzites and marbles, Permo-Triassic phyllades and Upper Triassic dolostones. Erosion of these source rocks supplied sediments to fan deltas which partly infilled the shallow-marine basin.

Sedimentation occurred in a complex realm due to the coincidence of: (a) active tectonics along faults directed N60° E which marked the boundaries of the basin creating the slope necessary for the fans to develop, and also faults directed N 120° E, which did not cause a strong subsidence but determined both the lateral extension of and morphology of the bodies and the flow directions of the distributary channels of fans (Fig. 34); (b) successive eustatic sea-level changes, which determined the differential subaerial exposure, with the consequent different sedimentary behaviours, and (c) the various sedimentary processes acting both in the fan deltas and the neighbouring environments, which produced diverse sedimentary facies and sequences.

Mutual interference resulted in the deposition of prograding offlapping sequences, which have been referred to as «sequences of marine and terrestrial levels» or «marine terraces» (Goy *et al.*, 1986 a).

In this area, nine of these marine Quaternary episodes interlayered with terrestrial deposits, have been distinguished (Figs. 34 & 35), resting unconformably upon the Early to Middle Pliocene calcarenites. According to regional field data, we consider that episodes I, II and III as Early Pleistocene and episodes IV, V and VI as Middle Pleistocene. Three younger marine episodes (VII, VIII and IX) bearing *Strombus bubonius* (i. e. Tyrrhenian in the sense of Issel, 1914) occur encased into the former ones. An approach to the age of these levels can be made by comparing them with one of the most complete sequences of Tyrrhenian episodes found in the Spanish Mediterranean, in Almería where the isotopic measurements carried out (Zazo *et al.*, 1984; Hillaire-Marcel *et al.*, 1986) have given mean ages of 180 KA. (Tyrrhenian I), 128 KA. (Tyrrhenian II) and 95 KA. (Tyrrhenian III).

Sedimentary units fill a more or less rhomboidal pattern of uplifted and downthrown fault blocks. Those blocks experiencing positive subsidence were infilled by fan delta sediments, whereas raised blocks did not collect much fan delta sediments (except for the red mudstone facies). Continuous, gradual uplifting during Pleistocene resulted in a gentle relative fall of sea level which generated an offlapping sequence of successive units of fan delta deposits, interrupted by eustatic sea-level changes. Subsidence was not very prominent as demonstrated by the geometry of the resulting sedimentary units.

The purpose of this excursion is to show the basic sedimentary features of these fan delta deposits as related to the controls of sedimentation. Attention is also paid to the comparison of the gravelly, coastal deposits of fan deltas with the sequences described as coarse-grained, linear coasts.

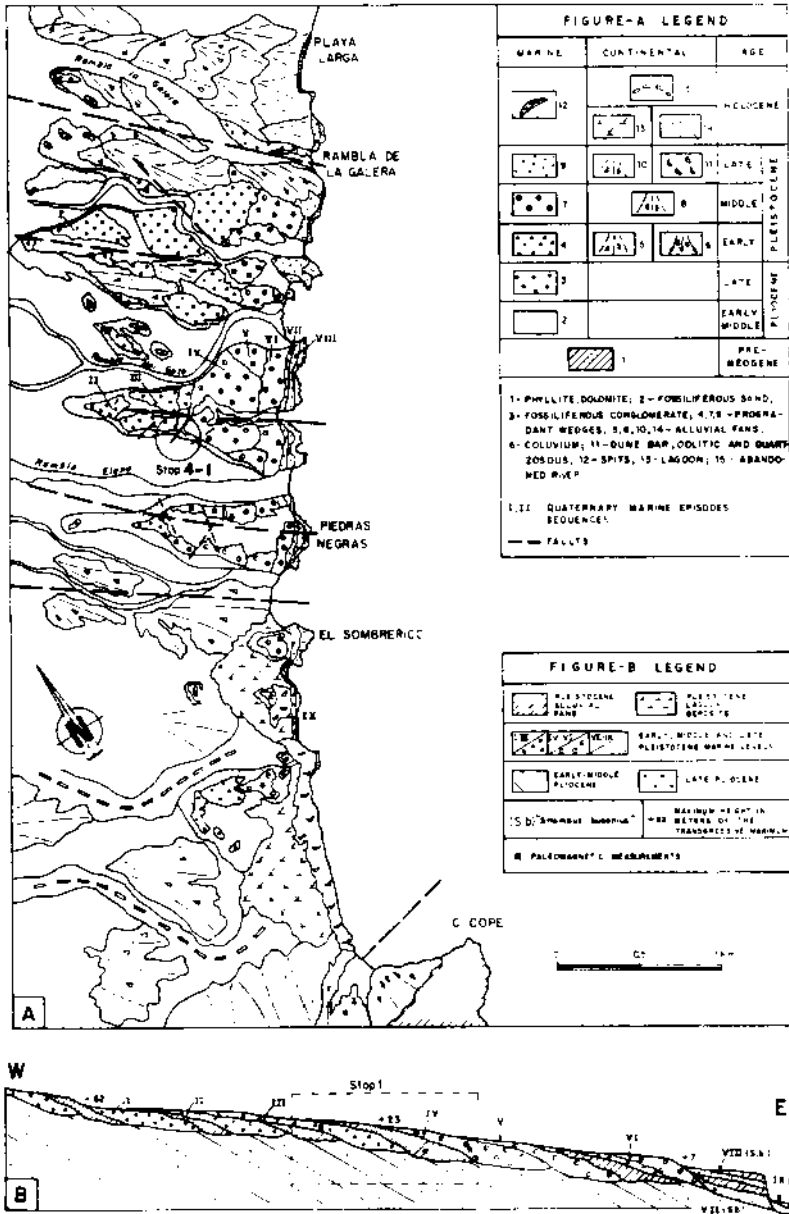


Fig. 34.—(A): Morpho-geological scheme of the marine and terrestrial episodes in Cope and location of STOP 4 - 1. (B): Synthetical section of the marine and terrestrial layers in the Cope Basin (after Goy *et al.*, 1989 a).

Fig. 34.—(A) Mapa morfo-geológico de la Cuenca de Cope con indicación de la parada 4 - 1. (B) sección idealizada de las secuencias marinas y continentales (modificado de Goy *et al.*, 1989 a).

Controls of Sedimentation

Tectonics (fault movements)

Long term, gentle subsidence along N 60°-directed faults occurred in the Basin of Cope during the Neogene. The fractures were reactivated as dextral strike-slip faults during the Quaternary due to compression oriented N 150° E, triggering two secondary systems of fractures: N 120° E and N 30-40° E in the basin interior (Fig.33). These two systems form a square-like pattern where differential subsidence took place during sedimentation of fan deltas. Thus, orientation and geometry of the fan delta bodies were controlled by the directions of the active faults.

