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ORIGINAL

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Echo characters and recent sedimentary processes as indicated by high-resolution sub-bottom profiling in Ría de Vigo (NW Spain)

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Abstract A detailed study of high-resolution (3.5 kHz) sub-bottom profiles reveals the presence of 17 different types of echo character (acoustic facies) in the recent sedimentary infill of the shallow Ría de Vigo (NW Spain). By correlating the echo character with surface sediments, we have been able to infer the recent sediment dynamics in the ría seafloor, 60.5% being related to modern depositional processes. In the outer ría area, where wave activity is strong, erosive and high-energy depositional processes dominate, whereas in the protected area of the inner ría the majority of recent processes are low-energy depositional, progradational and/or a combination of both.

Introduction

The most widely applied method for studying Quaternary sedimentary features and processes on continental rises is echo-character analysis (Damuth 1980). Since the early 1960s, high-resolution (3.5–12 kHz) echograms have been used extensively for this purpose. Correlation of echo-character analysis with current-meter data, sediment cores, and side-scan sonar imagery has been a highly successful method for understanding the distribution and origin of deep-sea bedforms (Poag and de Graciansky 1992).

The identification of acoustic facies relies on the sub-surface response to high-frequency seismic energy, in particular the observed echo duration, amplitude, and number of reflectors (Damuth 1975; Frappa and Duprat 1983). In addition, horizontal disposition and continuity of elementary echoes is also a characteristic of an acoustic facies. Finally, the ability to accurately define acoustic facies on the basis of echo character depends on the evolution of the seismic reflectors along and between individual survey lines (Frappa and Pujos 1994).

The acoustic energy returned by a given reflector depends initially on its differential acoustic impedance; that is, the impedance contrast between the units above and below the surface. Moreover, the energy reflected is a function of surface roughness and signal wavelength (Sheriff 1977). At 3.5 kHz, the wavelength for loose-grained surficial deposits is approximately 0.5 m (Frappa and Pujos 1994).

The study of high-resolution seismic sub-bottom profiler data (3.5 kHz) provides accurate information on the seabed's texture, microtopography, and erosive and depositional processes (Damuth 1980; Pratson and Laine 1989). This indirect technique has been widely used in deepwater environments (Damuth 1975; Johnson and Damuth 1979; Damuth 1980; Poag and de Graciansky 1992; Driscoll and Laine 1996; Howe et al. 1997; Pérez Fernández et al. 1997; Gilbert et al. 1998; Pudsey and Howe 1998; Lee et al. 1999; Gee et al. 1999; Sager et al. 1999; Wynn et al. 2000; Zaragosi et al. 2000; Droz et al. 2001). More recently, it has also been used for shallower marine areas (MacClennen 1989; Rey 1993; Reddy and Rao 1997; Yoon et al. 1997; Lobo and Hernández-Molina 1998; Frappa and Pujos 2000).

Although several studies have been conducted in the Galician rías, some focusing on their recent sediments (Fernández-Bastero et al. 1999; García et al. 2000; Rubio et al. 2000; Diz et al. 2001), only a few have targeted their Holocene sedimentary infill (Margalef 1956; Acosta 1984; Hernández-Molina et al. 1994;

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García-Gil et al. 1999a, 1999b, 2000a; Vilas 2003). The objective of the present study is to provide accurate information on the texture, microtopography, and erosive and depositional processes of the seabed of a ría environment through the detailed study of high-resolution sub-bottom profiler records.

Study area

The Ría de Vigo (Fig. 1a) is located on the passive Atlantic margin of southwestern Galicia (NW Spain), the ría coast known as Rías Baixas. The Ría de Vigo's physiography presents a distinctive funnel shape, with an areal extent of 176.4 km^2. The Ría de Vigo trends at nearly right angles to the region's Paleozoic basement structure (Fig. 1b). Its basement comprises Paleozoic metamorphic and granitic rocks cut by NE-SW, NW-SE and N-S trending faults. The entire ría coast is possibly related to the post-Pyrenean extensional phase, during both the Oligocene and Miocene (García-Gil et al. 1999b).

The water depths within the Ría de Vigo range from 7 m in its inner part, to 53 m at the outer (southwest) entrance to the sea (Fig. 2a). The north entrance is shallow, with a max. depth of 30 m, the deeper southern entrance being more than 50 m depth. The grain-size distribution of the present-day seafloor consists of mixed siliciclastic and skeletal gravels in both the outer ría area and along the edges of the ría , whereas the central and inner ría parts are dominated by clay and silt with up to 10% organic matter content (Vilas et al. 1995).

Materials and methods

During the summer of 1991 a survey was conducted aboard R/V "*El Investigador*". A total of 640 km of seismic lines were acquired in the Ría de Vigo on a rectangular grid with lines spaced 66 to 550 m apart (Fig. 2b). These data were provided by a high-resolution seismic 1036 model ORE (3.5 kHz) sub-bottom profiler, and an Atlas Deso 20 echosounder (33–210 kHz). Heave/swell correction was not applied during data acquisition. For navigation and position fixing, we used a Trimble 4000 RL Differential GPS station, combined with a transponder unit.

Sediment samples were collected using Van Veen and box core dredges during the Ministry of Public Works and Transportation (MOPT) cruise in 1991, and the University of Vigo (UVIGO) cruise in 1998. In the former samples, the particle size distribution of the sediments was measured using a combination of dry sieving for grain sizes larger than 63 μm and X-ray nephelometry for particles smaller than 63 μm (Micromeritics, Sedigraph 5100).

In the box core samples, grain-size distribution was determined by wet-sieving, with sieve columns ranging from 1 mm to 37 μm, spaced at 1 phi (1,000, 500, 250, 125, 62, 37 μm) when samples had a high amount of medium sand. The average for the first 5 cm was the

