Holocene fan deltas in a «Ria» morphology. Prograding clinoform types and sea-level control

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ABSTRACT

A transgressive system track is developed on the Ria of Muros (Galicia, Spain) during the Holocene sea-level rise in the last 18.000 years. The internal structure of this system has been studied by means of high resolution seismic sections. We recognize a sequence beginning with a seismic unit characterized by a channelized geometry of the reflectors and strong erosion of the acoustic basement. Upon this, a transgressive system track is developed within which we recognise seven progradational bodies separated by small discontinuity surfaces. These sedimentary bodies are composed by parallel, sigmoid and oblique prograding clinoform seismic reflection patterns.

The geometry and seismic facies relations of these bodies lead to interpret them as fan-delta depositional systems developed on the flanks of the Ria during still-stands of sea-level in a transgressive regime. The three types of prograding clinoforms observed are arranged into a sequence related to the increase of water-depth by marine flooding of the Ria. In this sense, we suggest that the sea-level rise increase rate in a Ria type morphology is the most important factor that controls the type of prograding clinoforms due that modify factors such as basin depth, salinity range, wave energy and oceanic currents input within the Ria.

Key words: Rias, Fan-delta, Holocene, Sea-Level, Reflection-seismic, prograding clinoforms.

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RESUMEN

En la Ría de Muros (Galicia, España) se desarrolla durante el ascenso Holoceno del nivel del mar (correspondiente a los últimos 18.000 años) un importante cortejo sedimentario transgresivo. La estructura interna de este sistema ha sido estudiada mediante perfiles de sísmica de alta resolución (Uniboom 300 J). La secuencia comienza con una unidad sísmica caracterizada por reflectores acanalados que presenta en su base una fuerte erosión del basamento acústico. Sobre esta unidad se desarrolla el cortejo sedimentario en el cual han sido distinguidos hasta siete clinoformas progradantes separadas por discontinuidades y cuya estructura interna está compuesta de tres tipos de reflectores progradantes: paralelos, sigmoides y oblicuos.

La geometría y relaciones entre las facies sísmicas de estos cuerpos nos lleva a interpretarlos como sistemas de abanicos deltaicos («fan-deltas») desarrollados a favor de los flancos de la Ria durante paradas del nivel del mar acaecídas en la transgresión Holocena. Los tres tipos de clinoformas progradantes observadas pueden ser asociadas con una secuencia de incremento de profundidad dentro de la Ria, debido a la progresiva inundación por aguas del Atlántico. En el presente trabajo se sugiere que el grado de ascenso del nivel del mar es el factor de mayor importancia para controlar el tipo de abanico deltaico desarrollado, ya que de él dependen variables como profundidad de la cuenca, salinidad, energía del oleaje, y entrada de corrientes oceánicas en el interior de la Ria.

Palabras clave: Rías, Abanicos deltaicos, Holoceno, Nivel del mar, Sísmica de alta resolución, clinoformas progradantes.

INTRODUCTION

The Ria of Muros (Fig. 1), from a morphotectonic point of view, is enclosed within the term «Rias» which constitute a well defined type of coast. The origin and evolution of the Rias have been studied and reported elsewhere (Pannenkoek, 1966; Nonn, 1966; Vidal Romaní, 1981) The Rias probably have a tectonic origin along N-S structures parallel to the ancient Atlantic rifting, which gave rise to a strong fluvial erosion in NE-SW direction. Alternatively, Rias originated from only eustatic sea-level changes due to valley incisions. Rey (1990) proposed a mixed model based on moderate movements of N-S listric faults during Mio-Pliocene as a result of the evolution of the «passive Atlantic margin» which would give rise to the progressive displacement landwards of the highstand system-track limits from Pliocene to Quaternary.