Uplifting and downing of blocks along the system N 120° E characterize areas of differential subsidence. As downed blocks were preferable used by floods, they pre-determined both flow directions and potential areas of accumulation of fan delta sediments. Thus, the system N 120° E controls the preferential direction of the feeding channels and also the elongation of the sedimentary bodies (Fig. 34). Raised blocks were mainly out of reach of coarse sediments during floods and most deposition there consist of red mudstone. The system N 30-40° E (at right angles to the former) determined the orientation and the relative place of Pleistocene and Holocene shorelines, fixing a limit to the subaerial part of the fan deltas; in addition, these faults uplifted the block closer to the coast (just where the fan deltas occur now a days) (Goy *et al.*, 1989 a).

Fault directions formed a square pattern of fault-bounded blocks. Those blocks experiencing positive subsidence were infilled by fan delta sediments, whereas raised blocks did not collect much fan delta sediments (except for the red mudstone facies).

Another factor involved in the sedimentation of Pleistocene sequences, is the rate of uplifting/subsidence at the margin of the basin. It was (and still is) mostly influenced by tilting along the fault system directed N 30-40° E (parallel to the shorelines) which acted as tilting line in response to the compressional stress. The continuous, gradual uplifting during Pleistocene resulted in a relative fall of sea level which generated an offlapping sequence of successive units of fan delta deposits (Figs. 34 & 35). The altimetric position of the tyrrhenian episodes, the distribution of lagoons and recent alluvial fans demonstrate the existence of a coastal tilting towards the SW from la Galera Fault (Fig. 33).

Subsidence was not very prominent during Pleistocene, although the positive relief of the mountains was pronounced. This conclusion is supported by the geometry of the resulting sedimentary units: they are thin wedges which slope gently toward the sea, showing offlap, with a tendency to toplap. In our opinion, strong subsidence generates thick accumulations of sediments. A continuous, gradual uplift would result in a long-term, relative fall of sea level able to

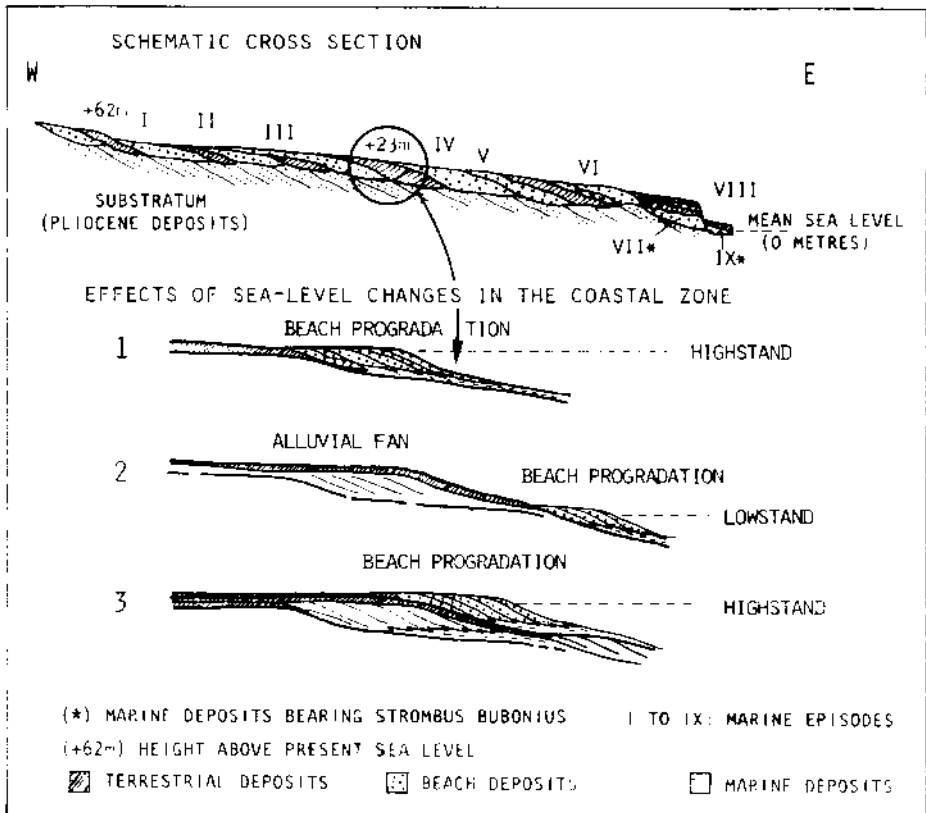


Fig. 35.—Development of an offlapping sequence of coastal and terrestrial units caused by relative changes of sea level in the Cope Basin (modified after Bardají *et al.*, 1987 and Goy *et al.*, 1989 a).

Fig. 35.—Desarrollo de secuencias imbricadas (offlap) de unidades marinas y continentales a causa de cambios relativos del nivel del mar en la Cuenca de Cope (modificado de Bardají *et al.*, 1987 y Goy *et al.*, 1989 a).

generate a single sequence of offlapping deposits. However, the occurrence of erosional surfaces separating successive marine and terrestrial deposits witnesses the superimposed shorter-term eustatic changes of sea level (Fig. 35).

This fact is interesting, because it can be used as a criterion of differentiation between the effects of eustatic and tectonically-influenced changes of sea level. In general, there is a clear relationship between tectonics and the generation of the Quaternary marine layers. When uplifting is continuous and gentle, sea level changes are recorded as separate ribbons of coastal deposits some metres apart from each other and at different heights. With reduced or no subsidence, successive sea-level changes generate sequences of stacked marine layers separated by erosional surfaces.

Eustatic changes of sea level

Pleistocene sea-level changes generated a succession of phases of highstand and lowstand in Cope Basin, which involved shifting of the coastline and development of an offlapping sequence of imbricate terrestrial and marine deposits.

We assume that during highstands most of the coarse sediments of the fan deltas remained next to the hinterland and the areal extent of the subaerial fans was very restricted. Under these conditions beaches on the periphery of the fan deltas actively prograded due to the high input of sediment. However, the preserved toplap and clinofolds indicate that sea level was stable or somewhat falling for any given unit (Fig. 35). In our opinion this is due more to the existence of higher relief rather than to uplift of the surrounding mountains or active subsidence of the basin. These features resemble present day processes and allow us to differentiate between the effects of subsidence (orogenic) and eustatic sea-level changes.

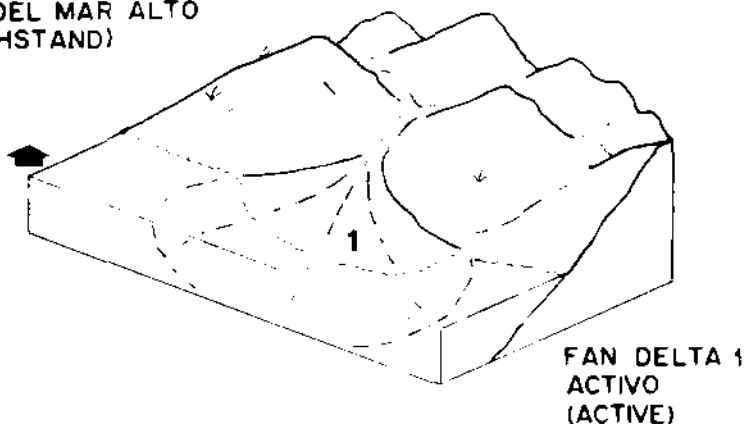
During lowstands a large part of the basin at the margins and fan deltas is exposed. Weathering of the exposed deposits occurs because most of the new input concentrates into telescopic fans, fed by deeply incised channels (Fig. 36), and deposited at the toe of the fans formed during highstands. The typical deposit in exposed areas is massive red mudstone. Virtually no coarse sediment accumulated outside the active incised lobes. No exposures of the lowstand delta fronts are exposed today.

