Interbedded mudstone slope and basin-floor sandy deposits in the Ondarroa turbidite system (Albian, Basque-Cantabrian Basin)

Depósitos interestratificados de talud lutítico y de fondo de cuenca arenosos en el sistema turbidítico de Ondarroa (Albiense, Cuenca Vasco-Cantábrica)

L. M. Agirrezabala (1) **y A. Bodego** (2)

Estratigrafia eta Paleontologia Saila, Euskal Herriko Unibertsitatea, 644 P.K., 48080 Bilbo.
(1) gppagmul@lg.ehu.es,
(2) aranbo82@hotmail.com

RESUMEN

El sistema turbidítico de Ondarroa constituye un sistema siliciclástico confinado con forma de L, depositado en una subcuenca marina profunda de tipo pull-apart. El estudio de nuevos afloramientos correspondientes al sistema externo ha permitido caracterizar dos sistemas de dispersión coetáneos perpendiculares. Un sistema de dispersión axial de dirección ESE correspondiente a las corrientes turbidíticas siliciclásticas, y otro sistema de dispersión transversal de dirección NNE representado por potentes slumps lutíticos de talud. El confinamiento de las corrientes turbidíticas axiales y el desarrollo de depósitos de talud habrían estado causados por la actuación sinsedimentaria de la falla de Elgoibar, paralela a los flujos axiales.

***Key words**: Turbidite system, slope deposits, basin-floor deposits, tectonics, Basque-Cantabrian Basin*

Geogaceta, 38 (2005), 83-86
ISSN: 0213683X

Introduction

Confined turbidite systems record the interaction between axially dispersed turbidity currents and submarine topography. In mass wasting-dominated confining slopes, large-scale submarine slumping represents an important mechanism in shaping of slopes because of vast amounts of sediments are transported and redistributed into deep-water from an originally shallow-water setting. Usually, resedimentation deposits constitute slumps complexes deposited in the lower part of the slopes interbedded with sandy turbidites deposited axially in the basin.

Facies analysis and sedimentological interpretations of interbedded mudstone slope and basin-floor deposits in modern turbidite systems are difficult because of lithological details cannot be readily observed. Moreover, few outcrop examples show the possibility of combining facies studies with the overall stratigraphic context. One of these examples is the Albian Ondarroa turbidite system (OTS) in the Basque-Cantabrian Basin (Fig. 1) described by Agirrezabala and García-Mondéjar (1994, 1995) and Agirrezabala (1996). New outcrops in the outer part of the system show interbedded thick mudstone slope deposits and thin, plane-parallel sandstone turbidites. The detailed facies and stratigraphic relationships of these deposits have not been published previously. The aim of this paper is to describe, characterise spatial variability and interpret these new facies in relation to the synsedimentary tectonics responsible of the turbidite system confinement.

Geological setting

The Middle-Upper Albian OTS was a deep-water, coarse-grained siliciclastic system that filled axially a subsiding pull-apart sub-basin. Inner and middle systems were characterised by the presence of coarse-grained channel-fill deposits and the outer system by thin bedded, plane-parallel sandstone turbidites. Surrounding topographically higher areas were characterised by shallow water mudstones or carbonates. The thickness of the OTS is highly variable, ranging from 295 m at the more proximal outcrop to about 1000 m at the distal end, indicating a high subsidence gradient in the same direction.

Stratigraphic context, facies and granulometric distributions and paleocurrent data indicate an elongate and confined, L-shaped dispersal system with inner and middle parts directed towards SSW and an outer part directed towards ESE (Fig. 1). The sharp turn of ~90º in direction of the longitudinal dispersal system occurred in the middle-outer system transition near the sinsedimentary strike-slip Elgoibar fault (Agirrezabala and García-Mondéjar, 2001). The trend of this sub-vertical fault is parallel to the axial dispersal system in the distal part. This suggests that the Elgoibar fault prevented axial turbidity currents from expanding south-westwards and obliged them to turn south-eastwards, by means of creation of a longitudinal submarine mudy slope dipping NNE. In the following, we focus on deposits occurred at the mudstone slope and basin-floor transition based on new outcrops near the Elgoibar fault, between Elgoibar and Altzola villages (Fig.1).

Deposits description and interpretation

Interbeded mudstone slope and sandstone turbidite deposits crop out in some localities near the Elgoibar fault (Fig. 1). Figure 2 illustrates principal sedimentologic features of these deposits corresponding to selected outcrops. Three main facies and two subfacies have been distinguished.