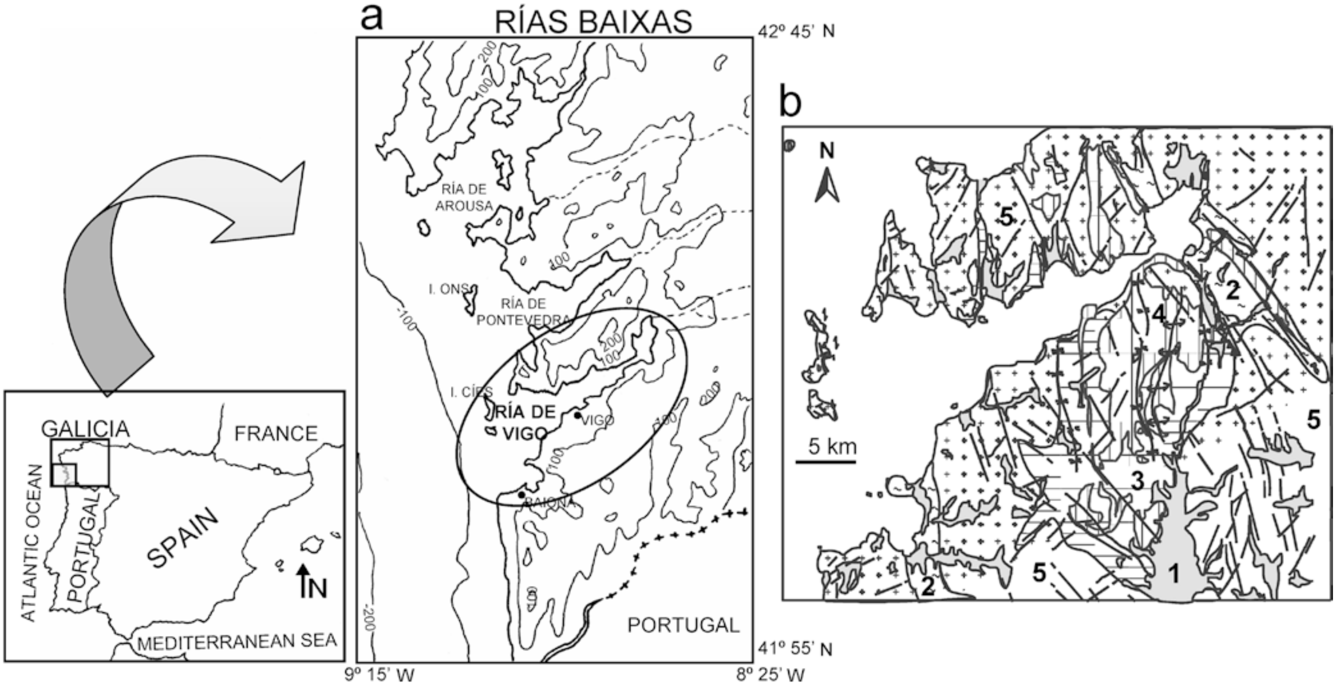


Fig. 1 **a** Geographical setting of the Ría de Vigo, located on the NW coast of Spain; **b** Geological map of the ría: *1* Quaternary sediments, *2* metasediments, *3* paragneis, *4* orthogneis, and *5* granites. *Continuous lines* represent mechanical contacts, and *dashed lines* represent faults, anticlines and synclines. Modified from Rubio et al. 1981

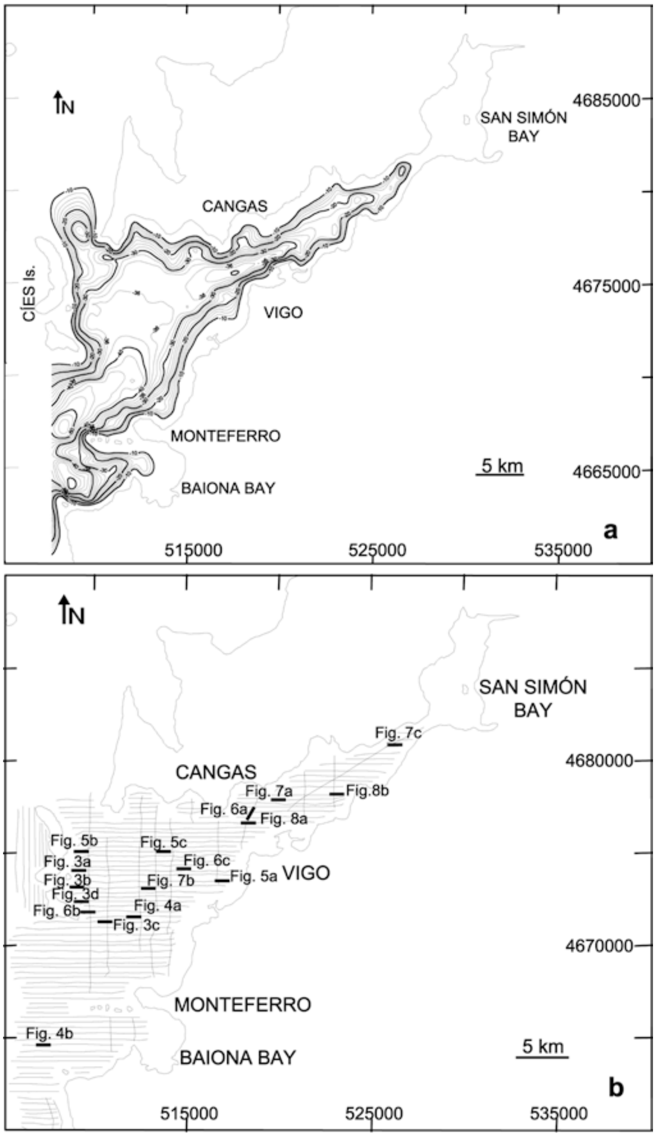


Fig. 2 **a** The bathymetry of the Ría de Vigo. *Bathymetric contours* at 2 m intervals. The *inner part* presents a central channel, where it attains its maximum depth. In the southern entrance, bathymetry is deepest. **b** Survey tracklines in the area, with figure locations represented as *thick lines* above the seismic survey

used value in this study. This new data set was combined with available information on the recent sediments of the Ría de Vigo (Vilas et al. 1995).

Results

Echo-character (3.5 kHz) analysis

A detailed and specific classification of the different echo characters in the Ría de Vigo has been obtained following the methodology and classification proposed by Damuth (1980) and Pratson and Laine (1989), comparing the ría with similar echo types reported on other margins world-wide. A total of 17 echo characters have been identified, and grouped into nine different classes, depending on their acoustic responses.

Class 1: Distinct echo

This echo character, the most common in the Ría de Vigo area, discerns part of the sedimentary infill below the ría seafloor, due to its higher acoustic penetration (Fig. 3). Occasionally, the reflectors of the seismic units can be seen in detail, whereas in other cases the only clear reflector is the basal reflector. There are several types of echoes within this class.

TYPE 1a: Transparent echo with visible seismic units and internal structure (Fig. 3a). When this echo appears, the seismic units, as well as their internal structure, can be observed on the seismic records. This echo character occupies 6.5% of the surveyed area.

TYPE 1b: Transparent echo with visible seismic units but without internal structure (Fig. 3b). This echo type corresponds to 3.5 kHz echoes where seismic units, separated by discontinuities, can be observed, but without any visible internal structure within the units. It represents 2.8% of the surveyed area.

TYPE 1c: Transparent echo without visible seismic units but with a basal reflector (Fig. 3c). In this type of echo, the only strong reflector is the basal reflector and this is not always very distinct. This echo character is the most widely occurring echo type in the ría, occupying 25.2% of the surveyed area.

TYPE 1d: Transparent echo with internal clinoforms (Fig. 3d). This echo type displays internal clinoforms which show progradational trends and covers an area of 2.8% of the ría.

Class 2: Indistinct echo

These echoes show part of the sedimentary infill below the ría seafloor, but with more internal reflectivity than the previous class 1 (Fig. 4). Occasionally, the reflectors of the seismic units can be distinguished. There are two echo-character types within this class.

TYPE 2a: Semi-transparent echo with visible seismic units (Fig. 4a). This is an echo character revealing seismic units, but generally without distinct internal structure. In the Ría de Vigo, this echo type appears only locally, representing a mere 1% of the mapped area.

TYPE 2b: Semi-transparent echo without visible seismic units (Fig. 4b). This corresponds to an opaque seabed reflector which impedes the view of the seismic units. It represents most of class 2 echoes, and is more common in the Ría de Vigo area than is type 2a, occupying 9.3% of the surveyed area.

