Late Holocene evolution of redox state of the sediments of Galicia Mud Deposit (outer continental shelf)

Evolução Holocénica Recente do estado redox dos sedimentos do Depósito Lodoso da Galiza (plataforma continental externa)

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Abstract

Outer continental shelf dynamics are influenced by terrestrial and marine processes. The past studies in this environment are important to understand the evolution of nearshore/slope processes and frame the actual processes. The main aim of this work is to study the Late Holocene evolution of redox state of the Galicia Mud Deposit (outer continental shelf) sediments related to the supply of organic carbon to the sea floor. West Iberian Margin is affected by intermittent upwelling episodes, in general during spring/summer, which determine the increase of oceanic productivity, influencing the supply of organic mater to the bottom.

Sedimentary grain-size, geochemical and micropalaeontological (benthic foraminifera) data, obtained along the OMEX KSGX 40 core (164-cm long) were analysed in this work. This core was collected in the Galicia Mud Deposit, from the NW Iberian outer continental shelf, off Ría of Vigo (North of Spain). Three radio-carbon datings (based on mixed benthic foraminiferal tests) were used to perform this core depth age model which is supported by calibrated (cal) ages before present (BP) after correction for marine reservoir. Data indicate a number of substantial changes in sedimentation (texture and composition) and food/oxygen availability to the benthic ecosystem during the last ~4.8 ka cal BP. Sedimentary fine fraction Fe and Mn content, two redox sensitive chemical elements, were used to identify the occurrence of significant authigenetic/diagenetic alterations during the periods of higher deposition of organic matter and lower oxygen levels.

A Benthic Foraminifera High Productivity (BFHP) proxy indicates a steadily increasing in the Corg flux and nutrient load contemporaneous with the deposition of finer sediments, suggesting an intensification of the eutrophication in the last 2.2 ka cal BP. Two periods of higher eutrophication contemporaneous of finer deposition of sediments (two muddy intervals) could have happened between ~2.2-1.2 ka cal BP and ~0.5-0.1 ka cal BP. The eutrophication pattern, based on the BFHP proxy, is clearly related to changes in texture of the sediments and should be related directly or indirectly to coastal upwelling-dominated depositional

intervals and/or with higher lateral Corg flux to the studied site. Benthic Foraminiferal Oxygen Index indicates deep decreasing in oxygen levels in sediments pore-water and probably in bottom water column during the ref-ereed periods leading to higher authigenetic/diagenetic changing as suggest Fe and Mn values.

Key words: Galicia outer continental shelf; Holocene; sediments redox state, Corg flux

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INTRODUCTION

The Western Iberian shelf is relatively narrow between 42º-43ºN, 30-40km wide, with typical depth 100-150m (HUTHNANCE *et al.*, 2002). In the south area, a tectonic depression within the shelf allowed the recent development of the Galicia Mud Deposit (DIAS *et al.*, 2002a, b; JOUANNEAU *et al.*, 2002) (fig. 1).

This coastal zone is characterized by the existence of four 'Rías': Vigo, Pontevedra, Arosa, and Muros (the so-called 'Rías Baíxas'). They have a WSW–ENE development and mouths wider than 10 km, reaching in general 40–50m of water depth and are sources of fine sediments to the shelf (REY SALGADO, 1993).

Recurrent upwelling episodes (~2 week period; BLANTON *et al.*, 1984; ÁLVAREZ-SALGADO *et al.*, 1993), more frequent during April/May to September/October, i.e. at the upwelling season, are induced by northerly winds at these latitudes (WOOSTER *et al.*, 1976). The upwelled cold and nutrient rich Eastern North Atlantic Central Water (ENACW) enhances the oceanic productivity in shelf areas (TENORE *et al.*, 1995) and inside the 'Rías Baíxas' (HANSON *et al.*, 1986). The subsequent remineralization of the sinking particulate organic matter can take place at the sediment-water interface (ÁLVAREZ-SALGADO *et al.*, 1997).

The increase in rain rate of organic matter to the bottom can result in a high consumption of oxygen by aerobic organisms and cause changes in the redox state of the surface sediments, in the areas of fine sediments, where pore-water oxygen renewal is difficult (JÖRISSEN *et al.*, 1995; De STIGTER, 1996; Van der ZWAAN *et al.*, 1999).

Foraminifera, (GOODAY *et al.*, 2001) as a group, probably more opportunistic than metazoans, can better tolerate oxygen depletion, and have population dynamics that are more closely coupled to organic matter inputs than other metazoans. So, this group has been used for many researchers to evaluate the palaeocarbon flux to the sea floor and oxygen conditions in the sediments and bottom water (e.g. JUSTIC *et al.*, 1987; JUSTIC, 1991a,b; KAIHO, 1991; BERNHARD *et al.*, 1997; JÖRISSEN, 1999).

Commonly, benthic foraminifera stratigraphic data are analysed with regard to the distribution pattern and the ecological meaning of the most frequent species (MURRAY, 1991). In this work, the benthic foraminifera species percentage per sample was used to calculate two main biological proxies. Considering that both dissolved oxygen and organic carbon flux are important controlling factors for benthic foraminiferal assemblages, we will contrast the Benthic Foraminiferal Oxygen Index (BFOI; based on KAIHO, 1994) and a Benthic Foraminifera High Productivity (BFHP) proxy with geochemical proxies of redox state of sediments. The aim of this work is to identify in core KSGX 40 variations in dissolved oxygen values of sedimentary pore-water and/or bottom water linked to the organic matter supply to the Galicia Outer Shelf during the Late Holocene.

MATERIALS AND METHODS

The OMEX (Ocean Margin Exchange Project) core KSGX 40 was collected at the Galicia Mud Deposit, located (fig. 1) on the NW Iberian outer continental shelf, off Ria of Vigo, North of Spain (42º14'98"N, 09º01'01"W and 115m). This core (164-cm long) was horizontally sliced into 1 cm intervals for grain size, geochemical and benthic foraminiferal studies.

Grain size analyses were carried out by Laser Diffraction in Particle Size Analysis (using a Mastersizer S instrument, Malvern Instruments), which provided the grain size distribution in the size range 0.05 to 878 ìm.

Iron and manganese concentrations were determined on fine fraction (<63ìm) by atomic absorption spectrometry. Calcium carbonate content was determined in the bulk sediment by the gasometric method.