At present, the hydraulic of Ria of Muros is characterized by mesotidal estuarine type circulation in the internal areas and by a clear asymmetric

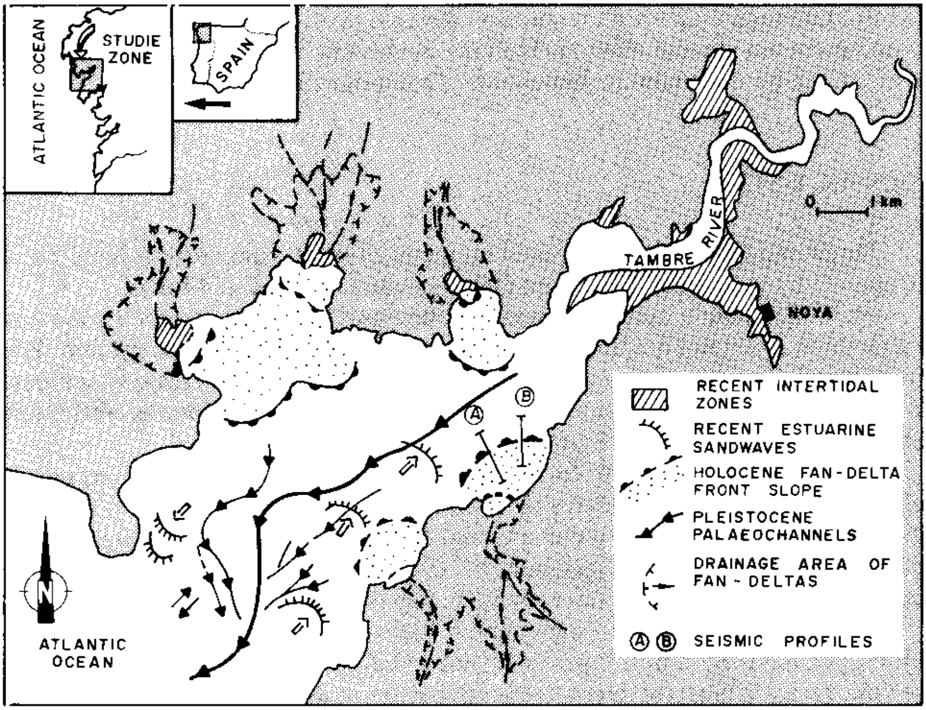


Fig. 1.—Pleistocene and Holocene morphodynamic features of the Ria of Muros and situation of seismic profiles showed in the figures 2 and 3. The fluvial palaeo-channels are situated mainly along the central axis of the ria whereas the fan-delta bodies are developed on the flanks.

Fig. 1.—Rasgos morfodinámicos de la Ría de Muros y situación de los perfiles sísmicos mostrados en las figuras 2 y 3. Los paleocanales fluviales se sitúan principalmente a lo largo del eje central de la ría mientras que los fan deltas se desarrollan en los flancos.

penetration of oceanic water mass inward along the South border and outwards along the North border. This circulation is clearly reflected by the formation of big sandwaves oriented in the entrance direction of these oceanic currents of general character (fig. 1).

Several examples of fan-deltas occurrence have been described in a Ria or Fjord type morphology, in the Pliocene Mediterranean (Clauzon & Rubino, 1990) and in the Holocene Pacific coast (Prior & Bornhold, 1990). The main feature is that the basin morphology preexists to the marine flooding and is poorly modified by tectonics. In the same way, the fan-delta architecture is related with eustatic control rather than tectonics. The main aim of this work is to analyze the geometry and seismic facies of Holocene underwater prograding bodies in a Ria morphology of the Atlantic Ocean coast, and its relation with eustatic control. In this sense, high resolution seismics allows a very good definition of the internal structures and internal geometry of partly lithified deposits. The high resolution seismic profiles used have been made with Uniboom system (300 J) (Herranz & Acosta, 1984) in several surveys carried out by the Instituto Español de Oceanografia.

SEISMIC UNITS

Three main seismic units based on the high resolution records have been proposed by Acosta and Herranz (1984) within the Ria of Muros:

(i) An acoustic basement represents the basal unit, below which coherent reflections could not be detected with the high resolution seismic system. We infer that the basement is constituted by materials of the herzinic basement. Its seismic character corresponds to a strong and continuous reflexion showing a strongly erosive irregular type surface.