Dynamics of fan deltas

We assume that the dynamic and climatic conditions of Late Pleistocene times were essentially the same to that presently found in southeastern Spain. This is supported by the remarkable parallelism observed in the sedimentary successions deposited in coastal environments of both ages (Dabrio *et al.*, 1984; Bardají *et al.*, 1986; Goy *et al.*, 1986; Zazo *et al.*, 1989).

The dynamic regime of the present day fan deltas in southeastern Spain is controlled by episodic, but catastrophic, discharges which cause flooding of the fans. This happens because the *ramblas* (local name for wadi-like ephemeral streams subjected to episodic flash floods) are unable to keep pace with the huge volumes of water and sediment involved in the heavy rains generated by the seasonal change of the atmospheric circulation in the Mediterranean Sea. Maximal precipitation occurs in spring (April) and, above all, in autumn (M.O.P.U., 1976): records of up to 300 mm of rain in one day are quite common in October, with a probable periodicity of ten years. Those episodes of rain, very often of catastrophic nature, imply very large inputs of sediment to the fan delta. They are followed by rather long periods of inactivity when longer term, but more continuous, coastal and shallow

NIVEL DEL MAR ALTO
(HIGHSTAND)



NIVEL DEL MAR BAJO
(LOWSTAND)

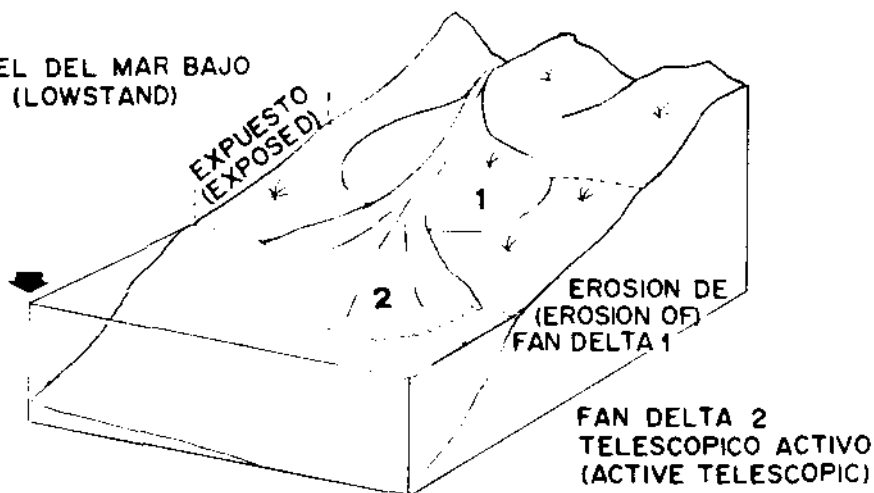


Fig. 36.—Sedimentary processes and development of fan-delta units in response to relative changes of sea level in Cope Basin (after Goy *et al.*, 1989 a).

Fig. 36.—Procesos sedimentarios y desarrollo de unidades de fan delta en respuesta a los cambios de nivel del mar en la Cuenca de Cope (según Goy *et al.*, 1989 a).

marine reworking takes place accumulating sediment in beaches and barrier islands (Fig. 37).

Thus, the coarse sediments of the fan deltas and ramblas feed the coastal zone and the resulting beach deposit exhibits a large-scale prograding geometry and a vertical sequence of facies in response to the coastal dynamics

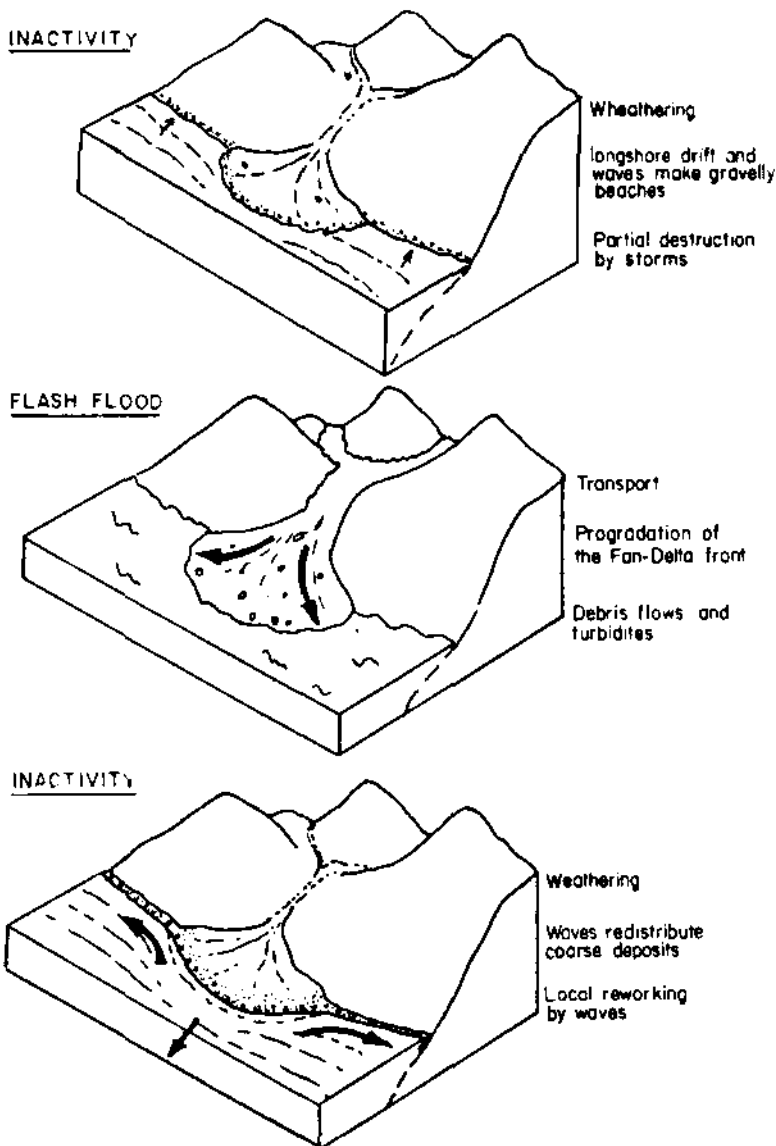


Fig. 37.—Succession of events related to the episodic activity of fan deltas. Episodic, but catastrophic, discharges cause flooding and rapid progradation. They are followed by long periods of inactivity when more continuous coastal and shallow marine reworking accumulate sediment in beaches and barrier islands.