The sand fraction (63-1000ìm) dried residue of 133 samples were analysed for benthic foraminifera studies using a light microscope. Foraminiferal abundance (number per gram of bulk sediment) was calculated counting shells from a known weighted sediment split. More than 300 well preserved specimens were determined and counted to identify benthic foraminiferal assemblages. Determination of benthic foraminiferal species was based on LOEBLICH & TAPPAN (1988) and ELLIS & MESSINA Catalogue (1940-1988), as well as references cited by MARTINS & GOMES
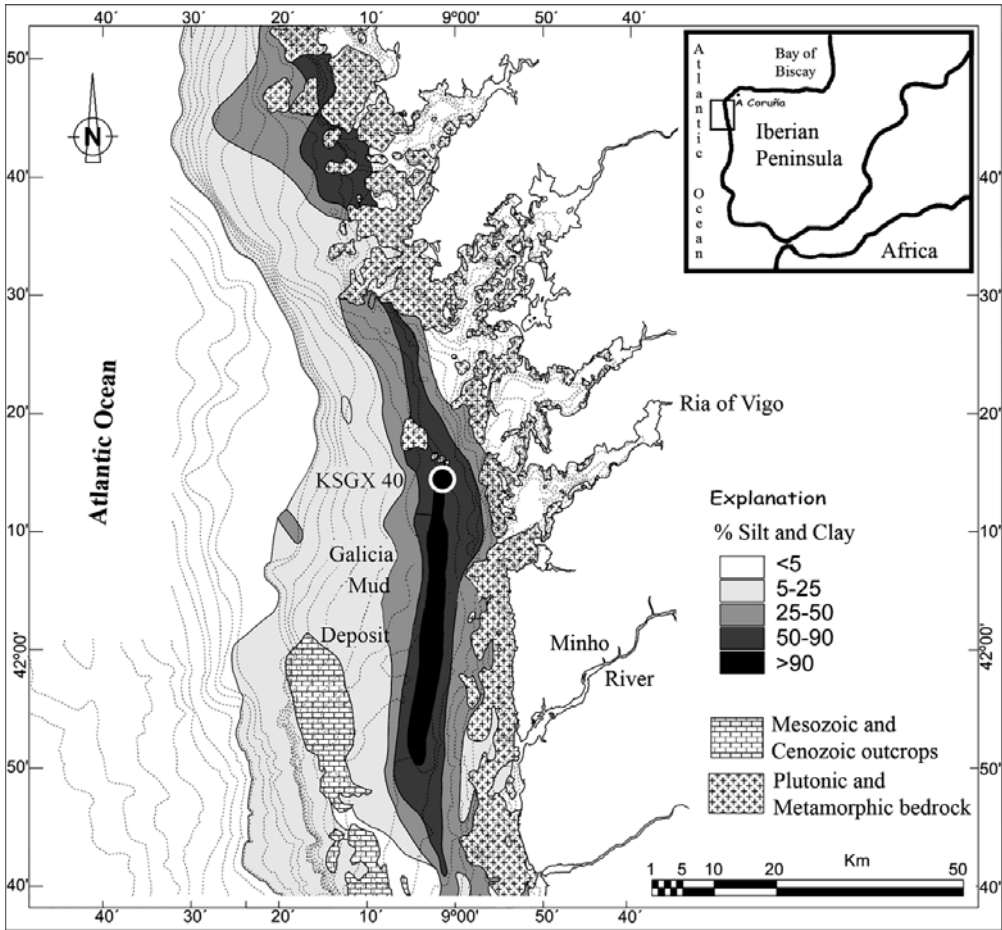
Fig. 1 – Map of the studied area (adapted from Dias et al., 2002 a,b) showing the location of core KSGX 40 and localities mentioned in the text.

(2004).

Three radiocarbon dates of mixed foraminiferal shells (10mg to 20mg) collected in the sedimentary size fraction >125mm of the layers 39-40cm, 69-70cm and 134-135cm were carried out by AMS method at "Beta Analytic Inc.", Miami, Florida, USA. Data were corrected to calibrated years BP using the CALIB 4.3 program (STUIVER *et al.*, 1998). The final results correspond to calibrated ages (cal) using 2 ó intervals (MARTINS, 2004).

Benthic foraminiferal proxies

The organic carbon flux (food) (Van der ZWAAN *et al.*,1999), is important in determining abundance of benthic foraminifera, which is subordinate when oxygen starts to be limiting. This is the case of almost all shallow water systems with muddy substrates where microhabitat patterns or

benthic foraminiferal distribution along a redox gradient appears to be correlated with specific redox levels.

Many palaeontologists accept that variations in oceanic primary productivity, flux of organic carbon to the sediments, and dissolved-oxygen levels at the sediment-water interface and in the sediments are important in the control of benthic foraminiferal test size, wall thickness, morphology, and species composition of assemblages (KAIHO, 1994, 1999; JÖRISSEN *et al.*, 1995; De STIGTER *et al.*, 1996; BERNHARD & SEN GUPTA, 1999; Van der ZWAAN *et al.*, 1999).

Considering the calcareous benthic foraminiferal morphologies found in poorly oxygenated deposits differ from those present in highly oxygenated deposits, (KAIHO, 1991) because benthic foraminiferal test morphology could be used to extrapolate relative amounts of dissolved oxygen of past deep-sea bottom waters. He classified the calcareous benthic foraminifera from DSDP samples of Cenozoic age from the world oceans and New Zealand Palaeogene samples into three categories: aerobic, anaerobic and intermediate forms. Following this, he used the ratio of aerobic versus aerobic plus anaerobic forms to estimate global changes in the oxygen content of deep oceanic waters.

This author, (KAIHO, 1991) also produced the Benthic Foraminiferal Oxygen Index (BFOI) based on these foraminiferal categories. BFOI can be calculated following the definition of indicators (oxic, suboxic, and dysoxic) and the equations of KAIHO (1994): (1) When O is greater than zero, $[O/(O+D)]$ x 100 (where O and D are numbers of specimens of oxic and dysoxic indicators, respectively). (2) When O equals zero and SD is greater than zero, $\{[S/(S + D)] − 1 \}$ x 50 (S is the number of specimens of suboxic indicators). (3) Black laminated mud or shales barren of calcareous benthic foraminifera but containing planktonic foraminifera (0–0.1 ml/l O_2), were given a BFOI of -55.

KAIHO (1999) demonstrated, however, that in the deep ocean the BFOI correlates most strongly with dissolved oxygen levels in overlying water ($R^2 = 0.81$), weakly with oceanic primary productivity ($R^2=0.55$), and weakly with organic carbon flux to the sediments ($R^2 = 0.51$). According to this author, dissolved-oxygen levels would reflect: (1) the inte-

grated effect of oxygen consumption controlled by the organic carbon flux ($R^2 = 0.43$) and global deep ocean ventilation (i.e., water mass age); and (2) dissolved oxygen levels in source areas of deep water controlled by its temperature and atmospheric oxygen levels at the point where deep water sinks.

Benthic foraminifera are also considered particularly useful for estimating carbon palaeoflux since they are more resistant to diagenetic changes caused by dissolution or oxidation than for example planktonic foraminifera or accumulation of organic carbon (CORLISS & CHAN, 1988). So, down-core variations in organic matter flux, estimated by grouping benthic foraminifera taxa which are known to flourish under high C_{org} flux, will be contrasted with the BFOI in order to estimate the more significant oxygen alterations in the bottom water column overlying the sediments and/or in sedimentary pore-water and geochemical proxies of redox state.

Benthic foraminifera high productivity proxies (BFHP) include the total percentage of *Bolivina/Brizalina spp.*, *Bulimina spp.*, *Cassidulina laevigata /C. carinata*, *Cassidulina teretis*, *Eggerella/Eggeroides spp.*, *Epistominella vitrea*, *Fursenkoina spp.*, *Globobulimina spp.*, *Nonionella spp.*, *Rectuvigerina phlegeri*, *Stainforthia spp.*, *Uvigerina peregrina* and *Valvulineria bradyana*. This sub-group determination was based on the references cited in appendix B.