(ii) A Pleistocene unit forms the lower set of Quaternary sequence, characterized by seismic facies of complex and chaotic filling types (fig. 2). This unit is interpreted as a channelized fluvial sequence whose disposition coincides with the present longitudinal axis of the Ria (fig. 1). A generalized erosion surface cuts the reflectors at the top of this unit.

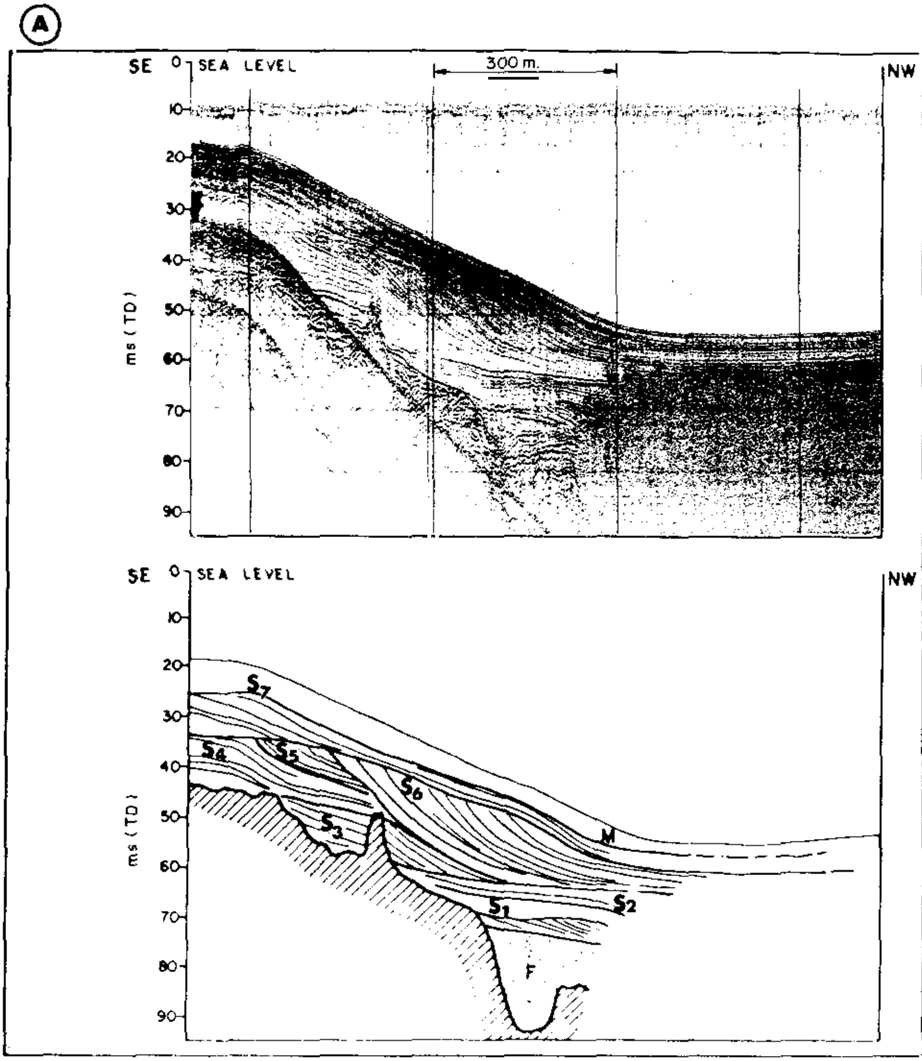
(iii) A Holocene section overlies the Pleistocene channel deposits and, in turn, is covered by a thin layer of recent estuarine muds. Two main types of seismic facies in terms of internal reflection patterns are differentiated within this unit, having different spatial distribution in the Ria. The first type of seismic facies present parallel to sub-parallel internal reflection patterns and is developed in the central part of the Ria. The second seismic facies has oblique and sigmoid internal reflection patterns with high continuity and give rise to prograding clinoforms with a well differentiated morphology within the Ria (fig. 1).