Mudstone facies:

This is thick to very thick mudstone to silty mudstone with scattered siderite concretions. Sandstone beds are absent and very scarce sandstone clasts may be

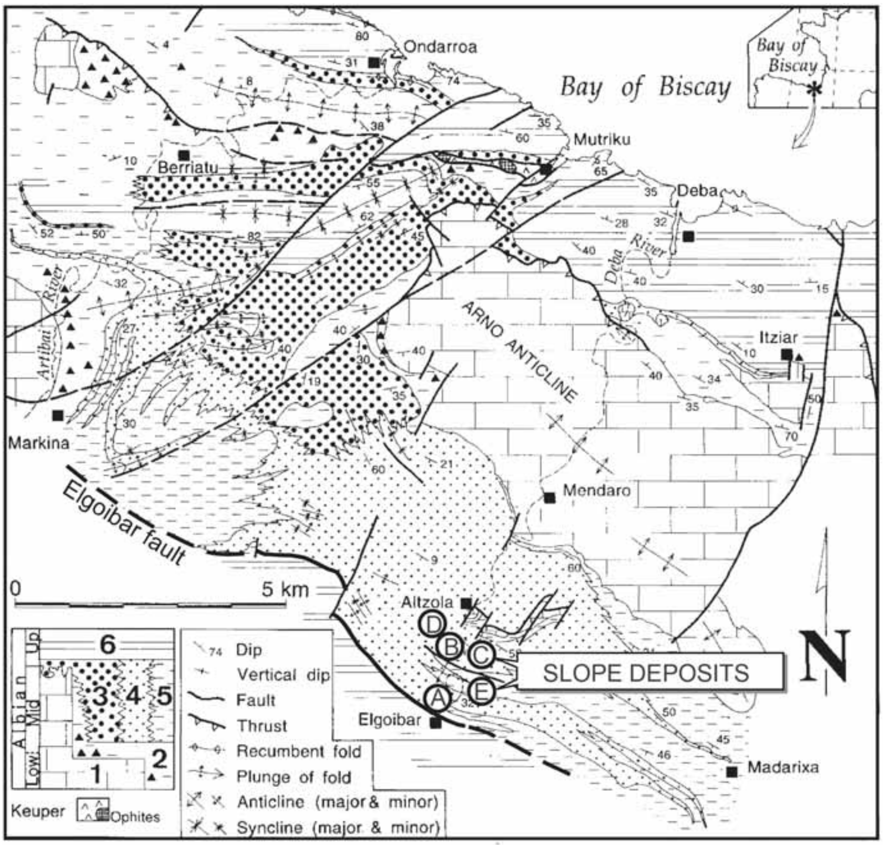

Fig. 1.- Geological map of the Ondarroa turbidite system (units 3, 4 and 5) and encasing rocks (units 1, 2 and 6). Legend: (1) Urgonian limestones; (2) mudstones, marls and megabreccias; (3) conglomerates, sandstones and mudstones; (4) sandstones and mudstones, (5) mudstones; (6) mudstones and sandstones. Letters A-E refer to the studied slope deposits outcrops.

Fig. 1.- Mapa geológico del sistema turbidítico de Ondarroa (unidades 3, 4 y 5) y rocas encajantes (unidades 1, 2 y 6). Leyenda: (1) calizas urgonianas; (2) lutitas, margas y megabrechas; (3) conglomerados, areniscas y lutitas; (4) areniscas y lutitas; (5) lutitas; (6) lutitas y areniscas. Las letras A-E indican los afloramientos de depósitos de talud estudiados.

present. According to internal structure, two subfacies are distinguished.

Undisturbed mudstone subfacies: It has been recognised only in A outcrop (Figs. 1 and 2A). It is 12 m thick and ~20 m long (minimum) mudstone mass that shows internal undisturbed, plane-parallel stratification concordant with both underlying and overlying deposits. Lowermost part, as well as other internal horizons, shows shearing features. This deposit is considered to represent a slide block displaced downslope.