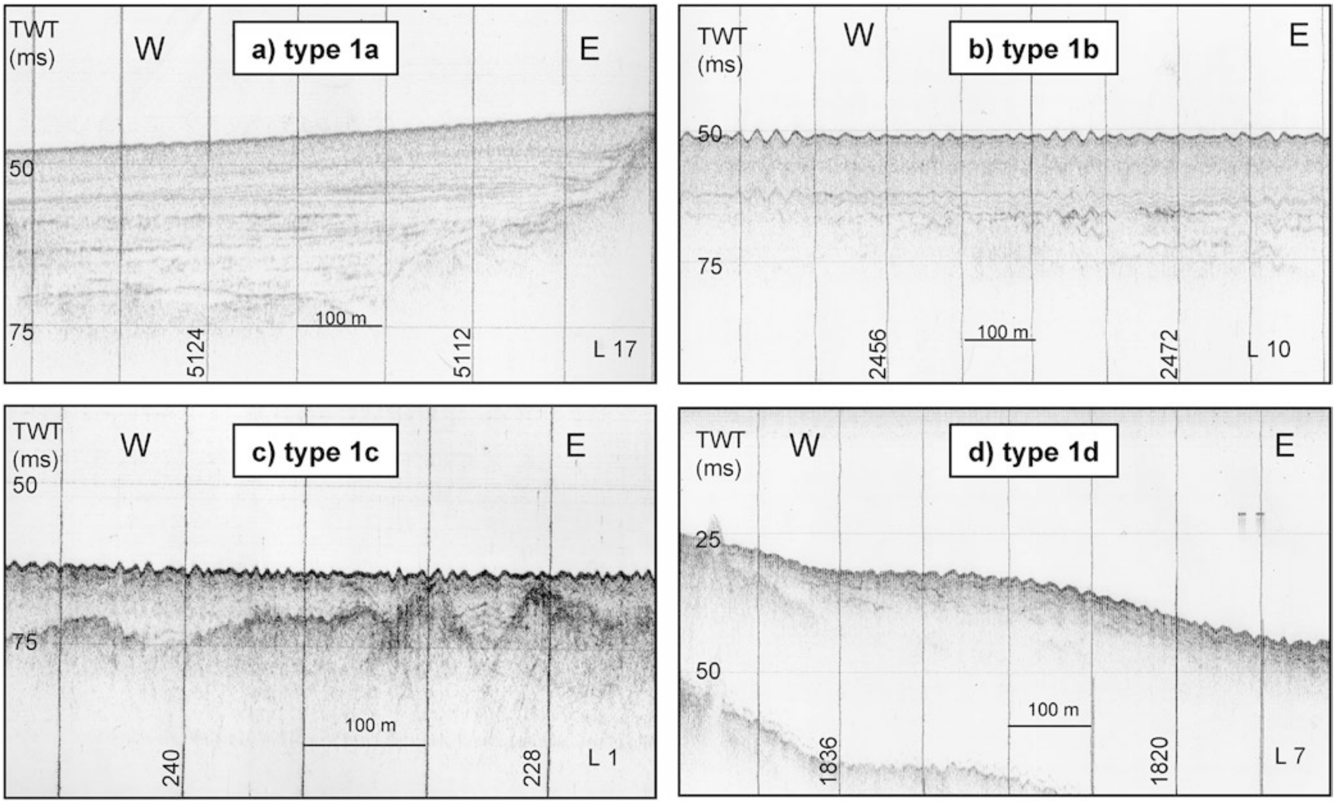


Fig. 3 Examples of 3.5 kHz seismic lines showing the four different echo-character types of class 1 (*distinct echoes*): **a** Type 1a, **b** Type 1b, **c** Type 1c, **d** Type 1d. See Fig. 2b for location of the seismic lines. Undulating seafloor reflector due to superimposed waves (*swell*)

Class 3: Highly reflective echo (one type)

TYPE 3: This echo is highly reflective and opaque, with a very irregular and erosive seafloor (Fig. 5a). It occupies 8.4% of the area.

Class 4: Echo in-step (one type)

TYPE 4: This echo character is opaque and hyperbolic with a high amplitude. It occurs very locally associated with a steep seafloor gradient (Fig. 5b), and represents only 1.4% of the area.

Class 5: Irregular echo (one type)

TYPE 5: This echo consists of irregular, hyperbolic and inclined reflectors, and appears very locally in the ría (Fig. 5c), representing a mere 0.5% of the survey area.

Class 6: Hyperbolic echo

This class of echo is characterized by the presence of a hyperbolic geometry (Fig. 6) with less amplitude than classes 4 and 5. Its areal extent is one of the largest that we found. Three different echo characters were present in this class.

TYPE 6a: Hyperbolic echo geometry with high amplitude (Fig. 6a). This is an echo character with a very open hyperbola, in which no internal reflector can be distinguished. It accounted for 1.4 % of the echoes found in the ría.

TYPE 6b: Hyperbolic echo geometry with variable amplitude (Fig. 6b). This echo is sometimes very reflective, and features tight hyperbolae. It represents most of class 6 echoes (23.4%). This echo type is associated with a very rough seabed and is similar to echo "type I" of Pudsey and Howe (1998).

TYPE 6c: Hyperbolic echo geometry with low amplitude and hyperbolae below the seabed (Fig. 6c). This is an echo type with tight hyperbolae below the ría seabed, sometimes with their apexes tangential to the apparent seafloor. It is similar to echo "IVa" of Driscoll and Laine (1996). This echo represents only 0.9% of the total.

Class 7: Wavy seafloor echoes

This echo character features wavy geometry, of variable amplitude with variable visibility of seismic units (Fig. 7). Three types can be found within this class.

TYPE 7a: Wavy seafloor, large and irregular. This appears in only 0.6% of the total area.

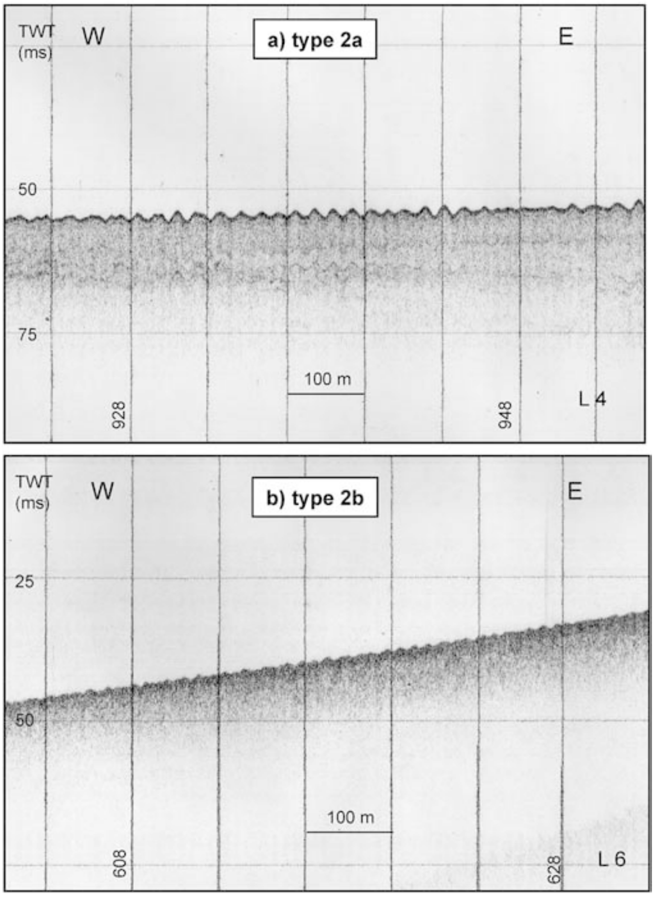


Fig. 4 Examples of 3.5 kHz seismic lines showing the two different echo character types of class 2 (*indistinct echoes*): **a** Type 2a, **b** Type 2b. See Fig. 2b for location of the seismic lines. Undulating seafloor reflector due to superimposed waves (*swell*)

TYPE 7b: Wavy seafloor, with or without internal structure, or with a channel shape. This appears in only 0.6% of the area.

TYPE 7c: Wavy seabed with internal migrating or lenticular reflectors: echo with large, irregular amplitude waves, and reflectors migrated vertically. This accounts for 2% of the echoes found in the ría.

Class 8: Echo with acoustic blanking (one type)

TYPE 8: This echo, also one of the most representative in the ría, is transparent to semi-transparent, with seismic units visible above the acoustic blanking (Fig. 8a). It represents 11.2% of the total. Frappa and Pujos (1994) detected a similar echo in which the seismic units terminated abruptly and were replaced by a high-energy reflector.

Class 9: V-shaped echo (one type)

TYPE 9: This seabed is characterized by V-shaped depressions generally associated with class 8 (Fig. 8b). It represents 2% of the total echoes in the area, and is similar to the V-shaped depressions described by MacClennen (1989).