PROGRADING CLINOFORMS, GEOMETRY AND SEISMIC REFLECTION PATTERNS

The detailed analysis of the Holocene complex (fig. 2 and 3) shows an architecture composed of, at least, seven prograding clinoforms separated by slight discontinuities. Three different types of internal reflection patterns show this system:

(i) parallel progradational arrangements, that present S1 and S2 bodies (Fig. 2 and 3) overlaying chaotic and filling seismic facies units. The thickness of these bodies is about four meters (S1) and eight meters (S2). At the top of S2 a strong subhorizontal reflector cut the internal parallel configuration of these bodies.

(ii) sigmoid configurations occur mainly in the S3 and S4 bodies downlapping the last ones. The thickness reaches 15 meters in the S4 body.



F - FLUVIAL CHANNELS

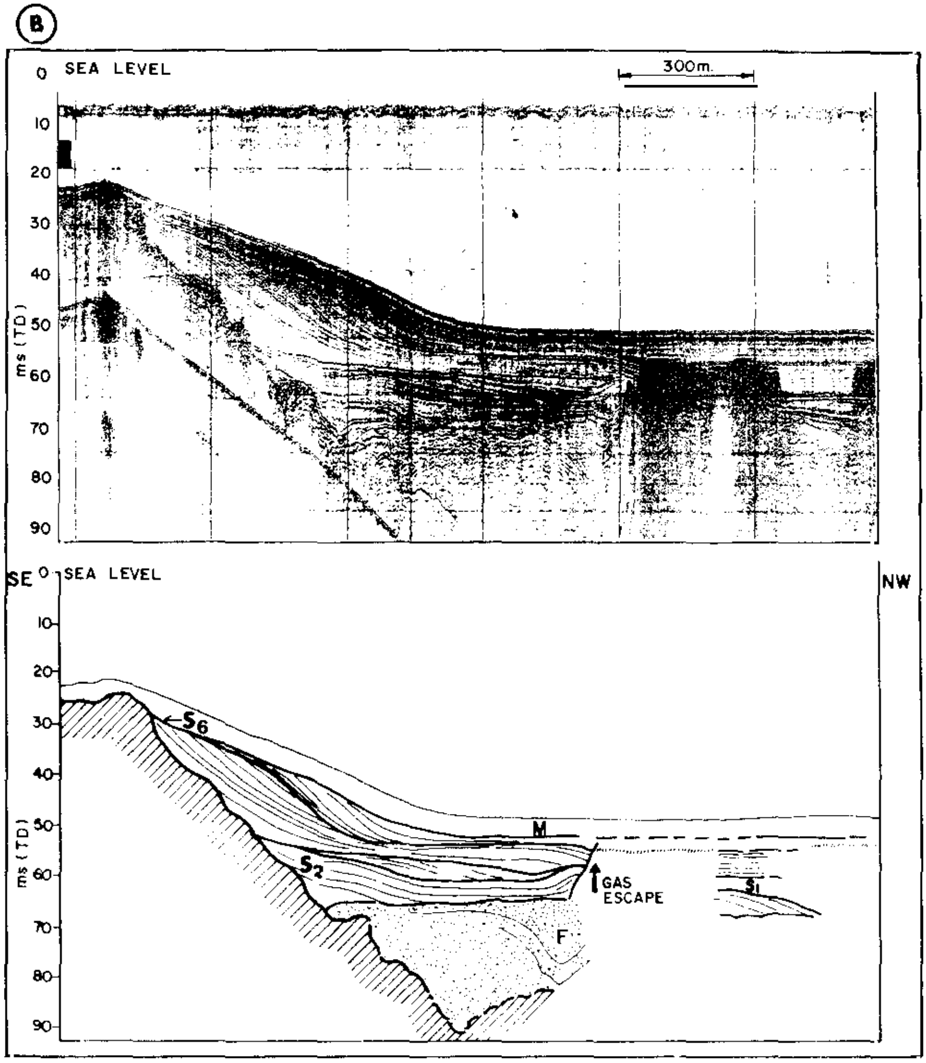
S_1 - S_7-HOLOCENE FAN-DELTAS

GAS MASKING

M - RECENT ESTUARINE SEDIMENTS

Fig. 2.—High resolution seismic profile (Uniboom 300 J) showing the internal structure of fan-delta system that is onlapping the pleistocene fluvial channels.