Disturbed mudstone subfacies: This deposit has been recognised in B-E outcrops (Figs. 1 and 2B-C). It constitutes 1,7-9 m thick mudstone beds showing folded or tilted internal bedding. Bottoms are sharp, non-erosive to slightly erosive and tops are flat to mounded. The thinnest beds show also intraclasts of turbidite sandstone, siderite and mudstone between folded or tilted mudstones. Slump folds, when distinguished, are isoclinal and present sheath shapes. Internal bedding of tilted mudstone blocks is discordant with overall bedding, resembling imbricated slabs. This subfacies is considered to represent downslope travel and deposition of mudy slumps. Mounded tops may correspond to compressional ridges, structures formed commonly in the accumulation zone of slumps (e.g. Frey-Martinez *et al.*, 2005). Local presence of scattered sandstone fragments may be interpreted as rip-up clasts incorporated to the slump by erosion of underlying sandstones during its downslope transport. In the rare cases where clasts are relatively abundant (Fig. 2B, up right photograph) they may represent more evolved flows with intermediate characteristics between slumps and mudflows.

Alternating sandstones and mudstones facies

These common deposits are present in all outcrops (Figs. 1 and 2) and consist of 5-70 cm thick, fine- to coarse–grained sandstones alternating with mudstones. The sandstone to mudstone ratios is about 3:2. Beds are perfectly tabular and do not show any disturbance. Sandstones show different Bouma sequences, mainly Tb, Tbc and Tab. They are considered to be the deposits of low to high density turbidity currents. Plane-parallel bedding reflects low relief or smooth floor.

Slumped sandstones facies

This facies crops out in B locality overlying an angular unconformity (Fig. 2B, meter 14 and low right photograph). It constitutes a wedge-shaped body of coherently to semicoherently folded alternating sandstone and mudstone beds showing isoclinal folds. This deposit is considered to represent downslope travel and deformation of sandstone and mudstone beds, and final deposition as slump.

Spatial variability of deposits

Alternating sandstones and mudstones (turbidites) are abundant in all outcrops localised to the north of the Elgoibar fault. Thickest mudstones (12 m) correspond to undisturbed mudstones (slide) in the nearest outcrop to the Elgoibar fault (A, Figs. 1 and 2A), whereas in the other studied outcrops (B-E, Figs. 1 and 2B-C) mudstones are thinner (1,7-9 m) and correspond to disturbed mudstones (slumps). More to the north, mudstones are absent. Thickness diminishing of mudstone intervals towards the north indicates that the source area of slides and slumps was localised southward, close to the Elgoibar fault. In this way, undisturbed mudstones (slides) would correspond to more proximal deposits than disturbed mudstones (slumps) suggesting that slides and slumps were generated by the same gravity flows but in different proximity to the source area. A similar downslope evolution of slides and slumps has been documented in the continental margin of Israel (Frey-Martinez *et al.*, 2005). On the other hand, the only slumped sandstones bed overlying an angular unconformity suggests a close relationship with basin tectonics.

Depositional model

Agirrezabala and García-Mondéjar (1994) and Agirrezabala (1996) interpreted the distal or outer part of the OTS as confined by a southern slope dipping NNE created by the Elgoibar fault. The same authors, in base to spatial facies and granulometry distributions and paleocurrent data from turbidites suggested that turbidity currents of the