Fig. 37.—Sucesión de acontecimientos ligados al funcionamiento episódico de los fan deltas. Las descargas, esporádicas pero catastróficas, producen inundación y rápida progradación que van seguidas de largos periodos de inactividad durante los cuales los procesos costeros y marinos someros, que son más continuos, retrabajan el sedimento acumulándolo en playas e islas barrera.

(Dabrio *et al.*, 1985). In the tideless southeastern littoral of Spain the major controls of coastal sedimentation are: (a) exposure to the prevailing winds and storms; (b) the availability and size of sediment; and (c) recent regional tectonics, i. e. movements of fault blocks (Dabrio *et al.*, 1984).

The most characteristic exposed facies of the Pleistocene fan deltas of the Cope Basin are the coastal deposits which are virtually identical to those fed by rivers or by longshore drift, but not directly related to fan deltas. They are comparable to sheltered and accretional beaches (as described by Bryant, 1983 and Short & Wright, 1983).

These features are closely comparable to others found in the western Mediterranean area. This is the case of the Pleistocene barrier islands of Tunisia (Hergla region, Mahmoudi *et al.*, 1987) and the Messinian and Pleistocene prograding sequences of gravelly beaches in southern Italy (Massari & Parea, 1988).

STOP 4 - 1: Casa de Renco

Purpose

Observation of the Pleistocene fan-delta sequence in Rambla Elena at Casa de Renco (+23 m.)

Tectonic control and sea level changes during the Quaternary, responsible of the geometry and sedimentary facies of the Fan Deltas

Description

Along the eastern margin of the Rambla de Elena, eight offlapping Pleistocene fan-delta units rest unconformably upon the yellow fossiliferous sands dated as Early to Middle Pliocene.

STOP 4-1 is located below a ruined house called Casa de Renco (Fig. 38). Subaerial facies (reddish subaerial alluvial fan deposits) and subaqueous marine facies. Subenvironments are clearly distinguishable inside Episode IV.

There follows a brief account of the most remarkable features of these facies.

Marine fan delta deposits (coastal and sublittoral highstand deposits)

Beach deposits consist mostly of conglomerate, sandstones and mudstones that form coarsening-upwards sequences, similar to those described by Dabrio *et al.* (1984, 1985). In ascending order, the most complete comprise (Fig. 39):

(1) A lower unit of parallel-laminated and wave-ripple cross-laminated micaceous sandstones, commonly burrowed, representing the lower shoreface and transition zones.

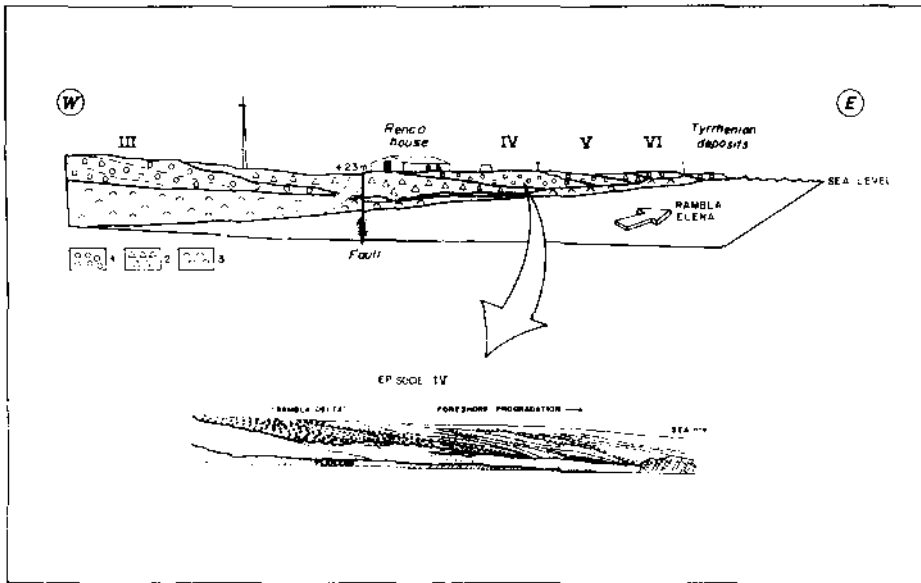


Fig. 38.—Early and Middle Pleistocene sequence of marine and terrestrial episodes in Casa de Renco (Renco's house), STOP 4 - 1. KEY: (1): marine episode; (2): terrestrial deposit; (3): Pliocene calcarenites; (III): Early Pleistocene; IV to VI.- Middle Pleistocene deposits (after Goy *et al.*, 1989).

Fig. 38.—Secuencia de episodios marinos y continentales del Pleistoceno Inferior y Medio en la Casa de Renco. PARADA 4 - 1. Leyenda; (1): episodio marino; (2): depositos continentales; (3): calcarenitas pliocénicas; (III): Pleistoceno Inferior; IV a VI.- Depósitos del Pleistoceno Medio (según Goy *et al.*, 1989).

(2) A middle unit of trough cross-bedded sands and gravels corresponding to shoreface zone under wave action. These two units are poorly, or not, exposed in Casa de Renco

(3) An accumulation of the coarsest grain sizes observed on the coastline, decreasing upwards up to well sorted fine gravels. These are deposits of the lower part of the foreshore (Miller & Ziegler, 1958, Dabrio *et al.*, 1985). In low energy coasts the breaker zone is characterized by a step at the base of the swash zone (Clifton *et al.*, 1971; Davis *et al.*, 1972) which probably marks the transition between upper and lower flow regime (Tanner, 1968) of backwash (Clifton, 1969). It is interesting to note that the breaker zone indicates very precisely the mean sea level during deposition in present tideless coasts. In fossil examples the step is preserved mostly in two ways depending on the predominant grain size (Fig. 40):

(a) in gravelly beaches (left, Fig. 40) it is marked by an accumulation of the coarsest grain sizes available;

(b) in sandy beaches (right, Fig. 40) it is marked by a change from parallel

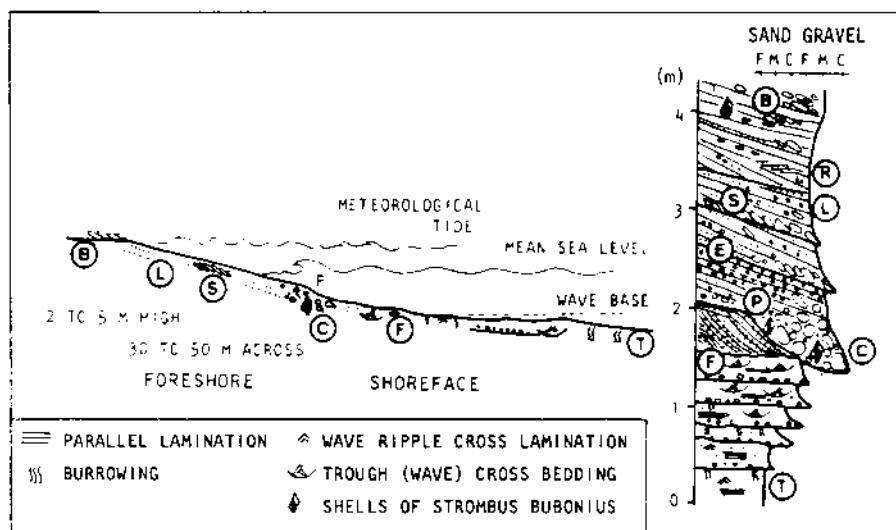


Fig. 39.—(A) Typical beach profile for Mediterranean gravelly coasts. (B) Composite sequence of facies generated by progradation of gravelly beaches. Key: B: berm; R: ridge and runnel system; L: parallel lamination; S: ephemeral, secondary berms; E: erosional surfaces; P: plunge step at the base of the foreshore; C: coarse pebbles and boulders (P & C: indicate the breakers zone); F: fining upward sequences; T: transition zone (Modified after Dabrio *et al.*, 1985).