Fig. 2.—erfiles sísmicos de alta resolución (Uniboom 300 J) mostrando la estructura interna del sistema de fan deltas que solapa los canales fluviales pleistocenos.



F – FLUVIAL CHANNELS
S1 - S7-HOLOCENE FAN-DELTA
GAS MASKING
M – RECENT ESTUARINE SEDIMENTS

Fig. 3.—High resolution seismic profile (Uniboom 300 J) showing the internal structure of the fan-delta system and the distal facies with high grade of organic matter and gas generation.

Fig 3.—Perfiles sísmicos de alta resolución (Uniboom 300 J) mostrando la estructura interna del sistema de fan deltas y las facies distales con alto contenido en materia orgánica y formación de gas.

A progressive step to oblique configurations can be observed from S4 to S5 body.

(iii) oblique configurations constitute the internal reflection patterns of the S5 and S6 bodies. These represent the major prograding clinoform of the system, reaching a thickness of 25 meters. One of the most important features of this type is that the reflective depositional surface is steeper than the other configurations.

SEISMIC FACIES AND DEPOSITIONAL ENVIRONMENT

The prograding clinoforms configurations are formed trough progre-ssive development of depositional surfaces that slope from a gentle dipping, relatively shallow water area into deeper water. Thus the reflection character and geometry of these prograding bodies are used to infer the depositional envi-ronment. Each prograding body can be divided into upper zones representing the topset, well developed on the sigmoide configurations, middle zones assumed as foreset and the lower zones as bottomset. In this way each prograding seismic clinoform reflects a sedimentary body of continental origin that intrude into the water and prograde from shallow water to deep water calling it «fan-delta» (Nemec, 1990).

Therefore, taking into account the relation between seismic character and environmental interpretation, a approach to the fan-delta facies in a Ria environment can be drawn. The subaqueous proximal facies of the fan-delta would be represented by parallel-subhorizontal reflectors of high reflectivity observed in the sigmoide prograding clinoforms. This seismic character is associated to high energy and non-channelized deposits. The foreset deposits area represented by high frequency reflectors arranged into sequences of high and low reflectivity. This is specially clear in the oblique prograding clinoforms (S6) (Fig. 2 and 3). This seems to be due to periods of coarse-grained supply (high reflectivity) intercalated with fine-grained sedimentation (low-reflectivity).

The distal zone (bottomset) of the delta would be represented by two types of facies:

(i) Lenticular configurations with high reflectivity located at the base of the the prograding clinoforms that could be interpreted as medium-coarse grained resedimentation lobes of the fan-delta front or, as lateral supplies of the Ria.

(ii) Subhorizontal and high frequency reflectors situated in the central part of the Ria are interpreted as fine-grained distal facies. The reflection character in the distal areas of the fan-deltas bodies show synsedimentary deformation and acoustic masking, an indication of high content in gas (Acosta, 1982). These deformations (fig. 4) have been interpreted as upwards movements of the gas contained in the sediment due to rapid increase of the load by redepositional lobes.

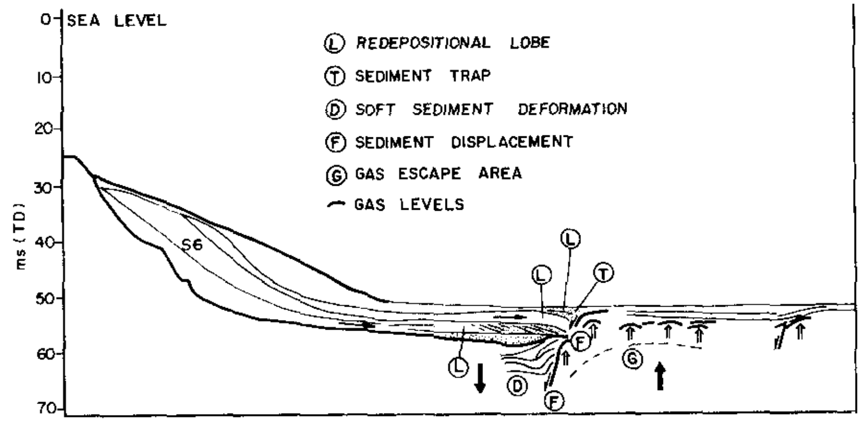


Fig. 4.—Schematic representation of a simple fan-delta body and its characteristics distal facies due to gas escape with overlapping of redepositional lobes.

