Available online at www.sciencedirect.com

SCIENCE DIRECT®

Journal of Marine Systems 54 (2005) 195–207

JOURNAL OF MARINE SYSTEMS

www.elsevier.com/locate/jmarsys

Geological antecedents of the Rias Baixas (Galicia, northwest Iberian Peninsula)

G. Méndez*, F. Vilas

Grupo de Geología Marina, EX1, de la Universidad de Vigo, Spain
Departamento de Geociencias Marinas y Ordenación del Territorio, Universidad de Vigo, 36200 Vigo, Spain

Received 19 March 2003; accepted 1 July 2004
Available online 7 October 2004

Abstract

The present paper reviews the current state of knowledge regarding the geology of the Rias Baixas (Galicia, northwest Iberian Peninsula), focusing specifically on characterisation, geometry, and evolution of the sedimentary bodies; physical and geological description; drainage patterns; and advances in palaeoceanography and palaeoecology.

Keywords: Rias; Galicia; Coast; Geology

1. Introduction

The current state of knowledge regarding the geology of the Rias Baixas, in the northwestern Spanish region of Galicia, is a consequence of an extensive and fruitful research process, with roots based on Von Richthofen's proposal (1886) to use the term *ria* to designate a type of coastline characterised by the existence of a valley occupied by the sea, and taking as its prototype the Galician rias. Various authors later tried to explain their geological evolution and define the dominant processes in that evolution to date. However, the scientific discourse then began to question whether the Galician rias, given their variety of origins, should be truly considered *rias* at all. In recent years, research has generally focused on determining their Quaternary evolution, establishing links with global processes and characterising the local processes. Moreover, a major line of debate has centered on characterising the so-called Rias Coast, establishing a clear distinction between the geological processes described as typical of estuaries from those specifically pertaining to the rias.

The present paper, besides reviewing the current state of this issue, presents an overall vision of the geology of the Rias Baixas.

A variety of intensive human activities impact on the rias and their surroundings, including harbours, industrial complexes, buildings, agriculture and live-

* Corresponding author.
E-mail addresses: mendez@uvigo.es (G. Méndez), fvilas@uvigo.es (F. Vilas).

0924-7963/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmarsys.2004.07.012

stock exploitations, as well as sewage emissions. Some of these activities even occupy areas reclaimed from the sea. Moreover, the rias comprise highly productive ecosystems traditionally exploited as fisheries, and there are also intensive aquaculture operations, mainly mussel farming using floating structures. Therefore, much of the basic research carried out in recent years has later continued as applied research. Thus, for example, variations in the nature of the rias' bottom sediments, collected for different studies, have conditioned the distribution of molluscs, crustaceans, and other species, commercial or not, so that knowledge about them is of the highest interest to different disciplines.

2. Physical and geological description of the Galician coast and the Rias Baixas

The Galician rias (Fig. 1) are a set of prolonged inlets in the shore distributed over 1720 km of the Iberian coast. They are considered to have several sectors: the ria itself is divided into inner and outer zones, according to their hydrodynamic and sedimentologic characteristics (Vilas, 2002). The outer zone is located in the ria's mouth, sometimes protected from direct oceanic influence by islands that could conditione several inlets. The estuary is close to the head of the ria, where the principal river flows into it, although there may also be an estuary system in the secondary fluvial outflow channels.

The Rias Baixas are limited to the western coast of Galicia. From north to south, they are the Muros y Noia, Arousa, Pontevedra, and Vigo rias. They are characterised by their significant width and the SW–NE orientation, compared to the N–S orientation of the outer coast. They are generally a funnel-shaped, with depths of their central axes from approximately 40–60 m in the outer zone to 5–10 in the zone of the mouth of their main river. They are the most extensive on the Galician coast, with surface areas ranging from 125 km^2 in the case of the Ria de Muros y Noia to 230 km^2 in that of Arousa. All of them, except Muros y Noia, have islands at their mouths which protect them and generate two entrances, north and south, with some differences from one ria to another. Moreover, the Ria de Vigo features two other differentiated physiographic bodies, the Bay or Ria of Bayona and the San Simón inlet. The Ria de Aldán constitutes another differentiated sector within the Ria de Pontevedra. The Grove inlet is a differentiated physiographic unit within the Ria de Arousa. The Rias Altas, as well as the Ria de Muros, are much more exposed, due to their orientation and the lack of protecting islands.

The geological history of the ria and their surroundings is complex. The western Galician coast, where the Rias Baixas are located, is within the Iberian orogenic Hercynian domain, formed during the Palaeozoic. The rias were formed mainly due to the processes of modelling the rocky bed, which were deeply altered in the faulted areas, occurring since the Miocene. The area is composed of granites and metasediments which form alternating bands in a N–S direction, varying further north to a NNW/SSE lineation. The fault system fracturing the basement (García-Gil et al., 1999a,b,c) has a NE–SW and NW–SE orientation.

Different structural domains can be distinguished: the Vigo–Pontevedra complex, the Cabo Home–A Lanzada complex, the Noia complex, the granodiorite of Caldas de Reis and the Laxe group or migmatic domain and that of the granitic rocks (I.G.M.E., 1985). Principally along the coast, there are geomorphologic relicts of erosion levels and detritic sediments, produced during Late Tertiary and Quaternary evolution.

3. The Galician rias: their origins and types

Von Richthofen (1886) proposed the term *ria* to designate forms typical of discordant coasts with flooded valleys. Later studies have shown that the Rias Baixas themselves do not exactly fit this model (Carlé, 1947; Torre Enciso, 1958; Méndez and Rey, 2000). However, the term is widely used in its strictly morphological or topographical sense. The Galician rias have been studied by geologists and physical geographers in order to establish their origins and to find data able to throw light about the evolution of the northwest of the Iberian Peninsula (e.g., Schurtz, 1902; Scheu, 1913; Carlé, 1947, 1949; Torre Enciso, 1954, 1958; Cotton, 1956; Nonn, 1966; Pannekoek, 1966a,b, 1970; Vidal Romaní, 1991, 1996; Twidale and Vidal Romaní, 1994; Vilas et al., 1995, 1996, 1999a; Pagés Valcarlos, 2000).