Fig. 39.—(A) Perfil típico de las playas de grava mediterráneas. (B) Secuencia compuesta de facies generada por la progradación de playas de gravas. Leyenda: B: berma; R: sistemas de cresta y surco; L: laminación paralela; S: bermas efímeras, secundarias; E: superficies erosivas; P: escalón en la base de la zona de batida del oleaje; C: cantos gruesos (P y C: indican la zona de rompientes); F: secuencias granodecrecientes; T: zona de transición al offshore (modificado de Dabrio *et al.*, 1985).

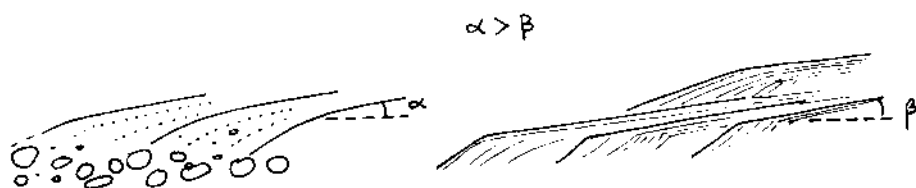


Fig. 40.—Two types of arrangements of facies in the prograding lower foreshore. Planar cross bedding is generated by migration of the plunge step (ps) towards the sea in sandy beaches. Accumulations of coarse grain sizes (and also some cross bedding) occurs in gravelly beaches. Note also higher values of dip slopes in coarse grained beaches

Fig. 40.—Dos tipos de organización de facies en el foreshore inferior progradante. En las playas arenosas la migración hacia el mar del escalón (ps) genera estratificación cruzada planar. En las playas de grava se producen acumulaciones de tamaños gruesos y también alguna estratificación cruzada. Obsérvese también que la zona de batida del oleaje (y las capas resultantes) buzcan más en las playas de grano grueso.

lamination (the common deposits of the swash zone in the foreshore) to tabular cross bedding (Dabrio *et al.*, 1985; Somoza *et al.*, 1987).

(4) An upper interval of well sorted, parallel-laminated gravel, gently inclined towards the sea, representing the upper part of the foreshore and berm.

The coastal deposits are the most characteristic facies of the exposed Pleistocene fan deltas of Cope Basin (Fig. 41). These gravelly coastal deposits are identical to those fed by rivers or by longshore drift not directly related to fan deltas.

Subaerial facies (lowstand deposits)

Low water stages are marked by erosional surfaces cutting through the upper part of the prograding sequence and clinoforms.

Alluvial fan deposits are typical deposits of periods of sea-level fall. Reddish or grey imbricate conglomerates and massive red sandy mudstone with some scattered clasts and no visible internal structure are found.

STOP 4 - 2: Rambla del Garrobillo

Purpose

Observation of alluvial fan (terrestrial) deposits and the interlayering of marine and terrestrial deposits. This is accomplished by visiting two exposures along the erosional walls of the rambla (wadi-like ephemeral river) which are informally called STOP 4-2-1 and STOP 4-2-2.