Fig. 4.—Representación esquemática de un cuerpo simple de fan delta y sus facies distales características debido a escape de gases con solapamiento de lóbulos redeposicionales.

SEA LEVEL FLUCTUATIONS AND PROGRADING CLINOFORM TYPES

The Holocene depositional sequence is interpreted to be the result of a general rise of sea level which produced a change in the hydrodynamic conditions within the Rias by progressive flooding of Atlantic oceanic water. The filling of the fluvial channels marks the start of sea level rise after it reached the lowest point of falling. After the initial incursion of marine water and deposition of channel fill, a intermediate phase of flooding was reached in which the Ria was a semi-enclosed environment without great influence of the strong oceanic currents. This protected condition allowed the progradation of marginal fan-delta bodies towards the center line of the Ria due to the low energy of the environment. The complex architecture of this marginal system is interpreted as a transgressive system track where the fan-delta bodies developed during stillstands of the sea level.

Taking into account as datum the inflexion of the upper part of the sigmoid and oblique prograding clinoforms of each body, and adjusting its depth to the general curve of the trend of sea level rise in the Holocene (Morner, 1987), we speculatively correlate the development of fan-delta units to stillstands of sea-level (fig. 5). Thus we suggest small periods of progradation coincident with a stillstand of the sea-level during a transgressive trend.

CONCLUSIONS AND DISCUSSION

The example of the Ria of Muros shows a model of a transgressive system track (Van Wagoner *et al.* 1988), observed on the high resolution seismic