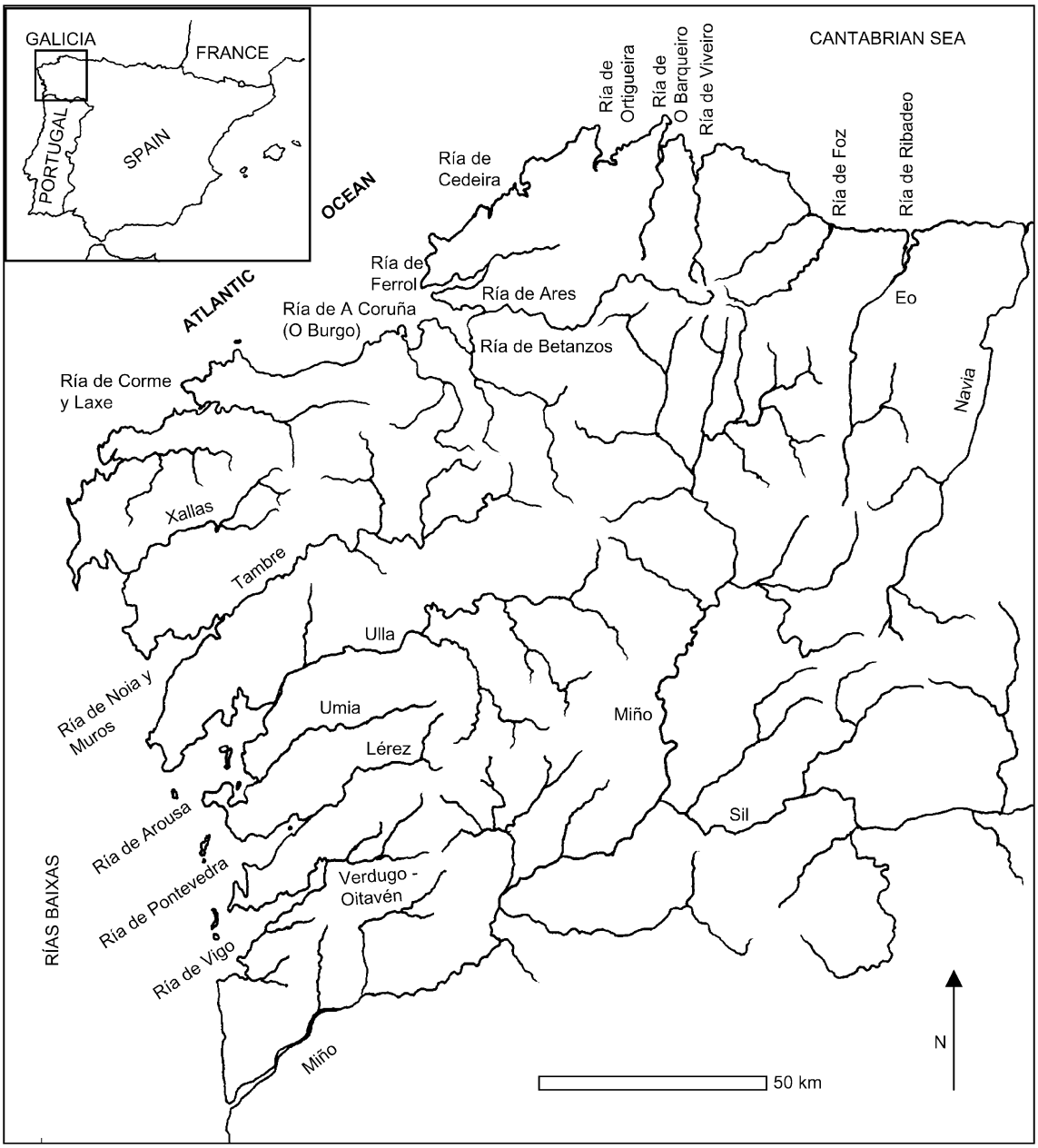

Fig. 1. Galician coast and rias.

Pannekoek (1966a,b), interpreting the events leading up to the current scenario, focused on the formation during the Pliocene of the western Galician rift valley known as the Carballo–Tui Meridian Rift. This depression could have set the course, upstream, of the rivers flowing into the rias. However, the relatively short period since then probably explains the lack of regularisation of the river profiles, just few kilometres long, based on their increasing erosive capacity and the nature of the rocky substrate. Pannekoek's dating estimates are based on materials deposited in the rift valley (specifically deposits

within the Louro Valley, which have been the subject of several studies). Moreover, considering that the main rivers flowing into the rias generally do not change direction after crossing the rift valley on their way to the sea, led him to conclude that this is an ancient direction, i.e., the river's direction of flow across the Galician peneplain. This interpretation was partially modified in a later paper (Pannekoek, 1970), which considered the rift valley and the rifts parallel to it as *graben*-type rifts, dating the deposits accumulated as of Miocene age. Pannekoek developed and interpreted an *envelope map of the relief*, as he defined it in a previous work, showing that the main characteristics of the relief are not controlled by the alineations of the Hercynian basement, but rather by faults of late- or post-Hercynian origin, some of them may have been reactivated during the Tertiary. He concludes that during the Miocene, there were wide valleys where the river bodies are today, mostly flanked by mountainous massifs. Near the present coast, the depths of these valleys were still far from today's sea level. The emergent zone extended further westward than it does at present. The sinking and flooding of these areas at the end of the Miocene, at least partially over the length of the faults, and probably an uplifting of the land, as well, set off a reactivation of the erosion processes, which penetrated the lower courses of the rivers and the Meridian Rift. This action intensified where there was local subsidence of parts of this rift. During the Pliocene to the present day, according to Pannekoek (1970), these recently incised valleys reached their present amplitude as a consequence of an intense alteration and retrocession of their slopes. After this period, the erosion that occurred during the first cold phases of the Quaternary situated the main valleys to their present depth (Fig. 2).

As part of the discussion about appropriateness of applying the term *ria* to different types of recesses in the shore having different origins, Nonn (1966) defined three types of rias on the Galician coast. The first type corresponds to the lower part of a flooded fluvial system. The river width is responsible for the width of the ria, and sometimes its course, as well. However, this author admits that other processes may be involved: the retreat or distancing of the slopes are favoured by an intense alteration in the land, a tectonic effect mainly on a small scale. The best examples of this type of ria are found on the Cantabrian coast (Ortigueira, Barqueiro, Foz, and Ribadeo). On the coasts exposed to the northwest there are similar examples: Cedeira, Ferrol, Ares,

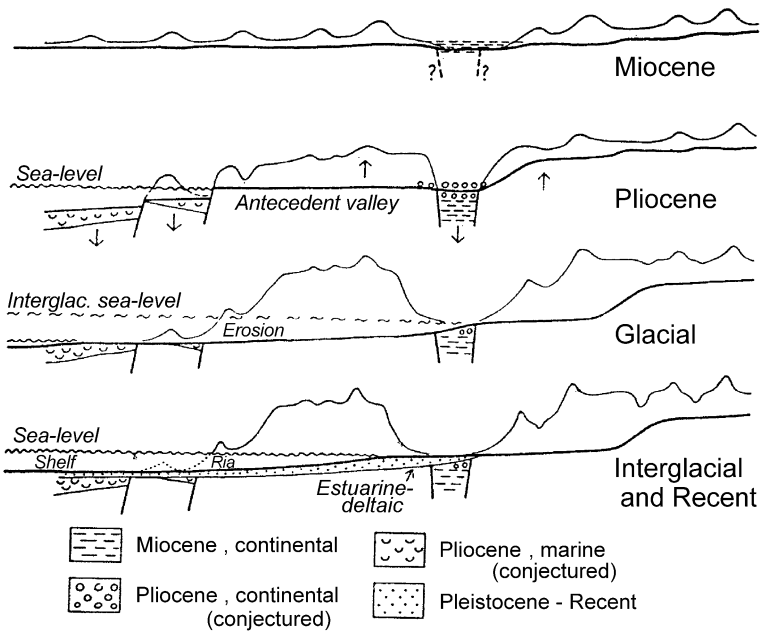

Fig. 2. Model of the evolution of the Rias Baixas, according to Pannekoek (1966a).