Iron and manganese contents are used in this core as indicators of redox-oxic changing conditions (*e.g.* FROELICH *et al.*, 1979; NEUMANN *et al.*, 1997; PEINERUD, 2000; TEKIROGLU *et al.*, 2001).

Statistic analysis

To determine how closely some of our data obey a linear relationship we used the R-squared value computed in Excel (varying between $0 < = R^2 < = 1$). The R^2 is a correlation coefficient and measures the strength between two variables. The high correlation between data is denoted with a high R-squared value. The high R^2 value helps to predict a Y value to a knowing X.

The correlation between two variables was also measured with the Pearson Correlation. Pearson's

correlation also reflects the degree of linear relationship between two variables. It ranges from +1 to -1. Where -1.0 is a perfect negative (inverse) correlation, 0.0 is no correlation, and 1.0 is a perfect positive correlation. The formula for Pearson's correlation takes on many forms. We used the formula applied by *Statistica* package.

RESULTS

Significant variation in grain size can be observed through the core KSGX 40 (MARTINS, 2004). The sedimentological parameters measured show that this core records a granule-decreasing upward sequence with a high sand content in the section between 164-80 cm (fig. 2). Gravel fraction, the coarser one, is rare and is composed mainly by mollusc's shells and other bioclasts. Fine fraction is predominant in the first 80 centimetres particularly between 80-50 cm and 20-0 cm. We designated these two sections as muddy intervals.

The carbonate content is an important parameter in the classification of the sediment and interpretation of the sedimentary regime (STOW & PIPER, 1984); however, one must be careful to determine the type carbonate (i.e. modern planktic foraminifera or reworked older carbonates in turbidites) which was not done by Stow and Piper. The studied core has low carbonate values, which varied between 2-18 %, since terrigenous particles are the main component of these sediments. Carbonate values correlate well with sediment grain size, decreasing as far as sediment mean grain size also decreased.

The absolute abundance of benthic foraminifera varied between 160 to 9600 in the number of specimens per gram of bulk sediment. The most remarkable feature in the foraminifera abundance (n.º/g) curve, like carbonate values, is the clear and progressive upward reduction of foraminiferal abundance as sediment mean grain size decreases (fig. 2). In fact, t he large amount of calcium carbonate content of these sediments is due to the contribution of molluscs and foraminiferal bioclasts.

Pyrite (FeS_2) filled foraminiferal tests and framboidal pyrite granules are present in sand fraction all along the core. Iron content varies between 1-5 % whereas manganese values oscillate between 88-

262ppm. Iron and manganese have a significant R^2 value (0.73) (fig. 3). Both elements have lower concentrations in sand-rich sediments and higher concentrations in fine grained deposits. This association is expressed by its positive and high Pearson's correlation with fine fraction (0.86 and 0.85, respectively; $p<0.05000$) and by the R^2 value (0.82, 0.69, respectively) (figure 4 plot).

A total of 354 taxa of benthic foraminifera were recognized (MARTINS, 2004), but only 111 taxa are listed in appendix A. Rare species that only occur in one sample or never exceed 0.4 % were excluded or grouped under its generic designation (like e.g. *Lagena spp., Oolina spp., Parafissurina spp., Nonion spp., Elphidium spp.*). This reduction represents 0-3 % of the whole foraminiferal assemblage.

Bolivina/Brizalina spp. (23-67%), *Cassidulina/Globocassidulina spp.* (3-30%), *Bulimina spp.* (3-16%), *Cibicides spp.* (0.3-19%), *Stainforthia/Fursenkoina spp.* (0-13%), *Nonionella spp.* (0-6%) and *Elphidium/Cribrononion spp.* (0-5%) are the most abundant taxa of the core KSGX 40 (fig. 5).

Bolivina/Brizalina spp. percentage is higher in finer sediments whereas *Cibicides spp.* are more represented in coarser one (richer in sand fraction). Percentage of *Bolivina/Brizalina spp., Stainforthia/Fursenkoina spp.* and *Nonionella spp.* become higher in the muddy intervals. *Cassidulina/Globocassidulina spp., Bulimina spp.* and *Elphidium/Cribrononion spp.* only decreased its percentage in the middle section of the core.

Age depth model of the studied core

Age depth model of the studied core was based on the interpolation of three radiocarbon 2 sigma calibrated ages which provided the following dates: 39-40cm, 1114-950 cal BP; 69-70cm, 2460-2300 cal BP; 134-135 cm, 4440-4240 cal BP. The referred C^{14} datings were corrected for a marine reservoir effect of 400 years (SOARES, 1989). This core records the past ~4.8 ka cal BP.

Benthic foraminiferal proxies

The dysoxic indicator (KAIHO, 1994) contains two kinds of benthic foraminifera. Firstly, taxa more commonly found on continental margins
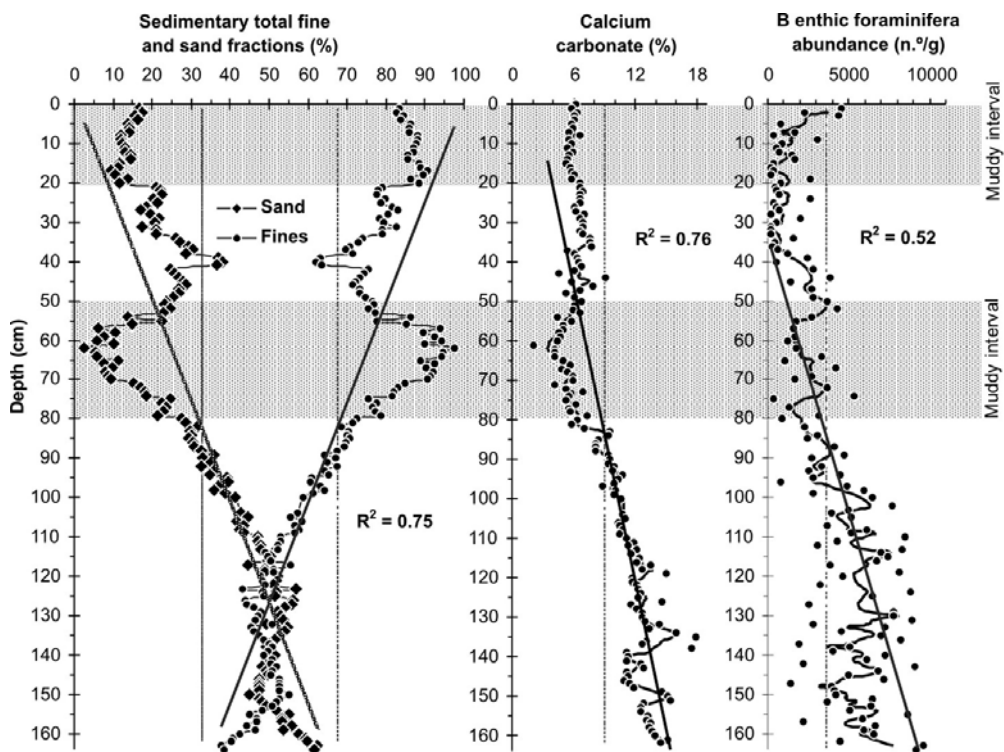
Fig. 2 – Total sedimentary fine and sand fractions, calcium carbonate content and benthic foraminifera abundance (n.°/g of bulk sediment). Smoothed lines (solid curves) between data (marks), the mean value (vertical dashed line) and some trend lines (solid oblique line) with their R2 values are also represented.
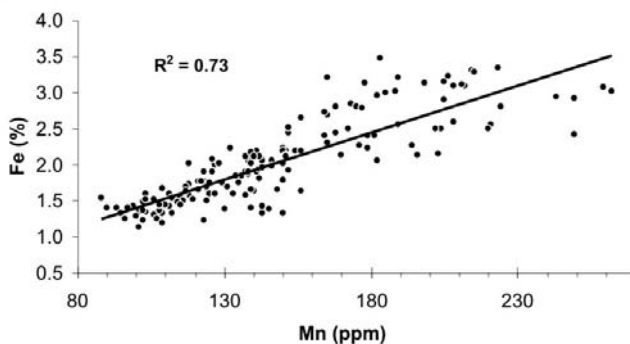