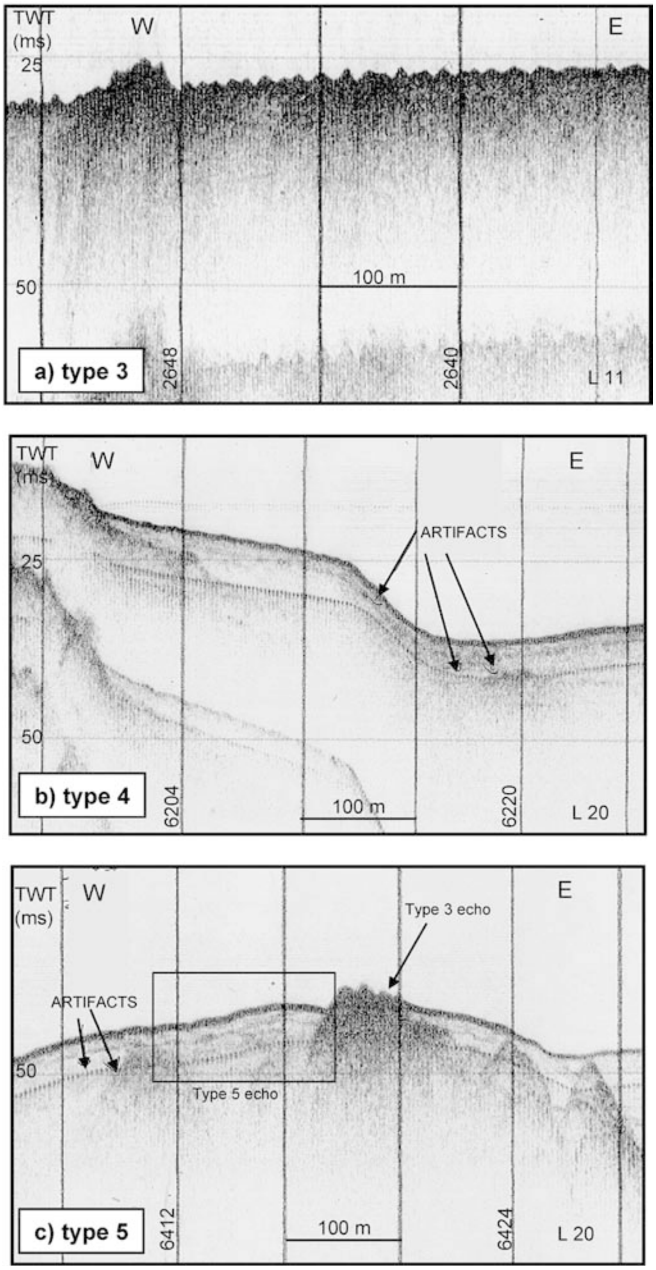


Fig. 5 Examples of 3.5 kHz seismic lines showing several classes of echoes: **a** Type 3: highly reflective echo; **b** Type 4: in-step echo; and **c** Type 5: irregular echo. See Fig. 2b for location of the seismic lines. Undulating seafloor reflector due to superimposed waves (*swell*)

Echo-character mapping and ground truthing

The various echo characters identified in the Ría de Vigo were compiled into an acoustic facies map (Fig. 9) by interpolating the acoustic classification (3.5 kHz) of the

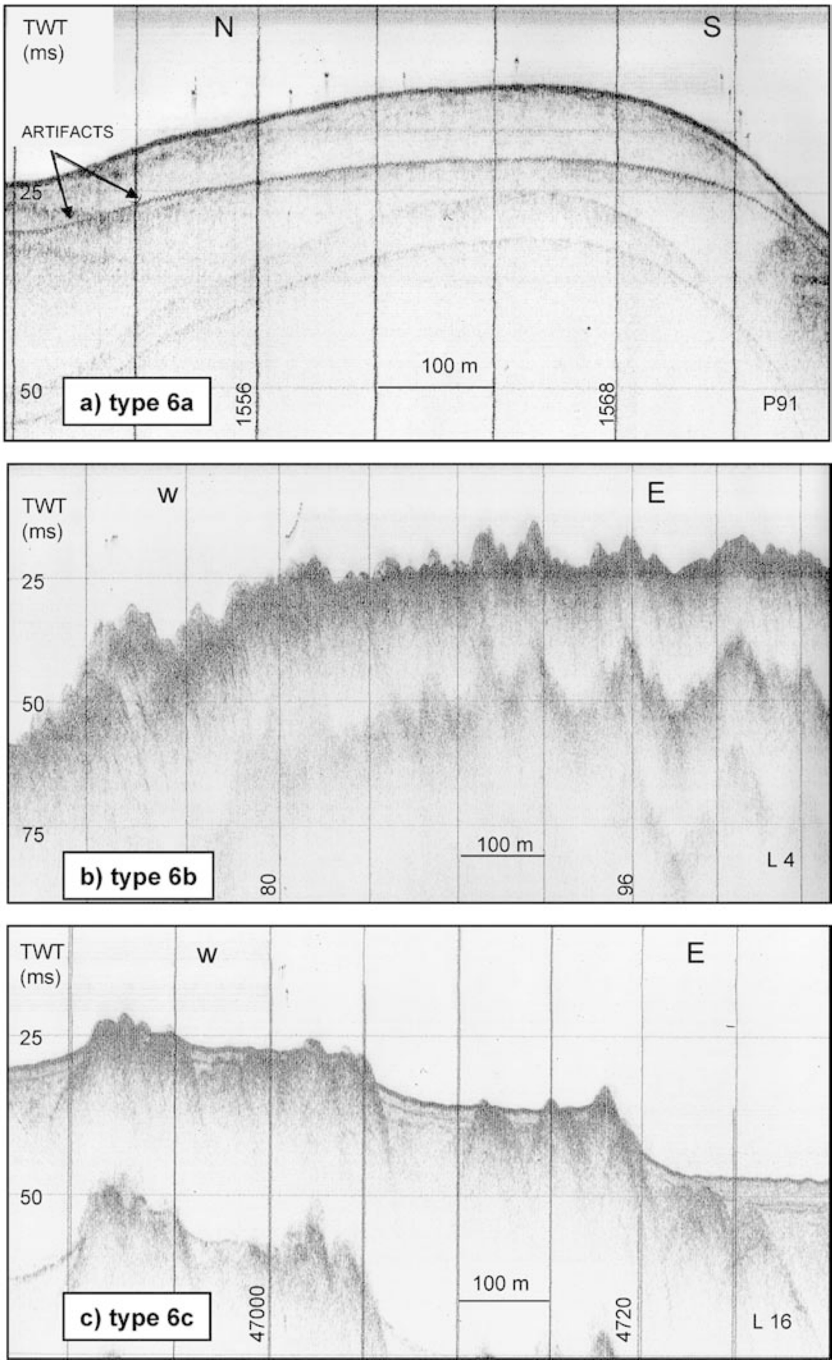


Fig. 6 Examples of 3.5 kHz seismic lines showing the three different echo character types of class 6 (*hyperbolic echoes*): **a** Type 6a, **b** Type 6b, **c** Type 6c. See Fig. 2b for location of the seismic lines

seabed and sub-bottom between the individual survey lines.

Class 1 echoes are located along the main axis of the ría. Type 1a occurs mainly in form of small patches in the inner ría and the central part of the outer ría. Type 1b is located mainly along the southern coast of the ría. Type 1c appears mostly in the central part of the outer ría, being the most representative echo type in the area. Type 1d occurs along the shallow edges of the outer ría.

Class 2 echoes occur along the northern and southern margins of the entrance of the outer ría, seaward of the Cíes Islands (type 2b). Type 2a occurs in isolated areas only.

The highly reflective echo of class 3 is located mainly in the northern entrance of the Ría de Vigo and locally along the southern coast of the ría. The echo in-step of class 4 is situated just east of the Cíes Islands and around some structural highs along the northern coast. The irregular echo of class 5 is rather rare and appears to be related to structural highs in the central part of the ría.