Betanzos, Laxe, and Camariñas. On the rias exposed to the west, this form could be limited to their inner areas. The second type is characterised by a preponderance in the tectonic and, especially, when the principal rivers are unable to justify the width of the ria. Thus, the hydrographic systems of the Verdugo-Oitavén (Fig. 1), corresponding to the Ria de Vigo, the Lérez in the Ria de Pontevedra, and the Tambre in the Ria de Muros y Noia are proof, according to Nonn (1966) that their present flow does not justify the dimensions of these rias, concluding that tectonics, through falling or dislevelment of the tectonic blocks of the emerged part, are responsible for the configuration of the Rias Baixas. The third type, according to this typology, corresponds to flooded basins altered during the Tertiary. They are still rias, because a river of some importance has its mouth there, but during periods of a lower sea level, it contributed to their erosion, and carved their course. Characteristic here is the *globular* or *ameboid* form (confirmed by aerial views), a type of ria represented on the Galician coast by the Coruña and the Arousa. In any case, the rias

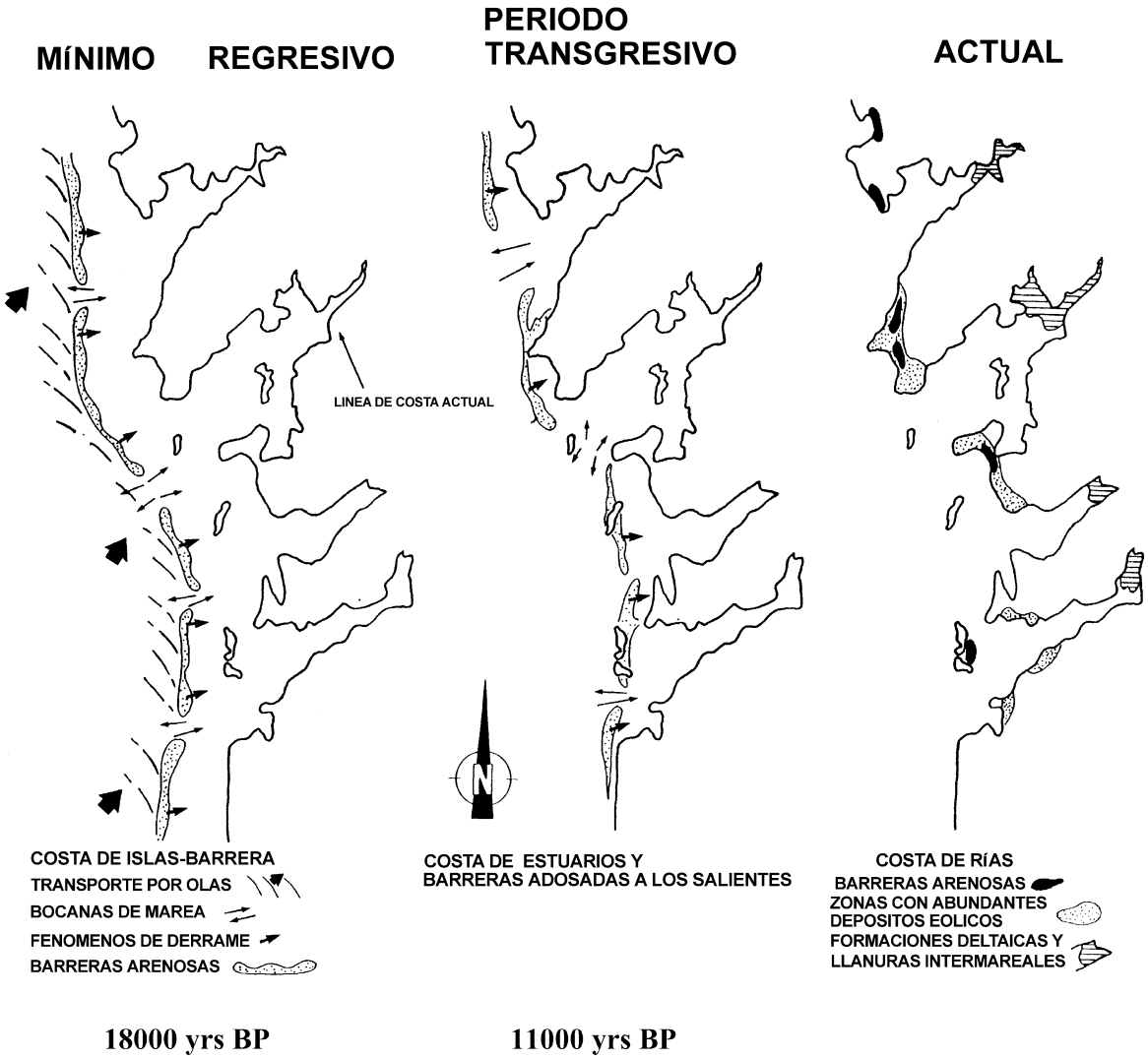

Fig. 3. Variation of the coastline since the last glacial maximum (LGM) (modified after Vilas et al., 1999a,b). Minimo regresivo=Minimum mean sea level; Periodo transgresivo=Early transgressive phase; Actual=Present.

may have mixed characteristics, and even the former classification was determined by the prevalence of some processes over others in settings where multi-causality is the norm.

According to Vidal Romaní (1996), Plate Tectonics gave rise to the lengthening, narrowing, and fracturing of the crust along the western Galician coast and the uplifting of the northern coast, with elevation of Cape Ortegal and immersion of the Cantabrian abrassion platform. This same author (Vidal Romaní, 1991; Twidale and Vidal Romaní, 1994) contends that western Galicia's meridian rift, and the parallel rifts at the end of the course of the Miño, which Pannekoek (1966a,b, 1970) first considered as *rift valleys* and later as *graben*-type depressions, are actually associated with the distensive tectonics corresponding to the origin of the Western coast of Galicia as the result of an opening up process, by means of rifting, of the oceanic Atlantic since the end of the Mesozoic. The surface stacking observed here, and the absence of well-developed marine abrasion platforms, seem to indicate that tectonics have been principally responsible for the origin of the Rias Baixas, with marine or fluvial erosion playing a complementary role.

In recent years, some geologists have focused their research on the evolution of the Galician littoral since the last glacial maximum (LGM), leading to a series of interpretations about the coastal evolution (Fig. 3) (García-Gil et al., 2002a,b; Vilas et al., 2002).

4. Drainage networks

Rivers are the most important entry route of continental sediments into the rias. Large particles stop flowing due to a drop in the kinetic energy associated with the river current. Suspended material is separated by flocculation, favoured by an increase in salinity (OSPAR Commission, 2000).

Despite their importance, drainage networks have not been subject of much research in Spain, perhaps because this is a difficult issue (Albentosa, 1989). In Galicia, in spite of the importance of quantifying the different sedimentary loads of the rias, few data is available, and only at the Vigo and the Pontevedra rias (Nombela, 1989; Alejo, 1994; Pazos et al., 2000; Perez-Arlucea et al., 2000a,b, 2001a,b, this issue; Freijido et al., 2000, Mendez et al., 2002). Generally speaking, the small size of the rivers and basins draining into the Rias Baixas is noteworthy; the largest is the Ulla River, 132 km long and with a surface area of 2803.6 km^2 (Río and Rodríguez, 1996). These rias make up 25–60% of the total length of the drainage basins. The basins, whose morphology has been described as rectangular, have their major axis in the same dominant direction of the rias (SW–NE). The rias show an asymmetry between the drainage networks on both sides of the watershed, especially Arousa and Vigo, whose southern watershed is more extensive, and with notably longer rivers having an angle of incidence differing from the norm (nearly 90° to the coastline).