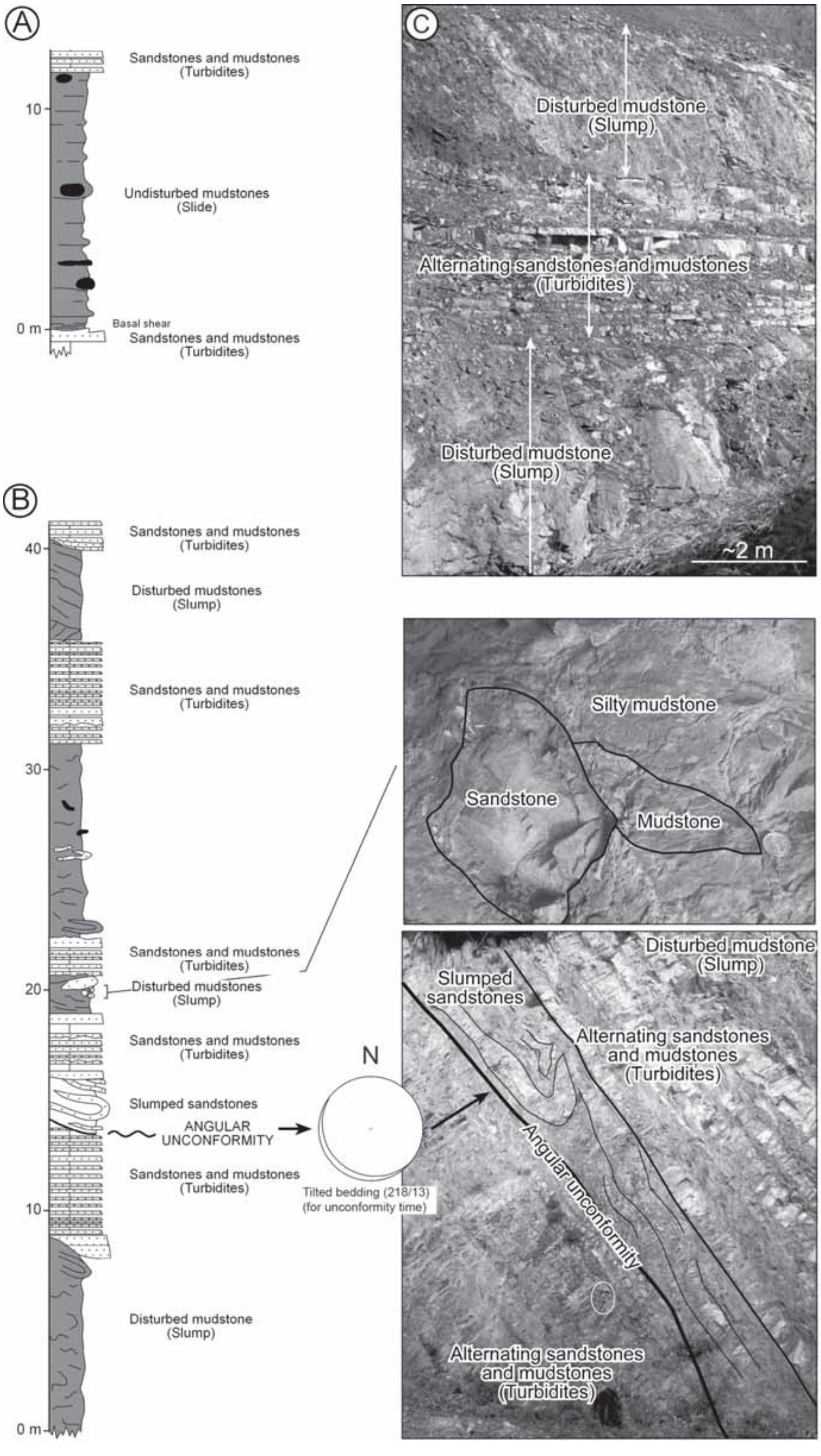

Fig. 2.- Sections and photographs of selected outcrops, showing main facies and subfacies. (A) Section of A outcrop. (B) Section and detail photographs of B outcrop. (C) Photograph of C outcrop. For outcrop location see Fig. 1.

Fig. 2.- Columnas y fotografías de afloramientos seleccionados mostrando las facies y subfacies principales. (A) Columna del afloramiento A. (B) Columna y fotografías de detalle del afloramiento B. (C) Fotografía del afloramiento C. Para la localización de los afloramientos ver Fig. 1.

outer system flowed along the basin axis towards the ESE, parallel to the Elgoibar fault (Fig. 3). Sedimentological interpretation of mudstone deposits indicates that slumps were derived from the SSW and transported to the NNE (Fig. 3), perpendicular to the turbidity current flows.

The abundance of slumps shows that the slope from which they were derived was highly unstable. Most likely, the turbidites were not deposited on this lateral slope but very close to its base. The largely undeformed, tabular sandstone packages or sheets that dominate the outer system, are more likely to have been deposited on a basin floor than on a slope. In contrast, the mudy slumps probably originated on the nearby slope (also indicated by their lithology) and travelled to near the foot of the slope or on to the adjacent basin floor. This seems to be the only likely alternative for why undeformed, plane-parallel turbidite packages are interbedded with thoroughly deformed slumps.

Discussion

The occurrence of large number of slump deposits (slump complex) as that observed in the study area raises the obvious question of what factor controlled repeated failure. Previous studies have identified a number of possible causes controlling the development of recent submarine slumps, such as destabilisation of gas hydrates (e.g. Andreasen *et al.*, 1990), presence of gas in the sediments (e.g. Prior and Coleman, 1978), high sedimentation rates (e.g. Imbo *et al.*, 2002), seismicity (e.g. Lewis, 1971) and steepening of slope angle (e.g. Hampton *et al.*, 1996).