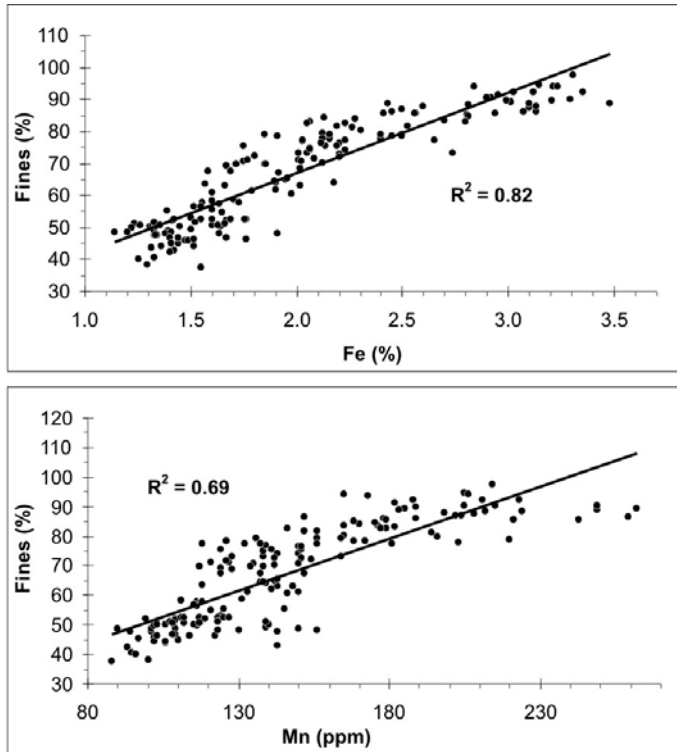Fig. 3 –. The R-squared value between the linear association of Fe and Mn.

Fig. 4 – The R-squared value between the linear association of Fe and Mn with the fine fraction, respectively.

which correspond to high productivity areas (e.g. *Bolivina*, *Bulimina*, *Fursenkoina* and *Globobulimina*); secondly, oxic indicator specimens, which are characterized by thick walls and large test (maximum size ≤350μm), consist of *taxa* commonly observed on the central floors of the deep ocean including seamounts, corresponding to low productivity areas, like *Cibicidoides* having an angular periphery, as well as species of *Nuttallides*, *Osangularia*, *Gavelinella*, *Globocassidulina*, and miliolids among others (KAIHO, 1999). However, smaller species of these latter *taxa* are often reported in low oxygen environments (maximum size ≤350μm) and occur in environments where dissolved oxygen is less than 1.2 ml/l O_2 (KAIHO, 1999). According to KAIHO (1994), the small specimens are not oxic indices but suboxic indices.

The small *taxa* (maximum size ≤350μm) are largely dominant downcore KSGX 40. So, we used

as oxic indicators not the recommended criteria (KAIHO, 1994, 1999), supported by specimens test size, but a subgroup of species with calcareous trochospiral tests, typical of epibenthic microhabitat (SCHÖNFELD, 2002a, b). Some of these species, such as *Cibicides*, are known to be suspension feeders (MURRAY, 1991; HAYWARD *et al.*, 2002), living in elevated habitats (BEAULIEU, 2001), attached to firm substrates (COPPA & DI TUORO, 1995; SCHÖNFELD, 2002a, b). They are favoured by coarse-grained sediments, with low concentrations of organic carbon and by energetic bottom currents (BARMAWIDJAJA *et al.*, 1995; RASMUSSEN *et al.*, 2002) supplying constant suspending detritus but without burying them (BANNER *et al.*, 1994). Some of these species are known to be limited by lower oxygen content. Oxic indicators in the core KSGX 40 comprise *Asterigerinata sp.*, *Asterigerinata mamila*, *Cibicides spp.*, *Discorbis spp.*,
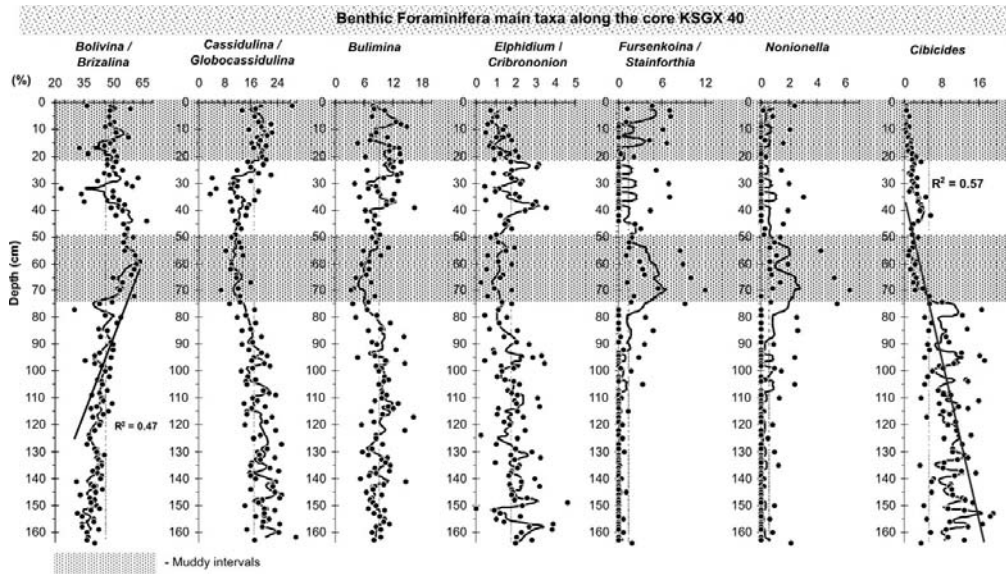
Fig. 5 – Depth profile of the most abundant genera of benthic foraminifera along the core KSGX 40. Smoothed lines (solid curves) between data (marks), the mean value (vertical dashed line) and some trend lines (solid oblique line) with their R2 values are also represented.