In this field, further research is necessary to quantify the continental contribution to the rias, distinguishing between natural and human sources, in order to evaluate the impact of human activities on the coastal system and on resources (mainly aquaculture).

5. Characterisation, geometry and evolution of subaqueous sedimentary bodies in the rias

Advances in the knowledge of the rias' geology, whilst parallel to their general underlying theories, are also closely linked to technological developments which have been making possible increasingly extensive, economically feasible direct sampling of the ria bottoms (e.g., dredging, coring) and remote prospecting both of the bottom and subbottom elements (e.g., high-resolution seismics and other acoustic techniques). The technological limitations of the former studies (e.g. Nonn, 1966) and in earlier work have been progressively overcome through the use of these new technologies, as can be seen in the research of Koldijk (1968) and Hinz (1970) in the Ria de Arousa; even more highly developed methods and better results can be seen in the seismic prospecting work of Acosta (1982, 1984), Rey Salgado (1993a,b) and García-Gil et al. (1999a,b,c, 2000a,b), among others. Regular sampling, using dense mesh, of ria sediments was used in the work of Vilas et al. (1995, 1996, 1999a). A similar process has been used in intertidal zone sampling, and the latest work in this field (Perez-Arlucea et al., 2001a,b; Mendez et al., 2002) including abundant subsurface sampling

thanks to the development of the TESS-1 suction corer (Méndez et al., 2003).

The study of submerged sedimentary bodies has generated a literature focusing on the Ria de Vigo (Vilas, 1979, 1983; Vilas and Nombela, 1985; Alejo et al., 1990; Nombela et al., 1987, 1995), which began with several doctoral theses, and then continued through different research projects.

5.1. Distribution of surficial sediments

Surficial sediments from the ria bottoms have been the subject of a number of studies, from both, purely scientific (Nonn, 1966; Koldijk, 1968; Rey Salgado, 1993a,b) and applied viewpoints (I.N.I., 1979). The Marine Geology Group at the University of Vigo has, since 1990, been conducting an ongoing investigation aimed at studying, classifying, analysing, and mapping the sediments of the Rias Baixas. Nowadays, the work corresponding to the distribution maps of the different types of bottom sediments have been completed for Vigo (Vilas et al., 1995), Pontevedra (Vilas et al., 1996), and Arousa rias (Vilas et al., 1999a). Other projects are still in different phases, including those for Ria de Muros y Noia, as well as for the adjacent continental shelf. To map their surficial sediments, a special methodology was developed (for details, see García-Gil et al., 1994a,b).

The Rias Baixas show similarities in the distribution of their surficial sediments. Grain-size distribution of sediments in the rias seems to be conditioned by bathymetry, river currents, and the different movements to which these water masses are subject, basically waves and tidal currents. Generally, in the inner zone of the rias the finer sediments, the muds, line up with the ria's central axis, with higher concentrations in the areas more protected from wave action (due to their greater depth or closeness to the river mouth, without reaching the outflow areas). On the other hand, the intensity of wave action near the coast is the characteristic condition for the appearance of sandy textures (Vilas et al., 1995, 1996, 1999a, 2001). This distribution can present lithologic variations, e.g., the content in biogenic carbonates increases in areas of sandy and gravelly textures, except in estuarine areas or those near the river mouths, where the siliciclastic component predominates, whilst in fine sediments there is more organic material.

Some of the latest research seeks to differentiate between the estuarine environment and the ria environment, based on the characteristics of the water masses and their specific hydrodynamic conditions, which are reflected in the bottom facies (Vilas, 2002; Vilas et al., this special issue) (Fig. 4).

New projects are aimed at delving deeper into the remobilisation of material from the rias and the shelf bottoms, their different behaviours during storms and intermediate periods, and calculating the sedimentary balances between the rias and the adjacent shelf.

5.2. The geometry of sedimentary bodies

Regarding the current state of knowledge on the geometry of sedimentary bodies, the available data mainly proceeds from seismic sampling and its partial contrasting with vertical cores.

The study of the seismic record drawn up by investigators from the Marine Geology Group of the University of Vigo and the Spanish Institute of Oceanography (Acosta, 1982, 1984; Acosta and Herranz, 1984; Herranz and Acosta, 1984; Rey Salgado, 1993a,b; García-Gil et al., 1999a,b,c, 2000a,b) has made it possible to calculate the thickness of the Quaternary sediments along the ria basements, distinguish between sedimentary sequences, and identify palaeoreliefs, particularly since the LGM (18,000 BP).

Different studies have centred on the latest 11,000 years BP, due to their environmental implications and the interest in studies on global change, and to the need to determine the impact of human influence; another factor is the technical and economic limitations on deep sediment sampling, which would make it possible to go further back in time.

The use of high-resolution seismic techniques and other acoustic techniques have made it possible to establish both the geometry of the sedimentary fill-in down to the basement, and the record of different levels of gas and gas escape in different sectors of the Rias (García-Gil et al., 1997, 2002b; Vilas, 1999). The results of this research confirm the tectonic–eustatic nature of the Vigo and Pontevedra rias, and their Quaternary infill. High-resolution seismic studies have enabled investigators to identify the granitic and metamorphic basements over which a major palaeorelief developed, with different units situated