The hyperbolic echoes of class 6 are located near the Cíes Islands and in nearshore areas mainly to the

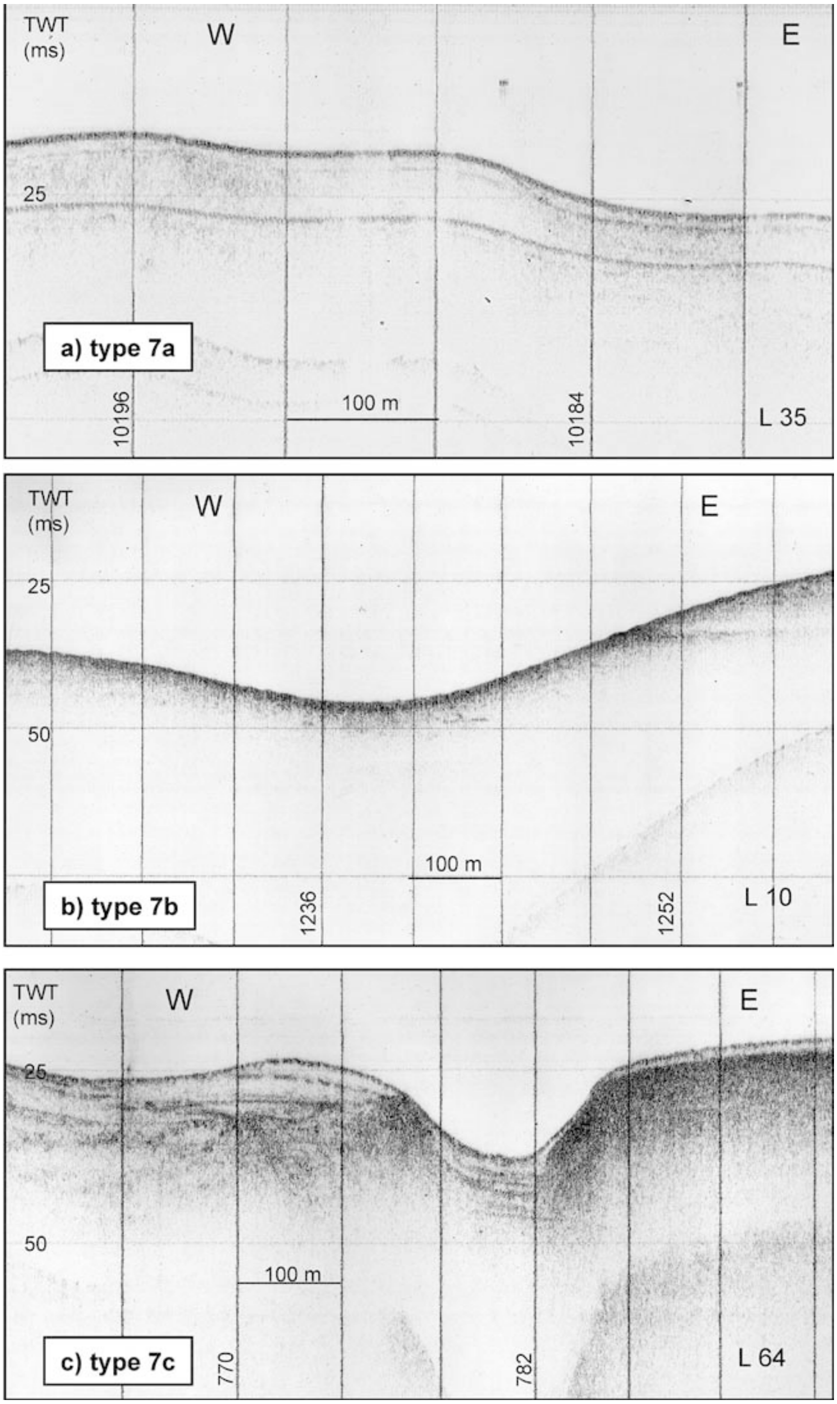


Fig. 7 Examples of 3.5 kHz seismic lines showing the three different echo character types of class 7 (*wavy seafloor*): **a** Type 7a, **b** Type 7b, **c** Type 7c. See Fig. 2b for location of the seismic lines

south and west of the outer ría where they are associated with basement outcrops. Type 6a is located along the northern coast of the inner ría. Type 6b occupies a larger area than types 6a and 6c, being restricted to the coastline of the outer ría, whereas type 6c was observed only along the southern coast of the outer ría.

The wavy seafloor associated with class 7 occurs in the north parts of the inner ría (types 7a and 7b) and in a small bay in the southern area of the outer ría (Baiona).

Finally, acoustic blanking and V-shaped echoes (classes 8 and 9, respectively) appear along the central axis of both the inner and outer ría respectively, being associated with gassy sediments and gas seep features (pockmarks).

Since the map of recent sediment distribution in the ría (Fig. 10) shows six different lithologies, further sampling would be required to provide a more accurate characterization of every echo type and to re-evaluate the grain-size analyses associated with the 17 echo types.

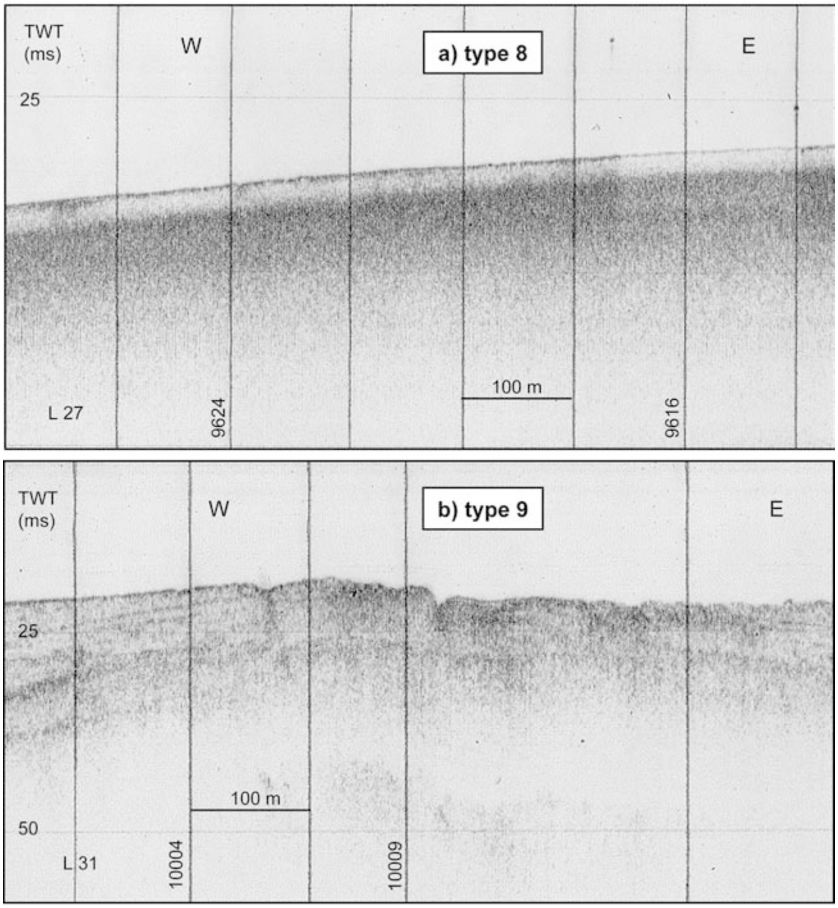


Fig. 8 Examples of 3.5 kHz seismic lines showing: **a** Type 8: echo with acoustic blanking; **b** Type 9: V-shaped echo (*pockmarks*). Fig. 2b for location of the seismic lines

Discussion and conclusions

Recent sedimentary processes

Taking into account our echo-character mapping (Fig. 9) as well as the sediment lithology and recent sediment distribution in the area (Fig. 10), there is a clear correspondence between these lithologies and the 3.5 kHz echo responses (Table 1). This has previously been noted by Damuth (1975) who pointed out that limited sub-bottom penetration suggests relatively coarse grain sizes, whereas deep penetration suggests fine grain sizes.