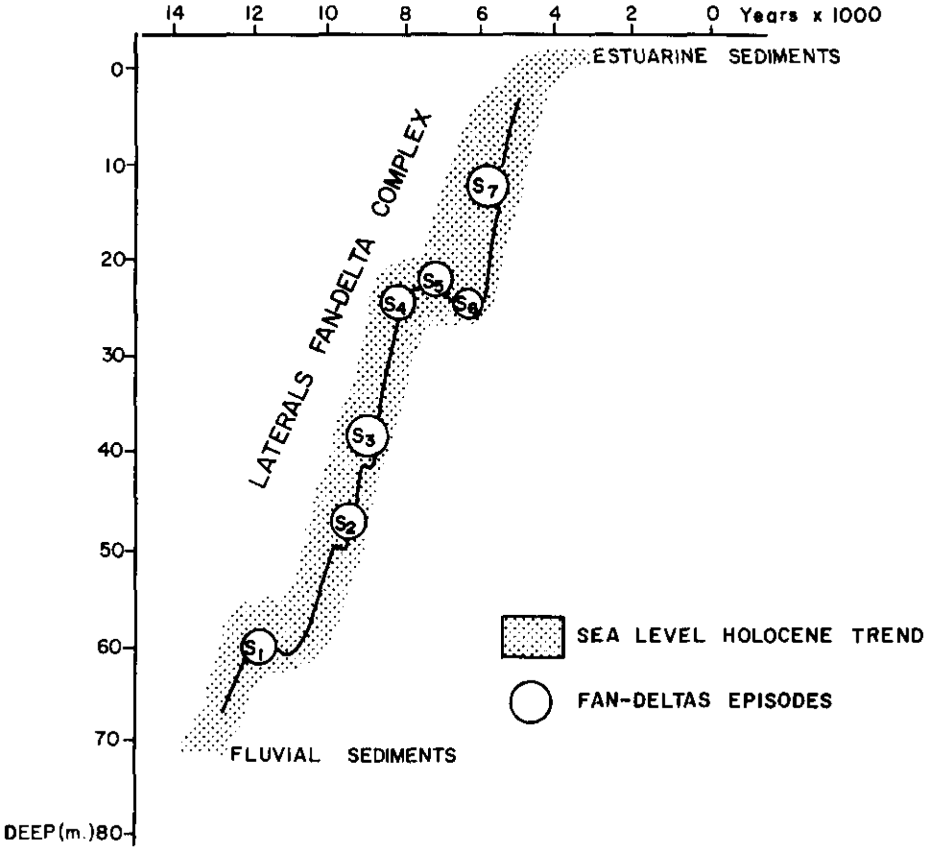


Fig. 5.—Atlantic Holocene sea-level curve (Morner, 1987) used to fit the "stillstand" related to the progradation of the fan-delta bodies.

Fig. 5.—Curva de cambios de nivel del mar holocenos (Morner, 1987) utilizada para relacionar los altos relativos con la progradación de los cuerpos de fan delta.

records (fig. 6), due to the Holocene sea-level rise in the last 18.000 years. Several prograding bodies along the flanks of the Ria have been defined within the transgressive sequence.

Three types of prograding clinoforms in terms of seismic reflection patterns have been considerated (parallel, sigmoid and oblique) that can be related to delta variability (Postma, 1990) (fig. 7) depending on the depth. The parallel prograding clinoforms are associated to shoal-water delta profiles where bed-load transport dominate. The sigmoid pattern occur with higher depth rates and can be related to «Gilbert-Type» fan delta profiles with more important homopycnal conditions. In the same way, oblique prograding clinoforms which have steeper slipface are related to delta-fed submarine

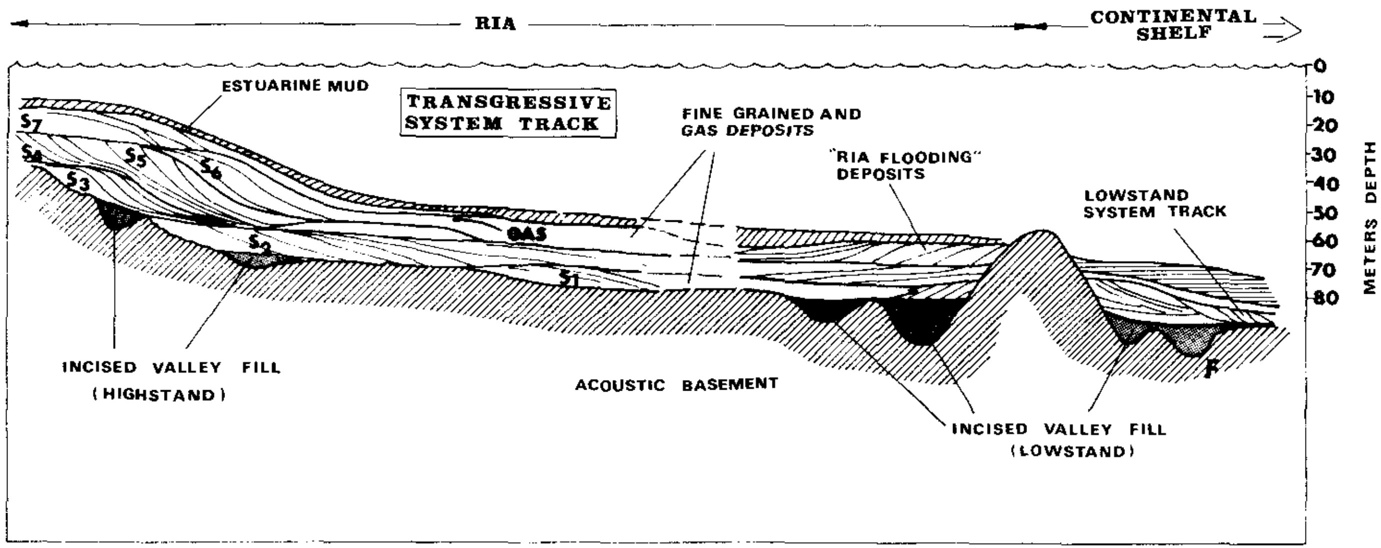


Fig. 6.—Schematic model representing the Holocene seismic sequence of the Ria and Continental Shelf of Galicia (partly modified from Rey, 1990). The transgressive system of prograding clinoforms (S1 to S7) is correlated with landward prograding deposits at the Ria mouth, interpreted as a flooding marine sequence.