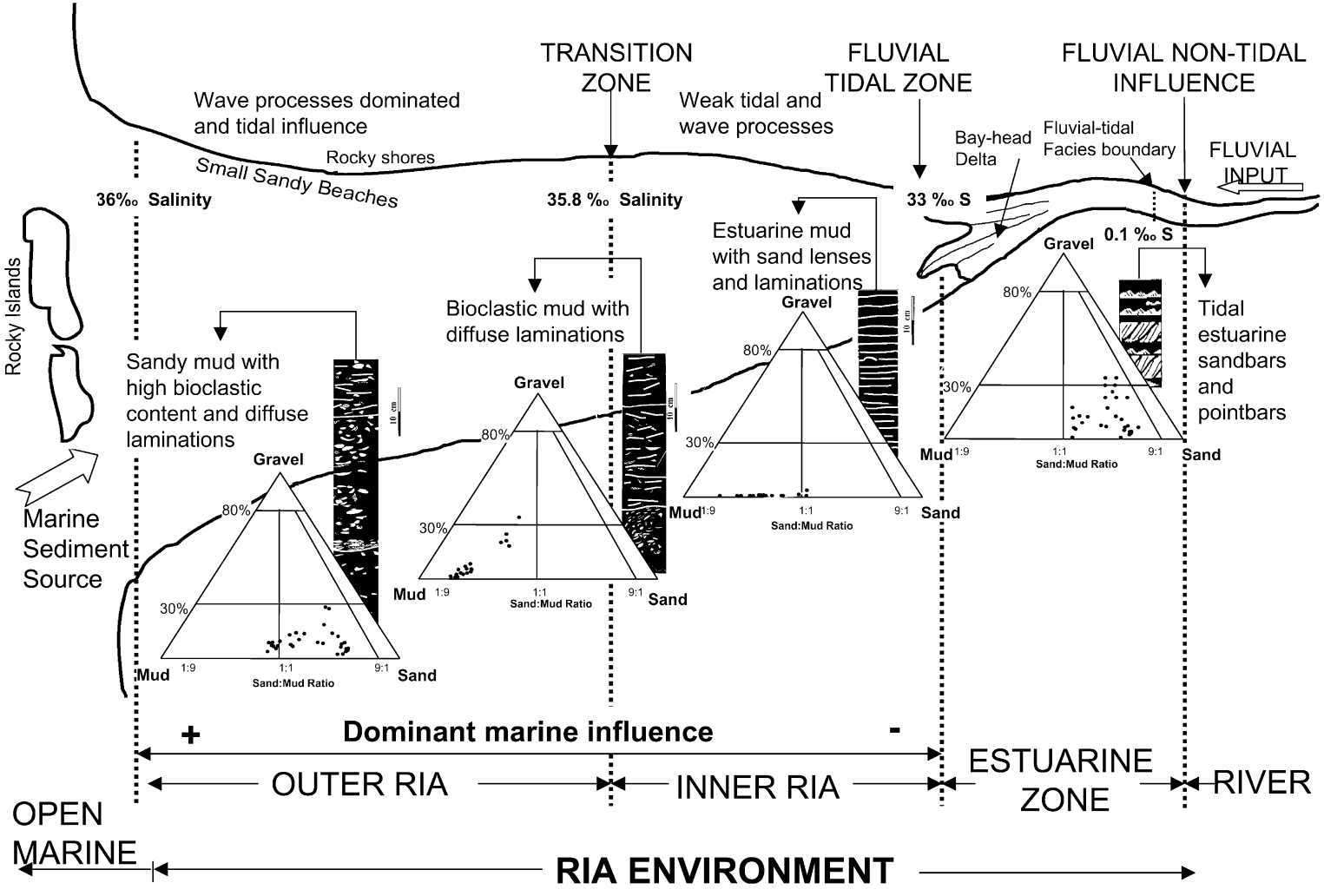

Fig. 4. Diagram showing the main domains, processes, and sedimentary facies over the course of a ria (Vilas, 2002).

over it. The basal unit that constitutes the oldest sedimentary infill could be an alteration of the basement. Over this, there are 3–4 units deposited during different sea level positions during the last eustatic cycle. The first of these was probably deposited during the LGM, at a time of low sea level. The coastline would, therefore, have been situated at approx. 150 m below the present level, and near the edge of today's shelf. The following units would have been above that, although the global eustatic drop 11,000 years BP produced the partial erosion of the previous materials, and the most recent unit is situated above this palaeorelief, deposited with the sea progressively rising. Noteworthy in this last unit is the identification of sedimentary bodies in a deltaic fan shape, with those situated at the ria mouth being considered high-energy events (García-Gil et al., 1999a,b,c, 2000a,b; García-García et al., 1999) (Fig. 5).

It has also been confirmed that the accumulations of sediments and organic material—controlled by the variations in sea level—led to the presence of gassy sediments (García-Gil et al., 1999a,b,c; García-García

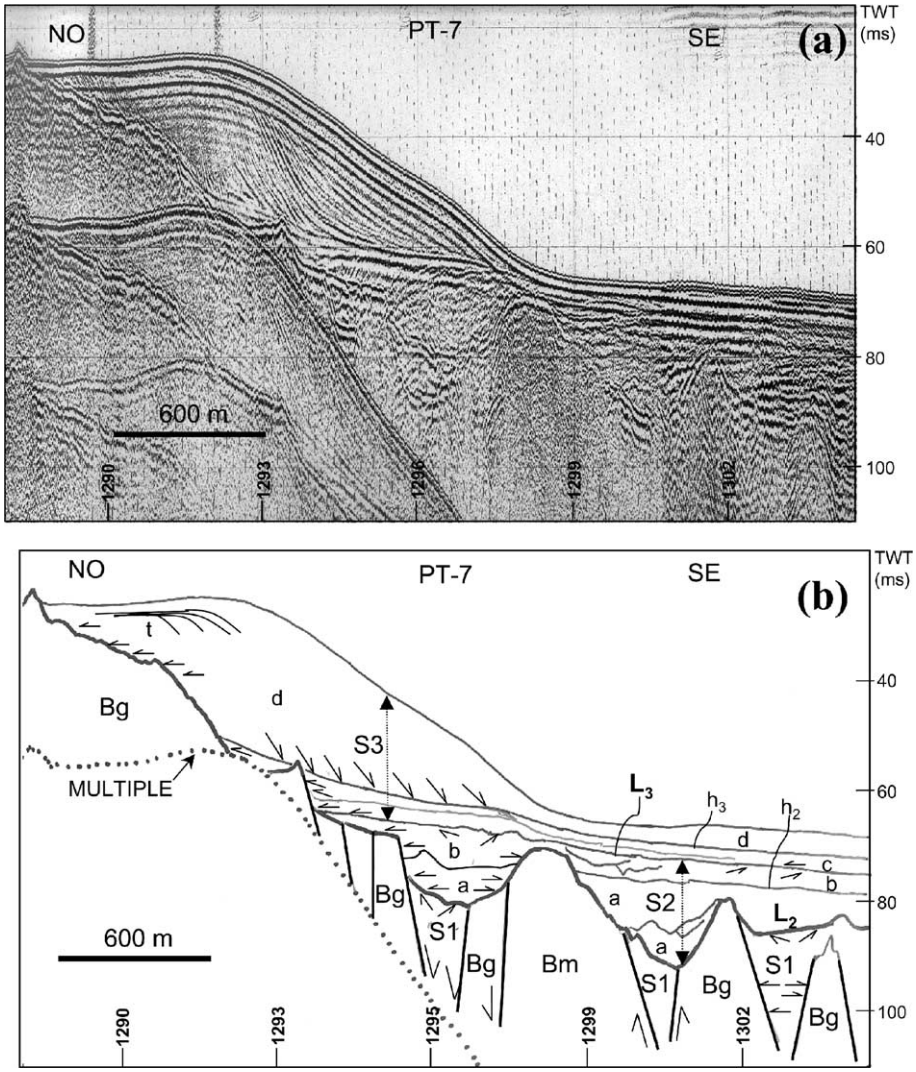

Fig. 5. Seismic reflection profile for the Ria de Pontevedra (PT-7): (a) uninterpreted profile, (b) profile interpretation showing the stratigraphic architecture of the units making up the sequences, as well as their limits and gaps (García-Gil et al., 2000c).

et al., 1999, 2001), seen as shielding on the seismic records. The levels of gas migrates at shallow levels and the gas escapes, taken together, seem to be characterised spatially by a higher accumulation of gassy areas on the ria's longitudinal axis, with more gas escapes along the borders of these areas. This distribution seems to be controlled by the facies, although seismic movements and human activities could also have an impact (e.g., Vilas et al., 1999b).