Distinct echoes (class 1) appear where the seafloor is generally covered with muddy sediments (Fig. 10). The grain size of samples belonging to type 1a echoes corresponds to muds (Table 1). Being fine sediments, the acoustic response in these records is very distinct, and it is possible to distinguish relatively thin sediment layers and individual seismic units. Type 1b echoes correspond to muds containing some sand. The acoustic signal therefore has a lower penetration than in the case of type 1a. As a result, individual seismic units cannot be distinguished. Where the sediment is coarser, the echo comprises only a basal reflector because the coarse material does not allow the signal to penetrate deep enough (echo 1c). The last type in this class, echo 1d, is associated with medium sands and muds (Table 1). The progradational units constituting this echo character therefore have a sandy composition, the acoustic energy penetrating only a few meters.

Seafloor sites characterized by indistinct echoes (class 2) are composed of coarser sediments than in the case of class 1. As shown in Table 1, the sediment of samples corresponding to echoes in class 2 is composed of sands. Type 2a comprises coarse-medium sands, giving poor penetration in the records. Sediments from type 2b are even coarser, being classified as coarse sands.

The highly reflective class 3 echoes generally correspond to schists and other rocks (Table 1). These echoes, located in the northern ría entrance and at several points in the south, are associated with metamorphic outcrops on the ría seafloor. These metamorphic rocks are the continuation of the outcrops on land.

The in-step echo (class 4) corresponds to sediment composed of muds and shell fragments. The coarse composition explains the poor acoustic penetration. Another irregular echo type (type 5) is associated with muddy sediments, on account of which the irregular subbottom can be seen. This echo type is always located near basement outcrops.

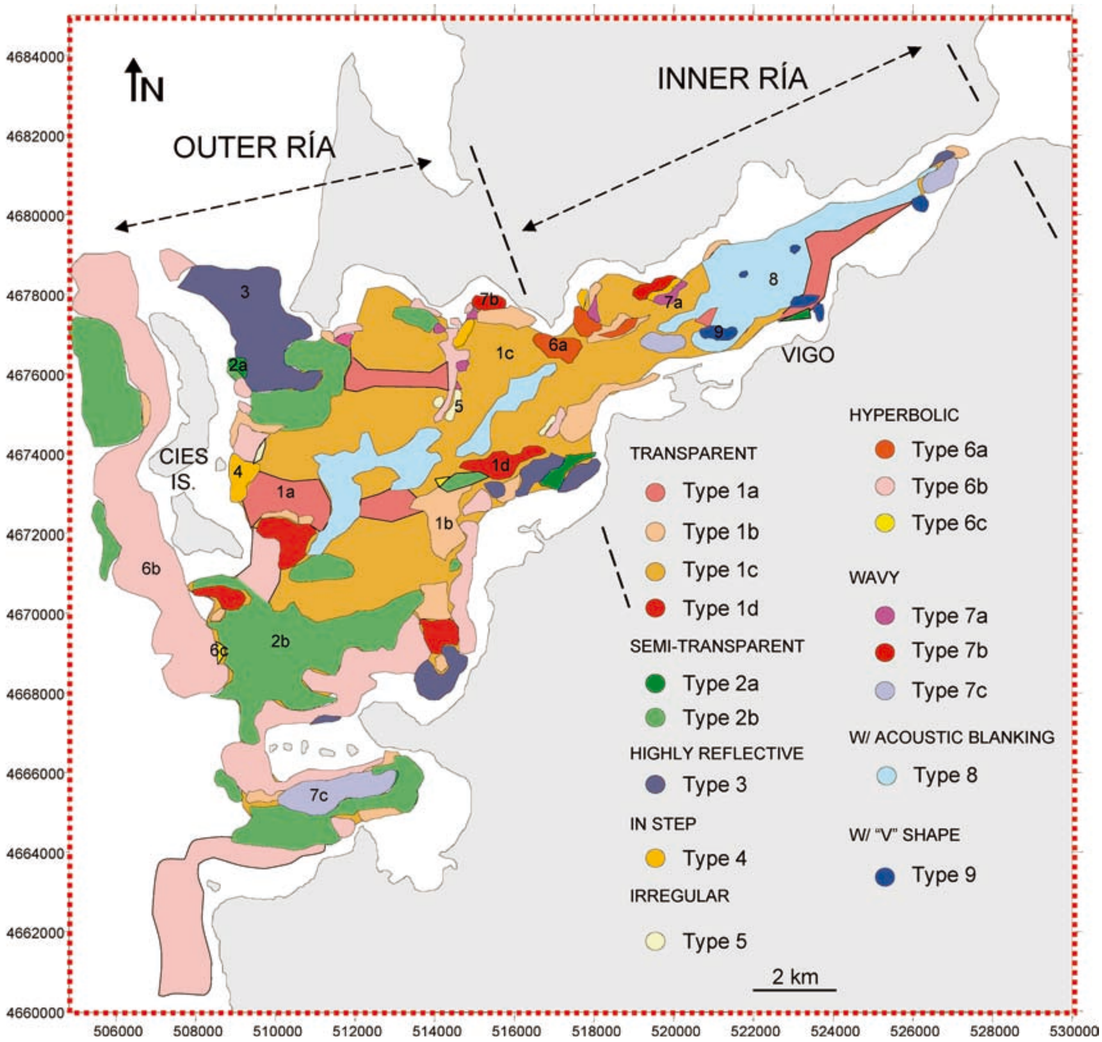


Fig. 9 Acoustic facies map based on echo-character mapping of the 17 different echo characters found in the ría: *1a* transparent echo with visible seismic units and internal structure; *1b* transparent echo with visible seismic units but without internal structure; *1c* transparent echo without visible seismic units, with basal reflector; *1d* transparent echo with internal clinoforms; *2a* semitransparent echo with visible seismic units; *2b* semitransparent echo without visible seismic units; *3* highly reflective echo; *4* echo in-step; *5* irregular echo; 6a hyperbolic echo geometry with high amplitude; *6b* hyperbolic echo geometry with variable amplitude; *6c* hyperbolic echo geometry with low amplitude and hyperbolae below the seabed; *7a* wavy echo, large and irregular; *7b* wavy echo with wavy shape, with and without internal structure, or channel-shaped; *7c* wavy echo with internal migrating reflectors, with lenses; *8* echo with acoustic blanking; *9* V-shaped echo

The hyperbolic echo type 6a, which occurs in the northern area, corresponds to bioclastic sands and muddy sediments (Table 1). Due to the sandy component, the signal cannot penetrate much further than the seafloor. Type 6b is the typical echo character of irregular basement outcrops associated with granitic terrain also found on land. Type 6c represents the same rocky area as type 6b, but buried and covered by finer muddy material, as indicated in the sediment distribution of Vilas et al. (1995).

Wavy seafloor (class 7) is indicative of muddy sediments (Table 1). Type 7a comprises sediments containing some fine and medium sands, which are responsible for the poor penetration. Type 7b consists of muddy sands, which account for the poor penetration in the sediment infill. Type 7c corresponds to muds and sands. Where the mud content is high the penetration increases, although acoustic blanking may occur due to the presence of gas in the sediments (García-Gil et al. 2002).

Classes 8 and 9 are located in the central-inner parts of the Ría de Vigo, where the sediment is mainly mud (Table 1). These two classes of echoes indicate the existence of gas-charged sediment in the ría (García-García et al. 1999; García-Gil et al. 1999a, 2002; Vilas et al. 1999), which produces acoustic masking. Gas accumulations occur mainly along the central axis of the ría in two main gas fields and together these areas represent 12.6 km^2. The seafloor area affected by seeps is about 96 km^2. In the whole Ría de Vigo area, these V-shaped depressions formed because of fluids (gas) escaping from the seabed (García-Gil et al. 2002).