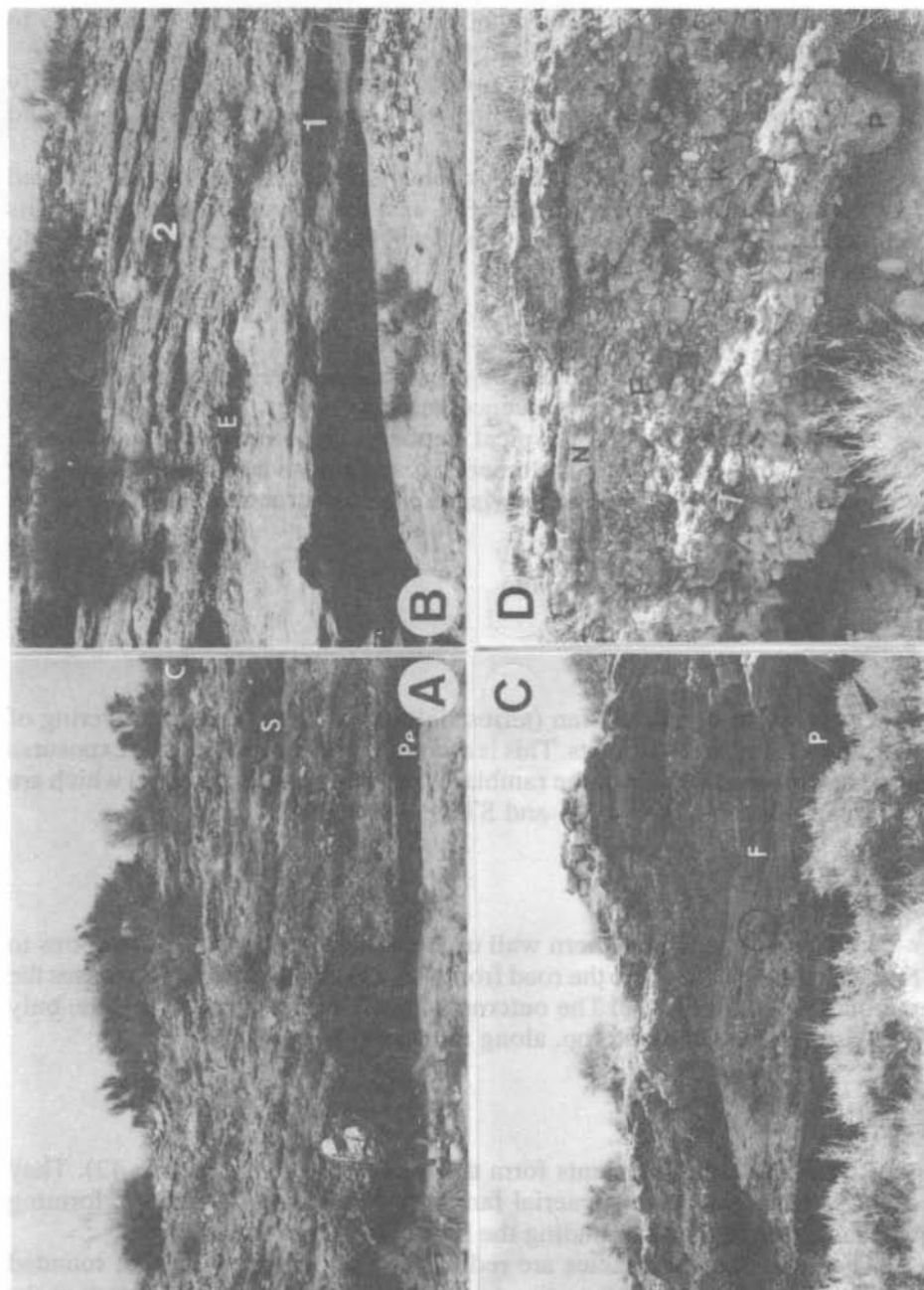
STOP 4 - 2 - 1

It is located in the southern wall of the river cut, about 1.5 kilometres to the east of the place where the road from Calabardina to Mazarrón crosses the rambla (Figs. 42, 43, 44). The outcrop is easily found because it is the only high escarpment, and outcrop, along this lower tract of the river.

Description

Red siliciclastic sediments form the wall of the river cut (Fig 42). They correspond to extensive subaerial fan delta deposits (alluvial fan), forming bajadas along the fault bounding the Sierra de Almenara.

The most abundant facies are reddish conglomerates with flat, rounded pebbles. These textural properties are related to the strongly schistose rocks forming the adjacent mountains. The high content of mica in the schists may have influenced the rheology of the masses of removed detritus. Weathering



forming the adjacent mountain. The high content of mica in the sediments may have influenced the rheology of the masses of removed detritus. Weathering

of iron-rich minerals, including phyllosilicates, in source areas is thought to cause the common red colour of deposits although the influence of diagenetic processes can not be discarded.

Briefly, the most interesting features of these facies are:

Channelized conglomerate facies

They occur as bodies of conglomerates with irregular, erosional lower boundaries. The thickness of layers is variable but common values range between 0.5 and 2 m. The most prominent internal sedimentary structure is crude horizontal stratification. Imbricated flat pebbles are common (I, Fig. 42). Imbrication points roughly to the sea (east) according with the paleoflow.

We interpret this facies as channel fill deposits having irregular shape both in the assumed longitudinal and transverse sections. Layers tend to be more continuous in axial directions (more or less E-W).

Local cross bedding associated to scours was interpreted as channel-fill cross bedding. Rare large-scale planar cross bedding found in some outcrops might be related to bars. Measured paleoflow directions point (as it would be expected) roughly away from the hinterland. Poorer organization and somewhat coarser grain sizes are recorded in more proximal areas.

Disorganized conglomerate facies (D)

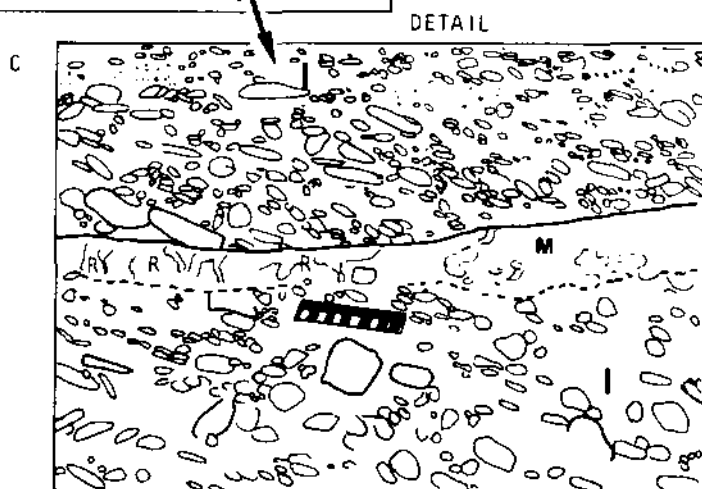
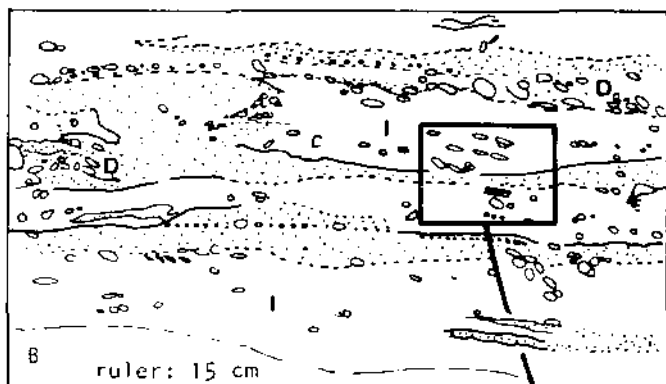
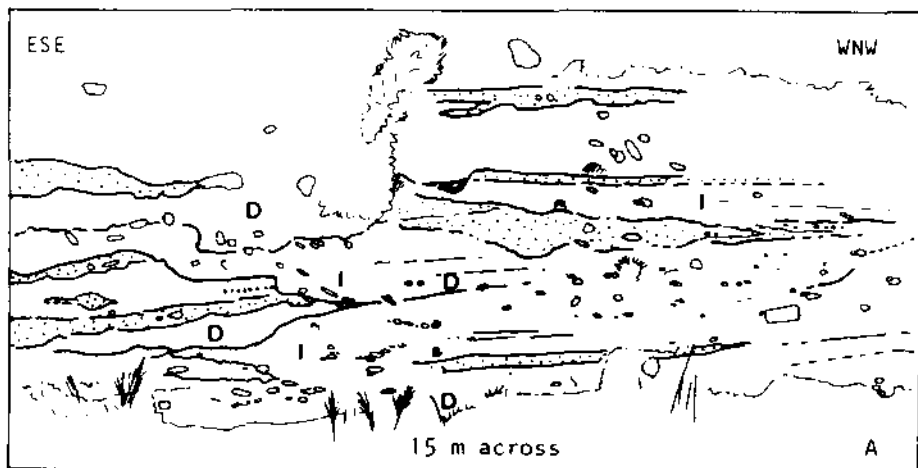
This facies occurs especially closer to the hinterland as masses of disorganized, matrix-supported, conglomerates, with angular, irregular-shaped clasts. Median thickness are about 1 to 3 metres. We have interpreted it as debris flows.

Sandstone facies

They occur as layers of medium to coarse-grained, litharenitic (derived from metamorphic rocks) sandstones. In proximal areas of the fans they

Fig. 41.—Early and Middle Pleistocene deposits in Casa de Renco, STOP 4 - 1. (A) Marine (coastal conglomerates, S) and terrestrial (carbonate crust, C) deposits above Pliocene (Pe) calcarenites; the boy is 125 cm high. (B) Close up of two successive beach units separated by an erosional surface (E) in Casa de Renco; the river cut is about 4 m high. (C) sequence of conglomeratic beach with boulders (plunge step, P) and inclined-laminated gravel (foreshore, F); the encircled hammer is 30 cm long. (D) Close up of beach sequence with same meaning of letters, plus N: inclined laminated coarse sands (middle foreshore); hammer is 30 cm long.