Dyocibicides biserialis, Elphidium spp., Eoeponidella pulchella, Gavelinopsis praegeri, Glabratella chasteri, Glabratella sp., Hanzawaia nitidula, Lamarckina haliotidea, Lepidodeuterammina ochracea, Lobatula lobatula, Neoconorbina parkerae, Patellina corrugata, Planorbulina mediterranensis, Remaneica helgolandica, Rosalina sp., Spiroplectinella sagittula, Trochammina spp. The separation of this sub-group is also based on previous works cited in appendix B. In spite of the diversity of this sub-group, most of these species are rare, only were found in some samples and have small size. In fact, the proxy of low organic carbon and high oxygen flux is ruled mainly by *Cibicides* relative abundance (*C. ungerianus*) which is an epifaunal species and an oxic indicator (e.g. KAIHO, 1994; MURRAY & ALVE, 1994; Den DULK *et al.*, 1998; RASMUSSEN *et al.*, 2002). They are the largest exemplars of benthic foraminifera in the core, with their higher abundances coincident with the coarser-grained sediments (164-80cm). So, the oxic sub-group as a whole has a high and significant Pearson correlation with the sedimentary sand fraction (0.82, *p<0.05000*) and could represent better ventilated bottom water conditions.

Most of the species included in the BFHP are related to decreasing oxygen levels in bottom waters and/or in sediment pore-waters. Besides, some of them, *e.g. Nonionella turgida, Epistominella vitrea* and *Eggerella spp.*, could be affected by stressful conditions associated with eutrophication and very depressed levels of oxygen (DUIJNSTEE *et al.*, 2004). Species of *Cassidulina*, for example, which are considered to primarily respond to both episodic food supply and current flow providing more sustained lateral input of organic matter from coastal upwelling, occurs beneath well oxygenated waters (HAYWARD *et al.*, 2002). We presume that some of these species development could have been conditioned in periods of increasing frequency of dysoxic or anoxic events.

Bolivinids and buliminids are generally seen as dysoxic indicators (*e.g.* PHLEGER & SOUTAR, 1973; SEN GUPTA & MACHAIN-CASTILLO, 1993; BERNHARD *et al.*, 1997; KAIHO, 1999), although the several species of *Bolivina/Brizalina* and *Bulimina* have different distribution patterns down-core KSGX 40.

Some bolivinids and buliminids of the site

should also have been negatively affected during periods of higher formation of H_2S in combination with anoxic conditions. Species have different abilities in their opportunistic strategy of life. Some species should loose in competition under more adverse conditions. However, the influence of biological parameters, such as competition and predation, are difficult to assess as observed by JÖRISSEN *et al.* (1995). Consequently, only species of benthic foraminifera abundant in intervals of fine-grained sediments and with higher concentrations of redox sensitive elements were chosen as indexes of lower oxic indicators and of more stressful environmental conditions. In the computation of the BFOI: the total percentage of *Bolivina ordinaria, Brizalina pacifica, Bulimina aculeata, Bulimina marginata, Buliminella tenuata, Chilostomella oolina, Chilostomella ovoidea, Fursenkoina loeblichi, Globobulimina spp., Nonionella spp.* and *Stainforthia spp.* (see the references of appendix B) were used as dysoxic indicators.

The BFHP and BFOI determined core KSGX 40 were plotted with sediment mean grain size, Fe and Mn content versus the depth age calibrated (cal) before present (BP) (fig. 6). Lower values of BFHP and higher values of BFOI were found at ~4.8 ka cal BP (in the core base). Whereas the BFOI curve shows a noticeably up-ward decreasing pattern with lower values after ~2.2 ka cal BP (in section 75-0cm), indicating more depressed levels of dissolved oxygen, the BFHP has an inverse pattern. This means that the percentage of all species related to high values of C_{org} increased as far as the BFOI index values decreased. This relation is expressed by the R^2 value (0.87) (see fig. 7 plot). Whereas the BFHP has positive correlations with Fe and Mn, BFOI has negative ones with these elements (fig. 8).

Higher values of Fe, Mn and BFHP and lower values of BFOI index, coupled with a finer sedimentation agrees with the control of C_{org} flux and sediments texture in the evolution of dissolved oxygen levels and in the immobilization of these elements, in the studied site during the Late Holocene.

DISCUSSION

Values of BFHP and BFOI were controlled mainly by the progressive predominance of bolivinid species which are in general opportunistic and shallow infaunal species and tolerant to low oxygen conditions (JÖRISSEN, 1999). The phytodetritus rainfall towards the sea floor in the site studied comprised probably the most important seasonal food source for benthic foraminifera communities.

Organic matter-rich sediments are related to periods of higher productivity and/or higher lateral supply of organic matter and/or higher organic C preservation in low-oxygen waters, due to a more intense and expanded oxygen minimum zone or to low-oxygen bottom waters (KASTNER, 1999) as far as the sediment became finer mainly in the last ~2.2 ka cal BP. The high decaying of organic matter to the bottom (food) could have developed a rich benthic fauna during the periods of higher dissolved oxygen levels in bottom water and in sedimentary pore-waters that is expressed by the higher values of benthic foraminifera abundance (n.º/g) before ~2.2 ka cal BP. However, after this age, coupling with a finer sedimentation, the supply of organic matter should have been much higher, mainly during the muddy intervals, between ~2.2-1.2 ka cal BP and ~0.5-0.1 ka cal BP.

During these periods the high consumption of oxygen by aerobic organisms could result in benthic dysoxia or even anoxia (e.g. JUSTIC *et al.*, 1987; JUSTIC, 1991a,b) if the flux of settling organic matter exceeds the flux of oxygen into the sediments. The redoxcline (defined here as the depth of zero oxygen content in pore-water) should have been established at a shallow depth in the sediments (O_2 -limiting conditions; EMERSON *et al.*, 1985). The presence of pyrite in the sediments of the core studied is a sign of such anoxic conditions (NEUMANN *et al.* 1997; BURKE & KEMP, 2002).