6. Palaeoceanography and palaeoecology

The ria muds and underlying deposits have high biogenic content, providing an important record of biogeochemical cycles. Different studies of the ria bottoms and their margins have led to advances in reconstructing their palaeoenvironment. These palaeoceanographic and palaeoecological studies of the Rias Baixas have their main antecedent in the papers of Margalef (1956, 1959) and Colom (1963). Based on their data, a palaeoecological framework was established for the last 8000 years, estimating that the sea level was, at the beginning of that time, 25–30 m lower than the present. Four climatic periods were also defined: Boreal (8500–7000 years BP), relatively warm; Atlantic (7000–4500 years BP), with temperatures and precipitations higher than present; Subboreal (4500–2600 years BP), warm and dry; and Subatlantic (2600 years BP–present) with considerable cooling and rainy phases.

In recent years, different authors have presented palaeoenvironmental interpretations based on short cores (around 3–4 m), which provided detailed accounts for the last 3000 years, inferring a dominance in the estuarine circulation of the rias between 3000 and 700 years BP, and an increase in the exchange of water between the ria and the ocean since about 500 years BP, after which time seasonal upwelling phenomena initiated (Francés et al., 1997, 1998a,b; Diz, 1998; Diz et al., 1998a,b; González Álvarez et al., this special issue). These studies suggest the existence of three environmentally different episodes: the first, with frequent variations in salinity; the second, with important contributions of organic material of continental origin; and the third, featuring increasingly frequent appearance of upwelling phenomena. Specifically, the frequency of upwelling, as well as a differentiating characteristic of rias versus estuaries, favours the conditions for the formation of certain autigenic minerals, such as verdine, goethite, and glauconite (Odin, 1988; Fernández-Bastero et al., 2000).

Human activity is also reflected in the most recent sediments. An increase in the rate of sedimentation has been calculated as four times higher today than in the last 700 years (Diz et al., 2002). Moreover, besides the vertical pattern of increases in certain heavy metals, another, horizontal distribution pattern relates metallic concentration with grain size (Rubio et al., 2000, 2001; Álvarez-Iglesias et al., in litt.).

Acknowledgements

This is paper no. 292 of the Marine Geology Group EX1 at the University of Vigo, and represents a contribution to projects REN2000-1102MAR (CICYT), PGIDT00PXI30105PR and PGIDT00MAR30103PR (Galician Regional Government). It is also a contribution to IGCP-464 (UNESCO). Thanks to D.D. Dunn for the English translation.

References

Acosta, J., 1982. Apantallamientos acústicos en el margen continental de Cádiz y en la Ría de Muros. Boletín del Instituto Español de Oceanografía T. VII (P.1), 125–149.

Acosta, J., 1984. Occurrence of acoustic masking in sediments in two areas of the continental shelf of Spain: Ria de Muros (NW) and Gulf of Cadiz (SW). Marine Geology 58, 427–434.

Acosta, J., Herranz, P., 1984. Contribución al conocimiento del cuaternario marino en la ría de Muros y Noya. Thalassas. Revista de Ciencias del Mar 2, 13–21.

Albentosa, L.M., 1989. El clima y las aguas. Editorial Síntesis, Madrid.

Alejo, I., 1994. Estudio dinámico y sedimentario de la Bahía de Baiona. Unpublished doctoral thesis. University of Vigo, Spain.

Alejo, I., de Ramon, M.I., Nombela, M.A., Reigosa, M.J., Vilas, F., 1990. Complejo intermareal de A Ramallosa, (Bahía de Baiona, Pontevedra). I. Ecología y evolución. Thalassas 8, 45–56.

Álvarez-Iglesias, P., Rubio, B., Vilas, F., in litt. Pollution in intertidal sediments of San Simón Bay (Inner Ria de Vigo, NW Spain): total heavy metal concentration and speciation. Marine Pollution Bulletin.

Carlé, W., 1947. Die westgalischen Meeresbuchten. Natur und Volk 77, 5–14.

Carlé, W., 1949. Las rías bajas gallegas. Estudios Geográficos 35, 320–330.

Colom, G., 1963. Los foraminíferos de la Ría de Vigo. Investigaciones Pesqueras 23, 71–89.

Cotton, C.A., 1956. Rias sensu strictu and sensu latu. Geographical Journal 122, 360–364.

Diz, P., 1998. Evolución paleoecológica y paleoceanográfica de la Ría de Vigo durante el Holoceno. Honours thesis, 153 pp. University of Vigo, Spain.

Diz, P., Francés, G., Alejo, I., Pimentel, F., Méndez, J., Vilas, F., 1998a. Las asociaciones de foraminíferos bentónicos del Holoceno de la Ría de Vigo. Libro de resúmenes del XIII Congreso Bienal de la Real Sociedad Española de Historia Natural, Vigo, Spain.

Diz, P., Francés, G., Pelejero, C., Alejo, I., Grimalt, J.O., Vilas, F., 1998b. How old is the upwelling phenomena in the West Iberian Margin? 6th International Conference on Paleoceanography, Lisbon.

Diz, P., Francés, G., Pelejero, C., Grimalt, J.O., Vilas, F., 2002. The last 3000 years in the Ría de Vigo (NW Iberian Margin): climatic and hydrographic signals. Holocene 12 (4), 459–468.

Fernández-Bastero, S., Velo, A., García, T., Gago-Duport, L., Santos, A., García-Gil, S., Vilas, F., 2000. Las glauconitas de la plataforma continental gallega: indicadores geoquímicos del grado de evolución. Journal of Iberian Geology 26, 233–247.

Francés, G., Diz, P., Alejo, I., Vilas, F., 1997. Evolución paleoecológica de la Ría de Vigo durante el Holoceno. Libro de abstracts del 2° Simposio sobre el margen continental Ibérico Atlántico, Cadiz, Spain.

Francés, G., Diz, P., Pelejero, C., Alejo, I., Grimalt, J.O., Vilas, F., 1998a. Sea level rise and mass-water dynamics in the Ría de Vigo (NW Spain) during the Holocene. 15th International, Sedimentological Congress, Alicante, Spain, pp. 345–346.

Francés, G., García-Gil, S., Diz, P., Alejo, I., Nombela, M.A., Rubio, B., Pazos, O., Vilas, F., 1998b. Efectos de los cambios globales en las zonas costeras: la Ría de Vigo como ejemplo. Libro de resúmenes del XIII Congreso Bienal de la Real Sociedad Española de Historia Natural, Vigo, Spain, p. 122.

Freijido, M., Pérez-Arlucea, M., Méndez, G., 2000. Evaluación de los aportes fluviales a la Ría de Pontevedra (SO de Galicia). 3° Simpósio sobre a Margem Continental Ibérica Atlântica, pp. 55–56. Algarve University, CIACOMAR and Centro de Investigação Marinha e Ambiental. Faro, Portugal.

García-García, A., 2001. Estratigrafía sísmica de alta resolución de la ría de Vigo. evolución e implicaciones ambientales. Doctoral thesis, University of Vigo, Spain.

García-García, A., García-Gil, S., Vilas, F., 1999. A seeping seafloor in a ria environment: Ría de Vigo (NW Spain). Environmental Geology 38 (4), 296–300.

García-Gil, E., Vilas, F., García-Gil, S., Nombela, M.A., Alejo, I., Rubio, B., Pazos, O., Rey, D., 1994a. Obtaining distribution maps of sediment in the Rías Bajas, Galicia (Spain) and their inclusion in a GIS. Edit. by Association Eurocoast-Portugal, I, 491–508.