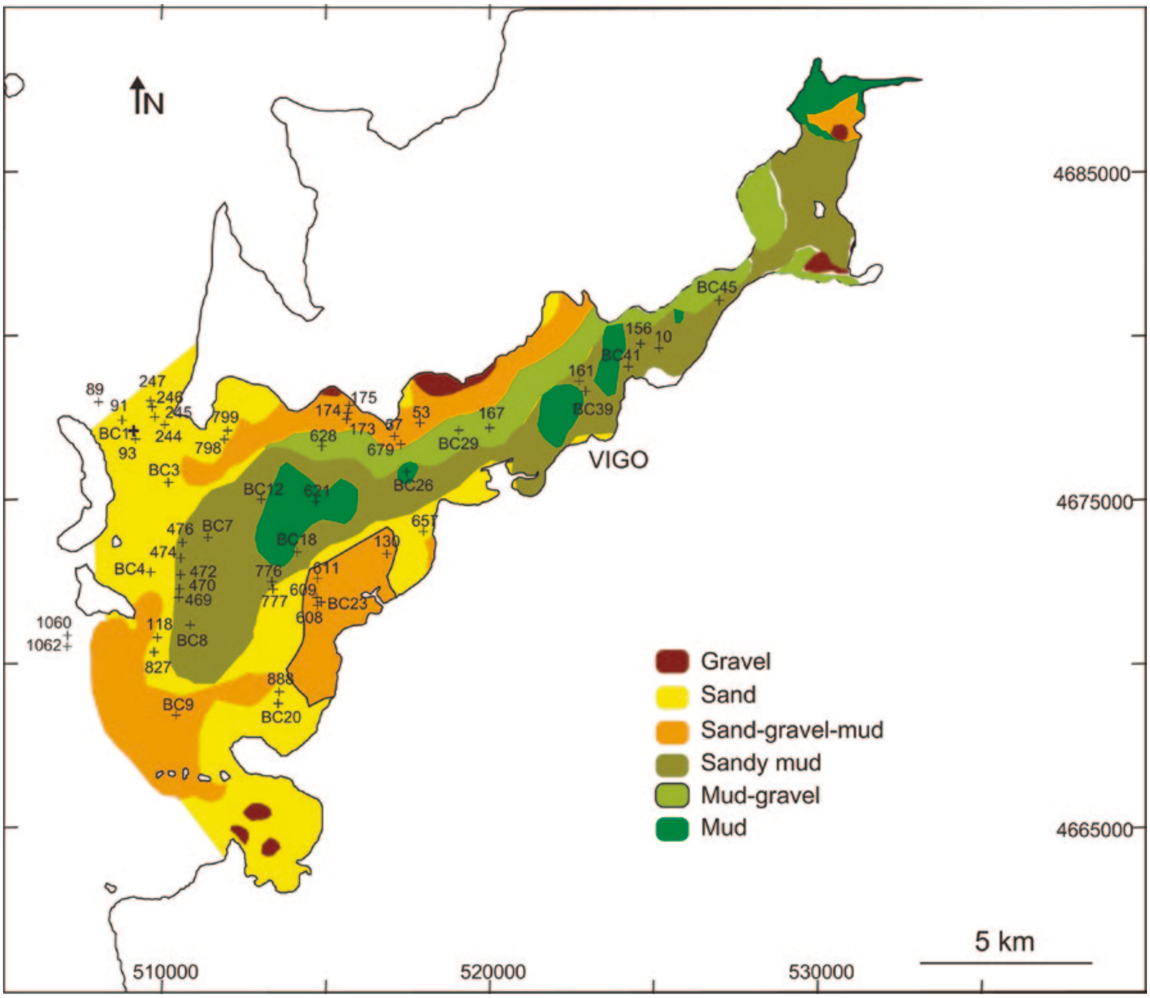


Fig. 10 Distribution of recent sediments in the Ría de Vigo seafloor (modified from Vilas et al. 1995). *Crosses* indicate Van Veen sample locations. *"BC" crosses* indicate box-core sample locations

Implications

The combined mapping of echo-character and recent sediment distribution in the area enables us to produce a map showing recent sedimentary processes (Fig. 11). As indicated in Table 1, and following the terminology of Damuth (1980), all echoes types in class 1 would correspond to low-energy depositional processes, which in turn correspond to muddy sediments deposited in restricted areas where hydrodynamic energy is low. Echoes in class 2 (types 2a and 2b) also indicate depositional processes but involve coarser sediments and are thus located in more exposed areas where hydrodynamic energy is higher.

Two other depositional processes are called *progradational* and *gravitational* (Fig. 11). Progradational processes (types 1d and 6a) present a continuous echo with dipping sub-bottom reflectors. Gravitational processes are associated with slump deposits (type 5).

The association of mainly depositional and combined (depositional and erosional) processes produce the echo type 4. Sediments of this echo type are mostly composed of sand deposits that are to some degree affected by erosion.

Erosive processes characterize two different echo signals: types 3 and 7b. Type 3 echoes are present in places where there is a lack of sediment and the seafloor consists of metamorphic rock. Type 7b represents a channel-like depression, where erosion is noticeable (Fig. 7b).

Along the ría coast both erosive and depositional processes can be observed. This is the case with types 7a and 7c in class 7, which have a wavy or channeled seafloor displaying both erosive and depositional areas.

The presence of gas-charged sediments leads to the formation of gas seeps in the form of V-shaped depressions or pockmarks (type 9). Using the 3.5 kHz system, these features were found to be restricted to the inner ría (Fig. 11). Using other seismic instrumentation, however, evidence of gas pockets has been found also in the outer ría (García-García et al. 1999; Vilas et al. 1999; García-Gil et al. 2002).

Finally, in the outer ría, types 6b and 6c echoes are typical of sites revealing acoustic basement. Type 6b is associated with granite outcrops, whereas in type 6c the basement is draped by a thin layer of sediments.

On an areal basis, the mapped seafloor is dominated by depositional processes, in total covering 60.5% (Fig. 11). Of this area, 45% represents low-energy depositional processes (types 1a, 1b, 1c and 8), 10% high-energy depositional processes (types 2a and 2b), 4% progradational processes (types 1d and 6a), 0.5% gravitational ones (type 5), and 1% combined processes (type 4). Erosion (types 3 and 7b) occurs in 9% of the total area, combined processes (types 7a and 7c) 4%, and gas seeps (type 9) 2%. Acoustic basement (types 6b and 6c) is exposed in 24.5% of the survey area.

Following the proposed zonation of ría environments (Vilas 2003), the surveyed area corresponds to the marine domain (Table 2). Although muddy sediments with high organic contents dominate in the inner ría where dynamic energy is low, the outer ría is characterized by mixed siliciclastics and skeletal gravels indicative of higher energy. Escape processes are entirely restricted to the inner ría, as well as 45.3% of low-energy depositional processes, 42.1% of progradational ones, and 53.1% of combined processes. By contrast, 100% of the gravitational processes occur in the outer ría, as well as 95.3% of basement outcrops, 76.6% of erosive processes, 81% of high-energy depositional processes, and 90.6% of depositional/combined processes.