As observed by MURRAY (2001), the redox boundary in muddy sediments is normally within a few centimetres beneath the sea floor even in those environments where the overlying bottom water is well oxygenated. Thus, all muddy environments potentially have oxygen-limited deeper infaunal taxa even though these taxa may live only a few millimetres or centimetres away from the surface, where the shallow infaunal and epifaunal taxa have an ample supply of oxygen. Thus, the dead assemblages in muddy sediments consist of a mixture of oxic and low oxic species. This is the case of core KSGX 40,
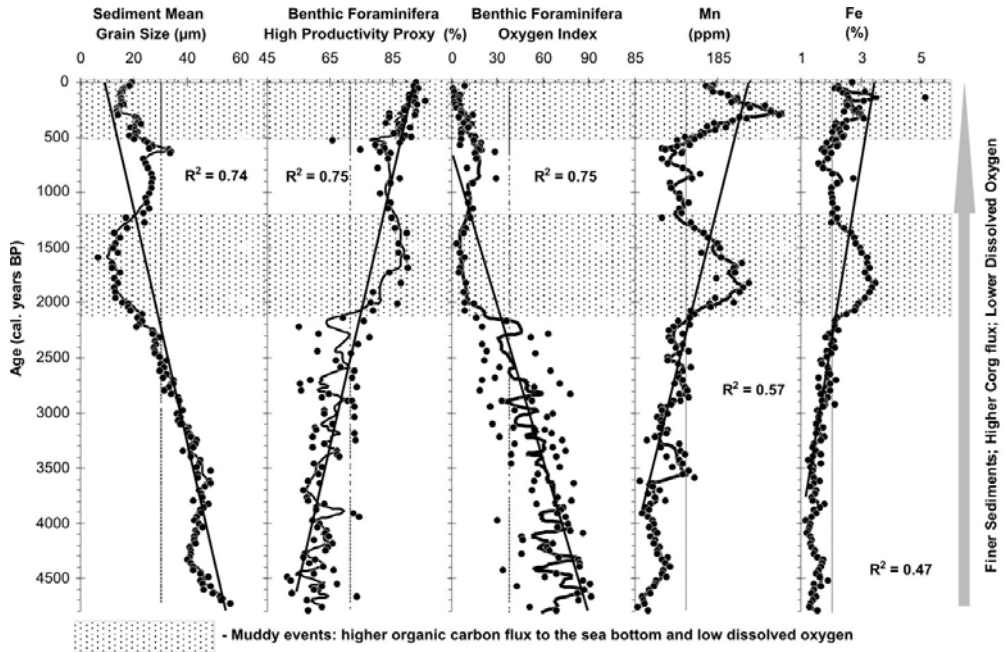
Fig. 6 – Age-depth profile of sediment mean grain size, BFHP, BFOI and Fe and Mn determined in the core KSGX 40. Smoothed lines (solid curves) between data (marks), the mean value (vertical dashed line) and some trend lines (solid oblique line) with their R2 values are also represented.
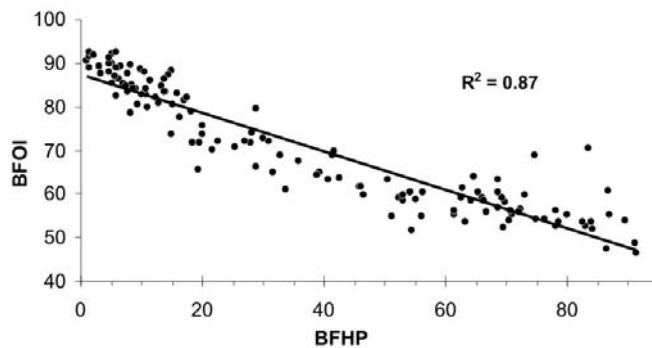

Fig. 7 – R-squared regression coefficient, R2 value, between the linear association of BFHP and BFOI.
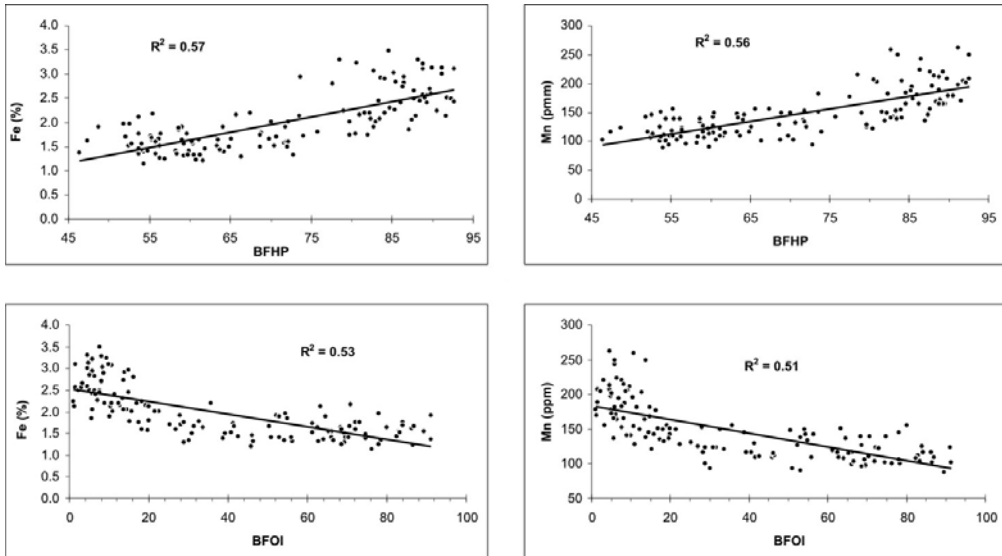
Fig. 8 – R-squared regression coefficient, R2 value, between Fe and Mn in linear association with BFHP and BFOI.

in which there are oxic and dysoxic benthic foraminiferal species everywhere, but in a very small number in the upper section of the core (70-0cm). So, we can suggest that the negative impact of frequent dysoxic/anoxic events in the benthic environment could have led to the impoverishment of foraminiferal fauna, in the upper section of the core (70-0cm), leading to a drastic decrease of benthic foraminifera abundance because of the decline of low oxic intolerant species. This fact has a significant expression in calcium carbonate values, which declined significantly after ~2.2 ka cal BP. Since then, more reducing conditions developed in the benthic environment.

Manganese responds to such reducing conditions developed in sediments by C_{org} remineralization (CALVERT & PEDERSEN, 1993). Like Mn, Fe reduction can be mediated by bacterial activity involved in organic matter remineralization (FROELICH *et al.*, 1979). So, Fe and Mn should be sequestered in a sulfide phase in the sediments of Galicia Mud Deposit. But while Mn^{2+} is soluble in anoxic and sulfidic waters (KREMLING, 1983; DYRSSEN & KREMLING, 1990) and is present as a detrital phase and as an authigenetic oxyhydroxide phases in oxic sediments (MERCONE *et al.*, 2001),

Fe^{2+} reacts quickly with excess free HS-, in anoxic conditions, to form particulate Fe-sulfides (NEUMANN *et al.*, 1997; BURKE & KEMP, 2002). Sediments beneath high productivity regions in continental margins with moderate sedimentation rates and burial of reactive organic matter, bacterial nitrate, Fe^{3+}, and sulfate reduction occur, and reactive Fe^{3+} is bacterially reduced to Fe^{2+}, setting in motion the Fe-redox cycling (KASTNER, 1999).

According to MOODLEY *et al.* (1998a,b) the formation of H_2S in combination with anoxic conditions may be a limiting factor to benthic foraminifera survival. Changing in benthic foraminifera assemblage and abundance along the studied core can also be related to this limiting factor, where the production of H_2S in sedimentary environment is indicated by the presence of pyrite nodules and of pyrite-filled foraminiferal tests in sand fraction. Sulfur enrichment in organic-rich marine sediments is mainly developed after deposition by the formation of FeS_2 (pyrite) following anoxic sulfidic remineralization of sedimentary C_{org} by SO_4^{-2} (BERNER, 1984):

$$C_{106}H_{263}O_{110}N_{16}P + 53SO_4^{2-} \rightarrow 106\,CO_2 + 16$$

$NH_3 + H_3PO_4 + 53\ S^{-2} + 106\ H_2O$.
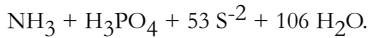
The production route to FeS_2 formation in sediments is complex, but is believed to occur through the progressive reaction of polysulfides or S(0) with precursor Fe monosulfides formed from Fe^{2+} in the sediments or pore-waters, in the sequence mackinawite $(Fe_9S_8) \rightarrow$ greigite $(Fe_3S_4) \rightarrow$ pyrite (WILKIN & BAMES, 1996). Pyrite forms where sulfate is bacterially reduced (KASTNER, 1999). In these environments Fe^{+3} is reduced and mobilized, reacting with the sulfide to form pyrite (BERNER, 1984; KASTNER, 1999). The foraminifera provide open space for colonization and local nutrients for bacterial growth, whereas the cell walls of the bacteria may provide a local nucleation site for sulfides (KOHN *et al.*, 1998). The abundance in faecal pellets and organic matter aggregates probably led to the same kind of processes.