García-Gil, E., Vilas, F., García-Gil, S., Nombela, M.A., Alejo, I., Rubio, B., Pazos, O., Rey, D., 1994b. Integración de los mapas de distribución de los sedimentos del fondo de la Ría de Pontevedra en un SIG. III Congreso AESIG, vol. 2, pp. 1–11.

García-Gil, S., García-García, A., Vilas, F., 1997. Presencia de gas somero en la ría de Vigo (NW España). Abstract Volume of the 2° Simposio sobre el Margen Continental Ibérico Atlántico, 17–20 September, Cadiz, Spain, pp. 197–198.

García-Gil, S., García-García, A., Vilas, F., 1999a. Identificación sísmico-acústica de las diferentes formas de aparición de gas en los sedimentos de la ría de Vigo (NO España). Revista de la Sociedad Geológica de España 12 (2), 301–307.

García-Gil, S., Vilas, F., García-García, A., Durán, R., 1999b. Holocene storm delta in incised-valley fill sediments of Ría de Pontevedra, NW Spain. EOS Transactions 46 (80), 559.

García-Gil, S., Vilas-Martín, F., Muñoz, A., Acosta, J., Uchupi, E., 1999c. Quaternary sedimentation in the Ría de Pontevedra (Galicia), Northwest Spain. Journal of Coastal Research 15 (4), 1083–1090.

García-Gil, S., Duran, R., Vilas, F., 2000a. Side Scan Sonar image and geologic interpretation of the Ría de Pontevedra seafloor (Galicia, NW Spain). Scientia Marina 64 (4), 393–402.

García-Gil, S., Vilas, F., García-García, A., 2000b. Estudio sísmico acústico de alta resolución de la discontinuidad sedimentaria del Würm en la Ría de Vigo (NO España). Geotemas 1 (1), 149–153.

García-Gil, S., García-García, A., Durán, R., Vilas, F., 2000c. Estratigrafía sísmica de alta resolución en las Rias Baixas: Pontevedra y Vigo (NO España). Journal of Iberian Geology 26, 217–231.

García-Gil, S., Vilas, F., Ferrín, A., Diez, R., Durán, R., Magariños, J., Iglesias, J., 2002a. High-resolution seismic stratigraphy from the southern Galician Shelf and its connection with the rías, NW Spain. Abstracts, 2nd Conference of the IGCP464 Project, Sao Paulo and Cananéia, pp. 37–39.

García-Gil, S., Vilas, F., 2002b. Shallow gas features in incised-valley fills (Ría de Vigo, NW Spain): a case study. Continental Shelf Research 22, 2302–2315.

González Álvarez, R., Bernárdez, P., Pena, L.D., Francés, G., Prego, R., Diz, P., Vilas, F., this special issue. Paleoclimatic evolution of the Galician continental shelf (NW of Spain) during the last 3,000 years: from a storm regime to present conditions. Journal of Marine Systems.

Herranz, P., Acosta, J., 1984. Estudio geofísico de la ría de Muros y Noya. Boletín del Instituto Español de Oceanografía 1, 48–78.

Hinz, K., 1970. Seismic reflection measurements with a pneumatic sound source in the ria the Arosa (NW Spain). Leidse Geologische Mededelingen 37, 169–184.

I.G.M.E. [Instituto Geológico y Minero de España], 1985. Mapa Geológico de España E. 1:200.000. Pontevedra-La Guardia. Ministerio de Industria y Energía, Madrid.

I.N.I. [Instituto Nacional de Industria], 1979. Investigación minera de detalle en los fondos submarinos de la zona de las rías de Pontevedra y Vigo (Gali-Rías). Unpublished.

Koldijk, W.S., 1968. Bottom sediments of the ría de Arosa (Galicia NW Spain). Leidse Geologische Mededelingen 37, 77–134.

Margalef, R., 1956. Paleoecología postglacial de la Ría de Vigo. Investigaciones Pesqueras 5, 89–112.

Margalef, R., 1959. Nuevos datos para el estudio de la historia de la Ría de Vigo, desde la última glaciación. Memorias de la Real Academia de Ciencias y Artes de Barcelona, no. 666 33 (2), 23–35.

Méndez, G., Rey, D., 2000. Perspectiva histórica del conocimiento geológico de las rías gallegas. Journal of Iberian Geology 26, 21–44.

Mendez, G., Perez-Arlucea, M., Clemente, F., Nombela, M., Rubio, B., 2002. Sediment yield and sedimentation rates in recent coastal deposits in the Ria de Vigo (Spain). Anthropogenic or climatic causes? Quaternary climatic changes and environmental crises in the Mediterranean Region. July, 2002. Departamento de Geología University of Alcalá de Henares, Madrid.

Méndez, G., Pérez-Arlucea, M., Stouthamer, E., Berendsen, H., 2003. The TESS-1 suction corer: a new device to extract wet, uncompacted sediments. Journal of Sedimentary Research 73 (6), 1078–1081.

Nombela, M.A., 1989. Oceanografía y sedimentología de la Ría de Vigo. Doctoral thesis, Complutense University, Madrid.

Nombela, M.A., Vilas, F., Rodríguez, M.D., Ares, J.C., 1987. Estudio sedimentológico del litoral gallego. III. Resultados previos sobre los sedimentos de los fondos de la Ría de Vigo. Thalassas 5, 7–19.

Nombela, M.A., Vilas, F., Evans, G., 1995. Sedimentation in the mesotidal Rías Bajas of Galicia, (NW Spain): Ensenada de San Simón, inner Ría de Vigo. In: Flemming, B.W., Bartholoma, A. (Eds.), Tidal signatures in modern and ancients sediments, Special publications of the IAS, vol. 24, pp. 133–149.

Nonn, H., 1966. Les régions cotières de la Galice (Espagne). Étude géomorphologique. Publications de la Faculté des Lettres de l'Université de Strasbourg, Paris.

Odin, G.S., 1988. Green Marine Clays. Developments in SedimentologyElsevier, Amsterdam.

OSPAR Commission, 2000. Quality Status Report: Region IV-Bay of Biscay and Iberian Coast. OSPAR Commission, London.

Pagés Valcarlos, J.L., 2000. Origen y evolución geomorfológica de las rías atlánticas de Galicia. Revista de la Sociedad Geológica de España 13 (3–4), 393–403.

Pannekoek, A.J., 1966a. The geomorphology of the surroundings of the Ría de Arosa (Galicia NW Spain). Leidse Geologische Mededelingen 37, 7–32.

Pannekoek, A.J., 1966b. The ria problem: the role of antecedence, deep wathering, and Pleistocene slope-wash. Tijdschrift van het Koninklijk Nederlandsch Aardrijkakunsif Genootschap 83, 289–297.

Pannekoek, A.J., 1970. Additional geomorphological data on the ria area of western Galicia (Spain). Leidse Geologische Mededelingen 37, 185–194.

Pazos, O., Nombela, M.A., Vilas, F., 2000. Continental contribution of suspended sediment to an estuary: Ría de Vigo. Scientia Marina 64 (3), 295–302.

Perez-Arlucea, M., Filgueira, M., Freijido, M., Mendez, G., 2000a. Parametros morfometricos e hidrologicos de las cuencas de drenaje y rios tributarios a la ria de Vigo. Estimacion de las variaciones anuales en las cargas en suspension y en disolucion. Journal of Iberian Geology Cuadernos de Geologia Iberica 26, 171–187.