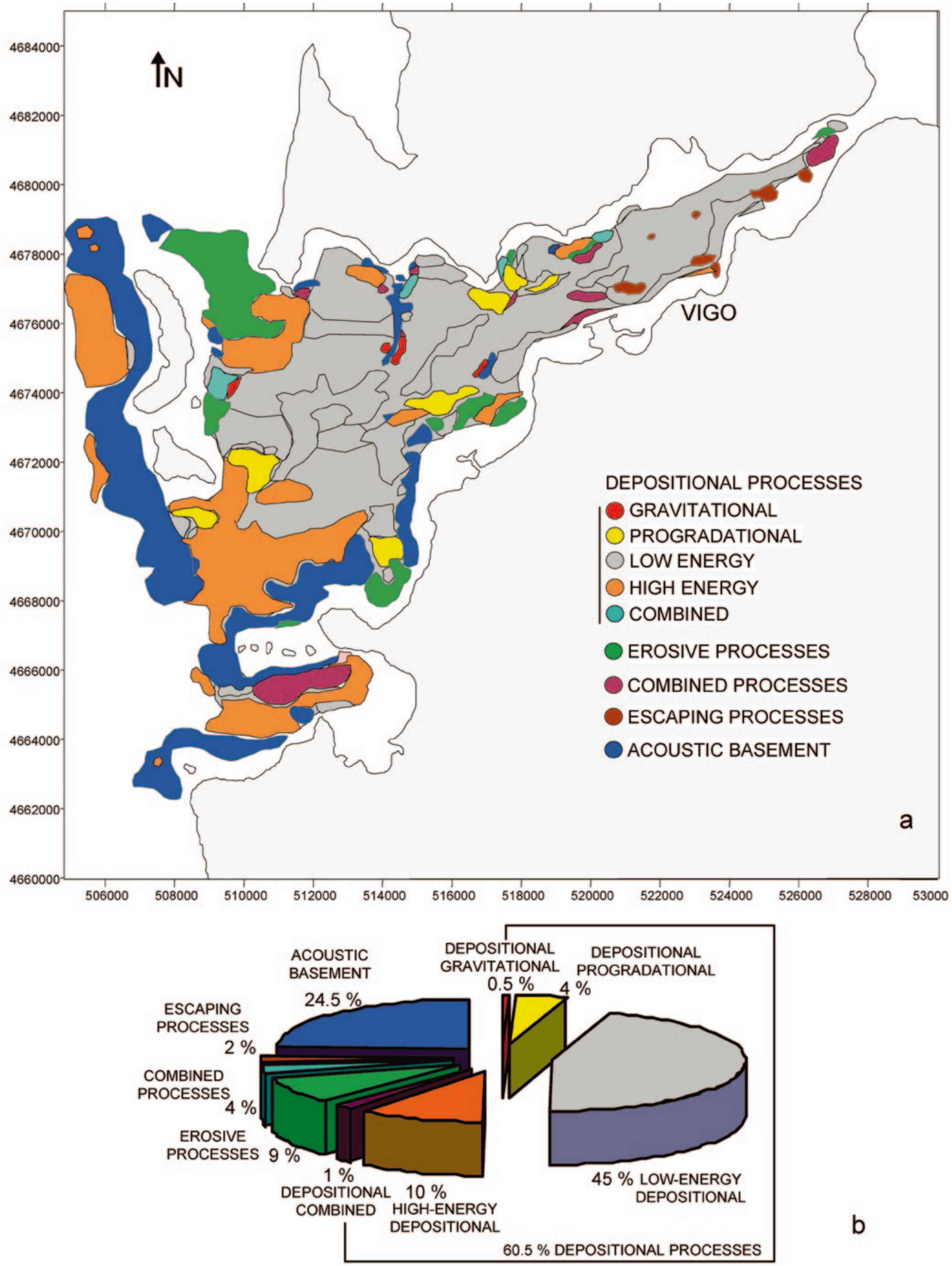
All of the available evidence points towards a good correlation between the proposed zonation of ría environments and recent processes observed in this particular ría. In the outer ría, where wave action is strong, erosive processes as well as high-energy depositional processes occur. In the protected area of the inner ría, the majority of recent processes are low-energy depositional, progradational, and combined processes.

▶

Fig. 11 a The inferred recent sedimentary processes as distributed in the Ría de Vigo; **b** Percentage occurrence of various recent processes in the ría. In total, 60.5% of the surface area of the Ría de Vigo is characterized by depositional processes, 9% by erosive processes, and 25% by acoustic basement

Table 1 Echo character types in the Ría de Vigo, seismic characteristics, and correspondence to lithology. Inferred recent sedimentary processes are also shown

Echo character classes	Echo character types	Seismic character	Sample number	Description	Lithology (Vilas et al. 1995)	Inferred sedimentary processes
1. Distinct	Type 1a	Visible seismic units and internal structure	41, 472, 474, 476	Mud	Muds, sands	Low−energy depositional
	Type 1b	Visible seismic units without internal structure	29, 173, 608, 609, 611	Mud/bioclastic sands	Muds, sands	
	Type 1c	No visible seismic units, with one basal reflector	12, 18, 26, 776, 777	Muds/sandy muds	Muds and sands	
	Type 1d	Internal clinoforms	469, 470	Medium sand/ bioclastic sands	Sands and muds	Depositional progadational
2. Indistinct	Type 2a	Visible seismic units	130, 657	Algae/Coarse−medium sands	Sands	High−energy depositional
	Type 2b	No visible seismic units	3, 8, 9, 118, 827	Sands	Sands	
3. Highly reflective	Type 3	Opaque with irregular limit	1, 89, 91, 93, 244, 245, 246, 247	Rocks, schists	Sands	Erosive
4. Echo in step	Type 4	Hyperbolic, high amplitude, opaque	4, 53, 628	Mud/shell fragments	Muddy/gravel sands	Depositional/ combined
5. Irregular	Type 5	Irregular	621	Mud	Muds	Depositional gravitational
6. Hyperbolic	Type 6a	High−amplitude	57, 679	Bioclastic sands/mud	Sand−gravel−mud	Depositional progradational
	Type 6b	Variable amplitude	20, 23, 799, 888, 1060, 1062	Rocks, shell fragments	−	Acoustic basement
	Type 6c	Low−amplitude, with hyperbolae below the seabed	−	−	Muddy sands	
7. Wavy	Type 7a	Big and irregular	798	Mud with fine−medium and bioclastic sands	Gravel/sandy muds	Combined (erosive and depositional)
	Type 7b	Channel−shaped	174, 175	Mud	Sands	Erosive
	Type 7c	With migrated infradepositional reflectors	45	Muds with sands	Sandy muds	Combined (erosive and depositional)
8. With acoustic blanking	Type 8	Acoustic masking	7, 39, 161, 167	Mud	Mud	Low−energy depositional
9. V−shaped	Type 9	"V" shape	10, 156	Mud	Mud	Gas escaping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COMBINED PROCESSES
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EROSIVE PROCESSES 9 %
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b

Table 2 Zonation of a ría environment, taking into account bottom morphology, sedimentary facies and dynamics (modified from Vilas 2003). Note that the surveyed area would correspond only to the marine domain

		Control		Morphology	Sedimentary facies	Dynamics
Ría environment	Estuary domain	Fluvial		Meandering channel, sandy levees, muddy sand flats and crevasse-splay deposits, roots, plant fragments	Coarse fluvial sand and gravel with no tidal structures and silty-clay lenses	Unidirectional water movement. Fluvial sediment source
		Tidal		Tidal estuarine sand bars and point bars, intertidal mud flats and salt marshes. Estuarine muds with isolated sand bodies	Channels with medium-grained ripples and cross-bedded sand. Masive muds with sand lenses and clay laminae	Intermittent dominance of fluvial-tidal Influence and changing water velocities. Sand movement in the fluvial-tidal zone. Bidirectional water and sand movement in the estuarine zone
	Marine domain	Inner ría	Tidal influence	Low-regime flat beds at the bottom. Small salt marshes and intertidal sandy-mud-flats, and sandy beaches to the flanks	Dominance of muds and fine sands. Low content in carbonates and high content in organic matter	Tide influence and weak waves. Bidirectional water movement. Local fluvial inputs. Low tidal velocities for sand movements
		Outer ría	Wave-dominated and tidal influence	Low-regime flat beds and low-relief sand bars at the bottom. Sandy beaches and small beach-barriers at the banks	Bottom: mixed siliciclastic and skeletal gravels with sandy or muddy component. Shoreline: coarser sands grading into clean skeletal carbonates sands. Low content in organic matter	Bidirectional water movement. Wave-dominated and tidal influence. Upwelling influence and local fluvial inputs

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