Fe-redox cycling can occur in the uppermost sediment column close to the sediment-seawater interface. Below this zone, sulfide produced by bacterial sulfate reduction combines with the bacterially mobilized ferrous ion, which precipitates mostly as pyrite, but occasionally first as greigite, because of kinetic constraints (KASTNER, 1999), as was referred. So, the presence of pyrite (FeS_2) in sand fraction also suggests the occurrence of anoxic and sulfide conditions in under-superficial sedimentary layers and/or nucleus at/or beneath the sediments surface (NEUMANN *et al.*, 1997; Den DULK *et al.*, 2000; BURKE & KEMP, 2002) in the studied site.

In the Galicia Mud Deposit the periods characterized by the deposition of coarser substrate allowed a deeper O_2 penetration and determined lower authigenetic/diagenetic changes related to O_2-limiting conditions. But during the two muddy events, between ~2.2-1.2 ka cal BP and ~0.5-0.1 ka cal BP, organic matter remineralization resulted in higher authigenetic/diagenetic changes controlling the sequestration of Fe and Mn in sediments. This behaviour is expressed by the higest correlation between Fe, Mn, the BFHP and the BFOI in core KSGX 40.

CONCLUSIONS

More oxic and more oligotrophic conditions could have prevailed in the site area at ~4.8 ka cal BP ago during the late Holocene Sub-Boreal chronozone. This situation changed progressively to more eutrophic conditions in the last ~3 ka cal BP, during the Sub-Atlantic chronozone.

Such early advantageous settings, due to the abundance of food in an oxic environment, at ~4.8 ka cal BP ago, promoted the growth of a rich and diversified benthic fauna. However, the increasing consumption of oxygen by aerobic fauna and organic matter remineralization processes since then, did led to the development of sulfide conditions. Sediments also became finer making oxygen renewal more difficult. Such limiting factors limited the growth of benthic foraminiferal assemblages by selecting the more resistant species.

Two long-term periods of low oxygen events in sediment pore-water and probably in the bottom water coupled with higher productivity events probably led to higher supply of C_{org} to the Galicia Mud Deposit between ~2.2-1.2 ka cal BP and between ~0.5-0.1 ka cal BP. This higher flux of C_{org} enhanced the occurrence of authigenetic/diagenetic processes, as was suggested by the BFOI, Fe and Mn values.

ACKNOWLEDGEMENTS

Species	Max	Min	Species	Max	Min
Ammonia beccarii (Linné, 1758)	7.0	0.0	*Eggerelloides scaber* (Williamson, 1858)	0.9	0.0
Amphicoryna scalaris (Batsch, 1791)	0.8	0.0	*Elphidium complanatum* (d'Orbigny, 1839)	0.6	0.0
Bolivina albatrossi Cushman, 1922	0.5	0.0	*Elphidium discoidale* (d'Orbigny, 1839)	1.6	0.0
Bolivina compacta Sidebottom, 1905	2.5	0.0	*Elphidium earlandi* Cushman, 1936	0.5	0.0
Bolivina difformis (Williamson, 1858)	6.9	0.0	*Elphidium jenseni* (Cushman, 1963)	0.6	0.0
Bolivina dilatata Reuss, 1850	4.8	0.0	*Elphidium pulvereum* Todd, 1958	0.6	0.0
Bolivina ordinaria Pheleger & Parker, 1952	33.4	0.4	*Elphidium* spp.	1.1	0.0
Bolivina pseudoplicata Heron-Allen & Earland, 1930	20.4	0.0	*Eoeponidella pulchella* (Parker, 1952)	0.5	0.0
Bolivina pygmaea Brady, 1881	1.5	0.0	*Epistominella cassidulinoides* Hornibrook, 1961	1.0	0.0
Bolivina robusta Brady, 1881	2.7	0.0	*Epistominella vitrea* Parker, 1953	5.7	0.0
Bolivina seminuda Cushman, 1911	9.8	0.0	*Fissurina annectens* (Burrows & Holland, 1895)	1.2	0.0
Bolivina skagerrakensis Qvale & Nigam, 1985	7.7	0.0	*Fissurina globosocaudata* Albani & Yassini, 1989	0.9	0.0
Bolivina spp.	2.2	0.0	*Fissurina lucida* (Williamson, 1884)	0.8	0.0
Bolivina striatula Cushman, 1922	0.9	0.0	*Fissurina marginata* (Montagu, 1803)	1.6	0.0
Brizalina pacifica (Cushman & McCulloch, 1942)	17.2	0.0	*Fissurina orbignyana* Seguenza, 1862	1.2	0.0
Brizalina spathulata (Williamson, 1858)	35.7	1.0	*Fissurina semimarginata* (Reuss, 1870)	0.8	0.0
Brizalina subaenariensis (Cushman, 1922)	4.4	0.0	*Fissurina* spp.	2.4	0.0
Bulimina aculeata d'Orbigny, 1826	1.5	0.0	*Frondicularia sp.*	0.5	0.0
Bulimina alazanensis Cushman, 1927	5.9	0.0	*Fursenkoina loeblichi* (Feyling-Hanssen, 1954)	7.0	0.0
Bulimina elongata d'Orbigny, 1846/ *B. gibba* Fornasini, 1902	10.5	0.0	*Galwayella trigonoelliptica* (Balkwill & Millett, 1884)	0.7	0.0
Bulimina exilis (Brady, 1884)	0.7	0.0	*Gavelinopsis sp.*	2.9	0.0
Bulimina marginata d'Orbigny, 1826	8.7	0.0	*Gavelinopsis praegeri* Heron-Allen & Earland, 1913	10.6	0.0
Bulimina spp.	2.2	0.0	*Glabratella chasteri* (Heron-Allen & Earland, 1913)	0.6	0.0
Buliminella tenuata (Cushman, 1927)	3.8	0.0	*Glabratella sp.*	0.5	0.0
Cancris auriculus (Fichtel & Moll, 1798)	1.8	0.0	*Globobulimina* spp.	2.5	0.0
Cassidulina crassa (d'Orbigny, 1839)	6.4	0.0	*Globocassidulina rossensis* (Kennett, 1967)	3.5	0.0
Cassidulina laevigata d'Orbigny, 1826 + *C. carinata* (Silvestri, 1896)	26.1	0.9	*Globocassidulina subglobosa* (Brady, 1881)	5.4	0.0
Cassidulina minuta Cushman, 1933	12.2	0.0	*Gyroidina umbonata* (Silvestri, 1898)	1.7	0.0
Cassidulina spp.	0.7	0.0	*Hanzawaia nitidula* (Bandy, 1953)	2.8	0.0
Cassidulina teretis Tappan, 1951	3.9	0.0	*Hoeglundina elegans* (d'Orbigny, 1826)	2.2	0.0
Cassidulinoides bradyi (Norman, 1881)	0.9	0.0	*Hyalinea balthica* (Schroeter, 1783)	10.9	0.0
Chilostomella ovoidea Reuss, 1850	1.2	0.0	*Lagena* spp.	0.9	0.0
Cibicides refulgens Montfort, 1808	0.5	0.0	*Lagena substriata* Williamson, 1848	0.6	0.0
Cibicides ungerianus (d'Orbigny, 1846)	19.1	0.3	*Lamarckina haliotidea* (Heron-Allen & Earland, 1911)	0.9	0.0
Cibicides variabilis (d'Orbigny, 1826)	1.7	0.0	*Laryngosigma cf. L. hyalascidia* Loeblich & Tappan, 1953	0.5	0.0
Cribrononion gerthi (van Voorthuysen 1957)	4.2	0.0	*Lenticulina* spp.	1.3	0.0
Discorbis spp.	0.7	0.0	*Lobatula lobatula* (Walker & Jacob, 1798)	2.2	0.0
Discorbis williamsoni s. l. Chapman & Parr 1932	0.7	0.0	*Marginulina sp.*	0.5	0.0