Perez-Arlucea, M., Freijido, M., Mendez, G., Filgueira, M., 2000b. Hydraulics and morphology of the tributary rivers entering the Ria de Vigo. Estimation on the annual variations in suspended and dissolved loads. Hidraulica y geomorfologia de los tributarios de la Ria de Vigo. Estimacion de las variaciones anuales en las cargas de fondo y en disolucion. In: 3° Simposio sobre a Margem Continental Iberica Atlântica, pp. 53–54. Algarve University, CIACOMAR and Centro de Investigação Marinha e Ambiental. Faro, Portugal.

Perez-Arlucea, M., Freijido, M.T., Mendez, G., Nombela, M.A., Rubio, B., Filgueira, M., Fernandez-Bastero, S., Gimenez, R., 2001a. Tasas de erosion, transporte y sedimentacion en un medio estuarico: el rio Miñor (Ria de Vigo, Pontevedra). XIV Congreso Nacional de Sedimentologia—IV Coloquio del Cretacico de España. Jaen, Spain, 10–16 September, 2001, Geotemas, vol. 3 (2), pp. 17–21.

Pérez-Arlucea, M., Freijido, M., Méndez, G., Nombela, M., Rubio, B., Filgueira, M., Fernández, S., 2001b. Sediment yield, short-term, erosion rates and fluvial sedimentation in the lower Galician Rias (NW Spain). Fluvial Sedimentology 2001. 7th International Conference on Fluvial Sedimentology. Program and Abstracts. University of Nebraska-Lincoln, Lincoln, NE, USA, p. 225.

Pérez-Arlucea, M., Méndez, G., Clemente, F., Nombela, M., Rubio, B., Filgueira, M., this special issue. Hydrology, sediment yield, erosion and sedimentation rates in the estuarine environment of the Ria de Vigo, Galicia, Spain. Journal of Marine Systems.

Rey Salgado, J., 1993a. Mapa fisiográfico de la ría de Arosa E. 1:50000. Instituto Español de Oceanografía. Publicaciones Especiales, no. 15. Madrid.

Rey Salgado, J., 1993b. Relación morfosedimentaria entre la plataforma continental de Galicia y las Rías Bajas y su evolución durante el Cuaternario. Instituto Español de Oceanografía. Publicaciones Especiales, no. 17. Madrid.

von Richthofen, F., 1886. Führer für Forschungsreisende. Oppenheim, Berlin.

Río, F., Rodríguez, F., 1996. Os ríos. As augas de Galicia. Ponencia de Patrimonio Natural. Consello da Cultura Galega, Santiago de Compostela, Spain.

Rubio, B., Nombela, M.A., Vilas, F., 2000. Geochemistry of major and trace elements in sediments of the Ria de Vigo (NW Spain): An Assessment of Metal Pollution. Marine Pollution Bulletin 40 (11), 968–980.

Rubio, B., Pye, K., Rae, J.E., Rey, D., 2001. Sedimentological characteristics, heavy metal distribution and magnetic properties in subtidal sediments, Ria de Pontevedra, NW Spain. Sedimentology 48, 1277–1296.

Scheu, E., 1913. Die Rias von Galicien. ihr Werden und Vergehen. Zeitschrift Gesteine Erdkunde, Berlin.

Schurtz, H., 1902. An der Riasküste Galiciens. Deutsche Geographische Blätter 25, 50–74.

Torre Enciso, E., 1954. Contribución al conocimiento morfológico y tectónico de la ría de La Coruña. Boletín de la Real Sociedad Española de Historia Natural 52, 21–51.

Torre Enciso, E., 1958. Estado actual del conocimiento de las rías gallegas. Homaxe a R. Otero Pedrayo, 237–250. Ed. Galaxia. Vigo, Spain.

Twidale, C.R., Vidal Romaní, J.R., 1994. The Pangea inheritance. Cuadernos do Laboratorio Xeolóxico de Laxe 19, 1–45.

Vidal Romaní, J.R., 1991. Problemas geomorfológicos del noroeste peninsular. In: Centeno, J., Garzón, G., Acaso, E. (Eds.), Problemas geomorfológicos del Centro y Noroeste de la Península Ibérica. Complutense University, Madrid.

Vidal Romaní, J.R., 1996. Geomorfología de Galicia. Galicia, Geografía Tomo XVII. Hércules de Ediciones, Corunna, Spain, pp. 36–63.

Vilas, F., 1979. Características de la sedimentación costera actual en las rías de Vigo y Baiona (Pontevedra). Unpublished doctoral thesis. Universidad Complutense de Madrid.

Vilas, F., 1983. Medios sedimentarios de transición en la Ría de Vigo: secuencias progradantes. Thalassas 1, 49–55.

Vilas, F., 1999. Proyecto MAR95-1953: Informe Final. Departamento de Geociencias Marinas y Ordenación del Territorio. Unpublished report. University of Vigo, Spain.

Vilas, F., 2002. Rías and tidal-sea stuaries. UNESCO-EOLSS Knowledge for sustainable development, an insight into the Encyclopedia of Life Support Systems, vol. II. UNESCO-EOLSS, Oxford, U.K. chap. 11.6.3.: 799–829.

Vilas, F., Nombela, M.A., 1985. Las zonas estuarinas de la costa de Galicia y sus medios asociados, NO de la Península Ibérica. Thalassas 3, 7–15.

Vilas, F., Nombela, M.A., García-Gil, E., García-Gil, S., Alejo, I., Rubio, B., Pazos, O., 1995. Ría de Vigo. Cartografía de sedimentos submarinos. Escala 1:50.000 (Memoria y Mapa). Xunta de Galicia. Santiago de Compostela, Spain.

Vilas, F., García-Gil, E., García-Gil, S., Nombela, M.A., Alejo, I., Rubio, B., Pazos, O., 1996. Ría de Pontevedra. Cartografía de sedimentos submarinos. Scale 1:50.000 (Notes and Map). Xunta de Galicia. Santiago de Compostela, Spain.

Vilas, F., García-Gil, E., García-Gil, S., Nombela, M.A., Alejo, I., Francés, G., Méndez, G., 1999a. Ría de Arousa. Cartografía de sedimentos submarinos. Scale 1:50000 (Notes and Maps). Xunta de Galicia. Santiago de Compostela, Spain.

Vilas, F., García-Gil, S., García-García, A., 1999b. Shallow gas in incised-valley fills of the Ría de Vigo, NW Spain. EOS, Transactions 80 (46), 557.

Vilas, F., Méndez, G., Bernabeu, A.M., 2001. Cartografía de los sedimentos de las Rias Baixas gallegas (NW Spain). Abstracts of Taller de Oceanografía, 7.

Vilas, F., García-Gil, S., Diez, R., Durán, R., Ferrín, A., Magariños, J., Iglesias, J., 2002. Southern Galicia continental shelf of NW Spain since the Last Glacial Maximum. Abstracts, 2nd Conference of the IGCP464 Project, 2002: 93–95. Sao Paulo and Cananéia. Brazil.

Vilas, F., Bernabeu, A., Méndez, G., this special issue. Sediment distribution pattern in the Rias Baixas (NW Spain): main facies and hydrodynamic implications. Journal of Marine Systems.