In the case of the slump deposits presented here, there is no evidence of gas hydrates and/ or gas presence in the Albian sediments. However, the high sedimentation rates evidenced by the great thickness of the axial turbiditic succession (up to 1000 m), may also indicate high sedimentation rates in the nearby mudy slope. In this sense, high sedimentation rates can result in underconsolidation of buried layers of mud sediments in which upward hydraulic gradients reduce the internal shear strength of the sediment and lead to slope instability.

Although earthquakes generation has not been documented for Albian times in the Basque-Cantabrian Basin, intense strike-slip tectonics of the area (high gradients of subsidence, local angular unconformity and confinement of pull-apart sub-basin) could have generated earthquakes responsible of submarine slope instability. In this way, the sinistral strike-slip Elgoibar fault (Agirrezabala and García-Mondéjar, 2001) is considered an active master fault of the Cretaceous Pyrenean strike-

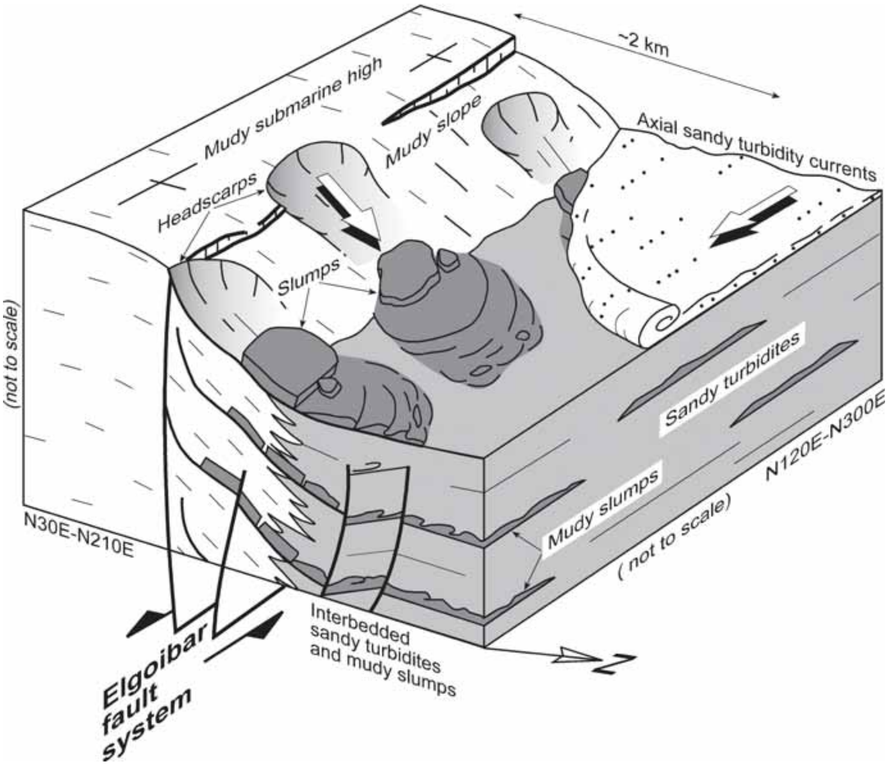

Fig. 3.- Depositional model for the outer part of the Ondarroa turbidte system.

Fig. 3.- Modelo deposicional para la parte externa del sistema turbidítico de Ondarroa.

slip system (García-Mondéjar *et al.*, 1996). Earthquakes have two effects on the sediments of a slope system: a) generate intermittent horizontal and vertical acceleration stresses that produce a direct loading on the sediment, and b) can increase fluid pressure in the sediments that cause reduction in the effective stress and therefore friction in the basal shear surface (Hampton *et al.*, 1978).

The high subsidence rates deduced for the very thick outer part of the OTS and its important confinement suggest an accused differential subsidence driven by the strike-slip Elgoibar fault. It is possible that the pronounced differential subsidence generated steep slope gradients and, therefore, slope instability nearby the Elgoibar fault trace. Slopes are stables as long as the angle of internal friction is greater than the slope angle. The typical angle of internal friction for claystones is 15º (Frey-Martinez *et al.*, 2005).

In summary, high sedimentation rates, seismicity and steepening of slope angle may be the controlling factors for slumping in the study area. Definitively, these three factors would have been driven by the activity of the Elgoibar fault.

Acknowledgements

Partial funds for this work were provided by Euskal Herriko Unibertsitatea, Project 9/UPV 00121.310-13556/2001 and Ministerio de Educación y Ciencia, Project BTE2003-04823.

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