Fig. 41.—Secuencia de depósitos del Pleistoceno Inferior y Medio en la Casa de Renco, PARADA 4 - 1. (A) Depósitos marinos (conglomerados litorales, S) y continentales (costra carbonatada, C) sobre las calcarenitas pliocénicas; el chico mide 125 cm. (B) Detalle de dos unidades sucesivas de playa separadas por una superficie erosiva (E) en Casa de Renco; el margen del río mide unos 4 m de altura. (C) secuencia de playa conglomerática con bloques (escalón, P) y gravas con laminación inclinada (foreshore, F); el martillo del círculo mide 30 cm. (D) Detalle de una secuencia de playa conglomerática con las mismas letras y, además, N: arenas gruesas con laminación inclinada (foreshore medio). El martillo mide 30 cm.



usually form irregular, discontinuous layers which occur deeply incised by erosion prior to the overlying conglomerates. These layers become more continuous toward the distal parts. They are interpreted as channel fill deposits.

Red mudstone facies (M)

Massive, red sandy mudstone with some scattered clasts are characteristic of the distal alluvial-fan deposits. They are interpreted as the result of settling of fines after flooding. Any original bedding or internal lamination has presumably been destroyed by pedogenic activity.

Facies relationships

The above facies occur interbedded (Fig. 43 A and B). The channelized conglomerate facies accounts for most of the volume of sediments. It may be followed upwards either by sandy or, more frequently, by red mudstone facies. Masses of disorganized conglomerates (debris flow) of metric vertical scale may be found interbedded with channel fill deposits near the hinterland. The amount and continuity of the finer grained facies increase toward more distal parts. The red mudstone facies is often the only representative of the subaerial fan delta facies in the most distal realms.

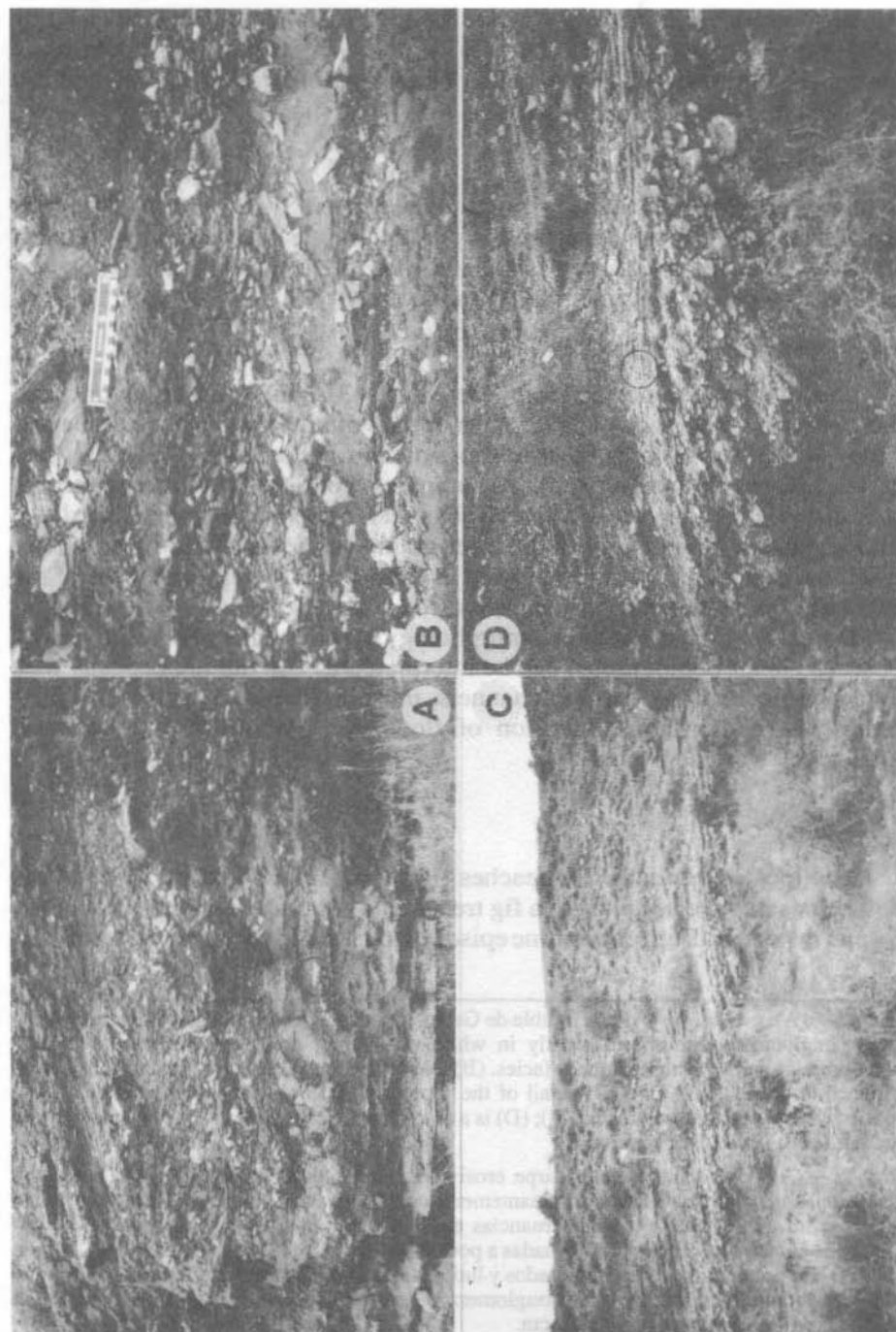
The association of facies and morphology of sedimentary bodies (still well observed in air photographs) can be interpreted as alluvial fan deposits with evidence for shifting, braided channels, mostly filled with coarse to sandy sediments, and a large extension of flood plain where finer, burrowed, mudstones were deposited.

STOP 4 - 2 - 2

It is located in the lower reaches of the rambla, about 50 m before it debouches into the sea, next to a fig tree. It is a continuation to the east of the former exposure. There is a marine episode interbedded between two terrestrial

Fig. 42.—(A): general view of the rambla de Garrobillo river wall. From right to left, transition from conglomerate-dominated (mostly in white with larger clasts pictured) to alternating conglomerate and sandstone (dotted) facies. (B): close up of the alternating facies taken a short distance to the left of A and (C) detail of the superimposed imbricate conglomerate (I) and rootled (R) sandy mudstone facies (M); (D) is a disorganized conglomerate. Sea is (and was) to the left (east). Ruler is 15 cm long.

Fig. 42.—(A): vista general del escarpe erosivo de la rambla del Garrobillo. De derecha a izquierda, transición desde facies predominantemente conglomeráticas (en blanco, pues sólo se han dibujado los clastos mayores) a alternancias de conglomerados y areniscas (punteado). (B) detalle de la facies de alternancias tomadas a poca distancia hacia la izquierda de A. (C), detalle de las facies de conglomerados imbricados y lutitas arenosas (M) con bioturbación de raíces (R) que se superponen a ellas. (D) es un conglomerado desorganizado. El mar está (y estaba) hacia la izquierda (este). La regla mide 15 cm.



alluvial-fan channel deposits, visible in the erosional escarpment of the southern margin (Figs. 43 C and D, Fig. 44).