Fig. 6.—Modelo esquemático representando la secuencia sísmica holocena de la Ría y de la plataforma continental de Galicia (parcialmente modificado de Rey, 1990). El sistema transgresivo de clinoformas progradantes (S1 a S7) se correlaciona con los depósitos progradantes hacia tierra de la desembocadura de la Ría, interpretados como una secuencia marina de inundación.

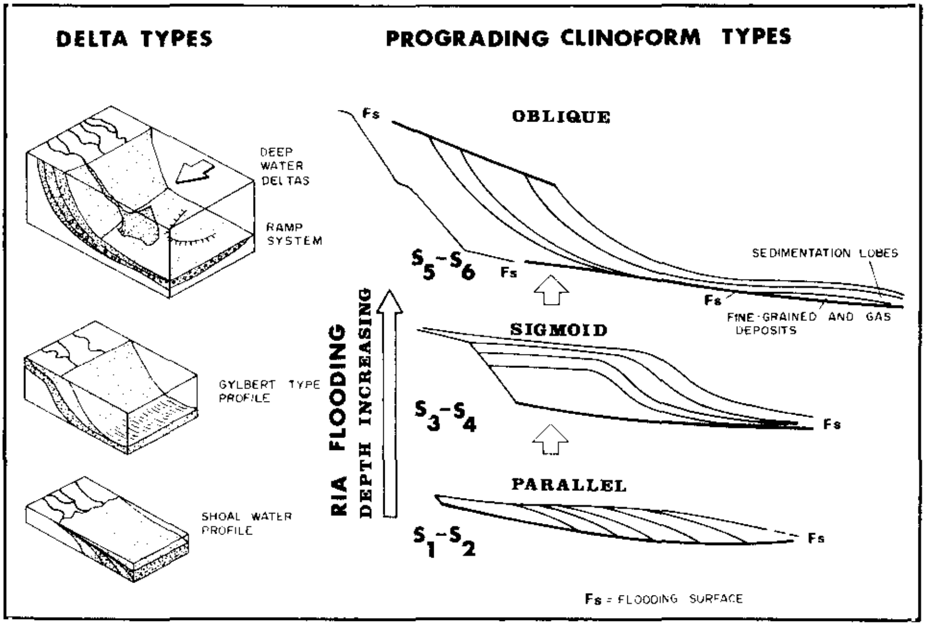


Fig. 7.—Evolution of prograding clinoform patterns in the transgressive systems track of the Ria of Muros and its relation with delta type variability (Postma, 1990) depending on the depth ratio.

Fig. 7.—Evolución de la tipos clinoformas progradantes en el cortejo de sistemas de facies progradantes de la Ría de Muros y su relación con la variabilidad de los tipos de deltas (Postma 1990) dependiendo de la relación de profundidad.

ramp system (fig. 7) with lobe system developed by sediment by-passing processes result of delta-front failure or hyperpycnal effluent (Prior & Bornhold, 1988).

We suggest that the prograding clinoforms types observed in the Ria are controlled mainly by the sea-level increasing rate during a transgressive trend. The sea-level rise should modify important factors within a Ria type morphology such as the freshwater-salt water mixed rate, wave and oceanic currents input and tidal range. Therefore the progressive flooding of the Ria change the type of prograding clinoforms and controls the basin depth, salinity rate, and wave energy. Each body is built up during stillstands or inflexions of the sea-level trend. In a non-tectonical coast the accommodation or creation of space for the sedimentation and the basin depth only depend on the sea-level rise increase rate between «stillstand» periods (Posamentier & Vail, 1988).

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