Description

As noted above the most distinctive features of the beach deposits are grain size (gravel or coarser), good roundness and, in general terms, high sorting, a particular vertical sequence of grain sizes and primary sedimentary structures, and the overall geometry of depositional units.

In STOP 4-2-2 an accumulation of very coarse, rounded clasts lay on top of the lower erosional surface. They represent deposition in the lower foreshore. The overlying inclined laminae with imbricated pebbles (note paleoflow direction pointing to the west, i.e. landward) represent foreshore deposits. The inclination of laminae increases towards the lower part marking the step at the base of the foreshore. Berm deposits have been eroded prior to the next terrestrial episode of deposition.

These features are the result of a relatively steep foreshore. Note that original dip slopes average 5° for beach units made up of coarse sand and 6 to 8° for those with fine gravel in Cope Basin. The slope becomes still more inclined towards the lower part of the assumed foreshore units, where the coarsest grain sizes accumulate.

These values are similar to those obtained in the Late Pleistocene and Present beaches of the Gulf of Almería: 6° for gravelly foreshores with maximum grain size of about 10 cm and slopes up to 10° for those reaching maxima of about 15 cm (Dabrio, *et al.*, 1984). Similar values are found in all the studied Pleistocene and Present beaches of southeastern Spain.

Low relief erosional surfaces separate beach and terrestrial deposits. These are made up of reddish conglomerates with prominent imbrication of pebbles suggesting paleoflow to the east (seawards), i. e. opposite to the one measured in beach deposits.

Fig. 43.—Rambla del Garrobillo, STOP 4 - 2. (A) Alluvial deposits (STOP 4 - 2 - 1) with red sandy mudstones in the lower part and imbricate or crudely-laminated conglomerates with erosional lower boundary to the top. (B) Close up of alluvial deposits (STOP 4 - 2 - 1) to illustrate alternating imbricated and disorganized layers with variable grain sizes. Compare both photographs with figure 42. (C) Deposits of prograding conglomeratic beach (compare with figures 40 and 44) and (D) detail of incurvation of laminae and accumulation of boulders. Ruler is 15 cm long. Pole in (c) is 1.20 m high

Fig. 43.—Rambla del Garrobillo, PARADA 4 - 2. (A) depósitos aluviales (PARADA 4 - 2 - 1) con lutitas arenosas rojizas dominantes hacia la parte inferior y conglomerados imbricados o groseramente laminados y de base erosiva hacia la superior. (B) primer plano de los depósitos aluviales (PARADA 4 - 2 - 1) que ilustra la alternancia de niveles imbricados y desorganizados de granulometrías variadas. Compárense ambas fotografías con la figura 42. (C) Depósitos de playa conglomerática progradante (compárense con las figuras 40 y 44) y detalle (D) de la incurvación de las láminas del foreshore y la acumuiación de bloques. La regla del círculo mide 15 cm. El poste en (c) mide 1,20 m. de altura

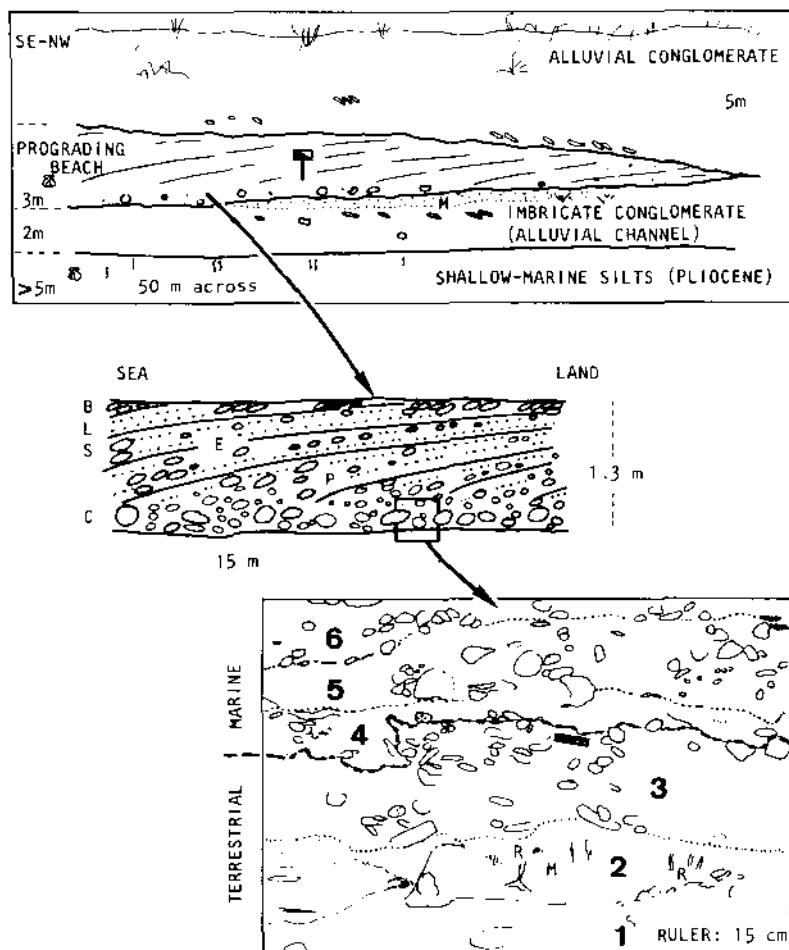


Fig. 44.—Above: a marine episode interbedded between two terrestrial imbricate conglomerates (channel deposits of alluvial-fan) exposed in the erosional escarpment of Rambla de Garrobillo. Centre, conceptual model of foreshore deposits in gravelly beaches (see figure 39 for comparison and meaning of letters). Below: close up of the boundary between terrestrial and coastal deposits. (1): imbricate conglomerates in alluvial channel; (2): red sandy mudstone, facies M (R: root burrows); (3): disorganized, angular pebbles; (4) fossiliferous calcarenite with pebbles increasing upwards (5); (6): accumulation of cobbles and boulders at the base of foreshore.

Fig. 44.—Arriba: un episodio marino intercalado entre dos conglomerados continentales imbricados (depósitos de canal en un abanico aluvial) expuestos en el escarpe erosivo de la Rambla de Garrobillo. Centro, modelo conceptual de los depósitos de foreshore en las playas de grava (véase la figura 39 para comparación y significado de las letras). Abajo: detalle del límite entre los depósitos marinos y continentales. (1): conglomerados imbricados en canal aluvial; (2): lutitas arenosas rojizas, facies M (R: bioturbación de raíces); (3): cantos angulosos desorganizados; (4) calcarenitas fosilíferas con aumento hacia arriba del contenido en clastos; (6): acumulación de cantos y bloques en la base de la zona de batida del oleaje (foreshore).

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