Species	Max	Min	Species	Max	Min
Melonis barleeanum (Williamson, 1858)	1.1	0.0	Quinqueloculina stelligera Schlumberger, 1893	1.0	0.0
Melonis spp.	0.5	0.0	Rectuvigerina phlegeri Le Calvez, 1959	3.6	0.0
Neoconorbina parkerae (Natland, 1950)	1.9	0.0	Remaneica helgolandica Rhumbler, 1938	0.5	0.0
Nonion spp.	0.5	0.0	Sagrina subspinescens (Cushman, 1922)	3.9	0.0
Nonionella bradii (Chapman, 1916)	1.6	0.0	Spiroplectinella sagittula Defrance, 1824	0.7	0.0
Nonionella iridea Heron-Allen & Earland, 1932	1.7	0.0	Stainforthia complanata (Egger, 1895)	3.6	0.0
Nonionella spp.	0.7	0.0	Stainforthia feylingi Knudsen & Seidenkrantz, 1993	2.0	0.0
Nonionella stella (Cushman & Moyer, 1930)	4.3	0.0	Stainforthia fusiformis (Williamson, 1858)	8.2	0.0
Nonionella turgida (Williamson, 1858)	1.1	0.0	Textularia conica d' Orbigny, 1840	1.3	0.0
Nonionoides clavatus (Cushman, 1931)	0.6	0.0	Textularia deltoidea Reuss, 1850	1.8	0.0
Oolina spp.	0.7	0.0	Textularia spp.	0.5	0.0
Palliolatella bradyiformis (McCulloch, 1977)	0.9	0.0	Trifarina angulosa (Williamson, 1858)	2.2	0.0
Parafissurina spp.	0.5	0.0	Trochammina sp.	1.5	0.0
Paumotua terebra (Cushman, 1933)	0.7	0.0	Uvigerina peregrina Cushman, 1923	6.4	0.0
Planorbulina mediterranensis d' Orbigny, 1826	0.9	0.0	Vaginulina patens Brady, 1884	1.5	0.0
Quinqueloculina akneriana d' Orbigny, 1846	1.3	0.0	Valvulineria bradyana (Fornasini, 1900)	17.6	0.0
Quinqueloculina spp.	0.7	0.0			

Appendix A
List of taxa and its maximum and minimum percentage along the core KSGX 40
Taxonomy of the most relevant species was described in MARTINS & GOMES (2004).
Taxonomic references for genera and families are given in LOEBLICH & TAPPAN (1988).

Taxa	References
Bolivina difformis	FONTANIER *et al.*, 2003
Bolivina dilatata	ROSS & KENNETT, 1984; ALAVI, 1988; SCHMIEDL *et al.*, 1997; CITA & PODENZANI, 1980
Bolivina ordinaria	HERMELIN & SHIMIELD, 1990; AHARON *et al.*, 2001; this species is frequently refereed as *B. variabilis* in European studies.
Bolivina pygmaea	Den DULK *et al.*, 1998
Bolivina robusta	JIAN *et al.*, 1999
Bolivina seminuda	PHLEGER & SOUTAR, 1973; ALVE & BERNHARD, 1995; BARMAWIDJAJA *et al.*, 1995; ERNST, 2002; GORBARENKO *et al.*, 2002
Bolivina striatula	LUTZE & COULBOURN, 1984
Bolivinids	*Bolivina* as well as *Brizalina* are known to survive in oxygen-deficient environments (CITA & PODENZANI 1980; MULLINEAUX & LOHMANN, 1981; QUINTERNO & GARDNER, 1987; ALAVI, 1988; MACKENSEN *et al.*, 1990; ROSS & KENETT, 1984; PEREZ-CRUZ & MACHAIN CASTILLO, 1990; MURRAY, 1991; MIAO & THUNELL, 1993; SEN GUPTA & MACHAIN-CASTILLO, 1993; RATHBURN & SEN GUPTA, 1994; BERNHARD & SEN GUPTA, 1999). Their flattened elongate morphology is considered to be an adaptation to the low-oxygen conditions (BERNHARD, 1986). <u>Note</u>: in this sub-group were also integrated *Bolivina albatrossi, Bolivina compacta* and *Bolivina pseudoplicata* and not only the species included in this table.
Brizalina pacifica	KITAZATO *et al.*, 2000; ALTENBACH *et al.*, 2003
Brizalina spathulata	BREMER, 1983; ALAVI, 1988; FONTANIER *et al.*, 2003
Brizalina subaenariensis	PHLEGER & SOUTAR, 1973; LUTZE & COULBOURN, 1984
Bulimina aculeata	OLAUSSON, 1960; ALAVI, 1988; MACKENSEN *et al.*, 1990; WELLS *et al.*, 1994; MIAO & THUNELL, 1996; ALMOGI-LABIN *et al.*, 2000; JIAN *et al.*, 1999;
Bulimina elongata/gibba	DONNICI & BARBERO, 2002
Bulimina exilis	CARALP, 1984, 1989; JONKERS 1984; JANNINK *et al.*, 1998
Bulimina marginata	ALAVI, 1988; PHLEGER & SOUTAR, 1973; LUTZE & COULBOURN, 1984; Van der ZWAAN & JÖRISSEN 1991; DONNICI & BARBERO, 2002
Buliminella tenuata	DOUGLAS & HEITMAN, 1979; GOODAY, 1993; SILVA *et al.* 1996
Buliminids	CITA & PODENZANI, 1980; ALAVI, 1988; MACKENSEN *et al.*, 1990; MIAO & THUNELL, 1993
Cassidulina laevigata/ C. carinata	GUPTA, 1997; De STIGTER *et al.*, 1998; ALMOGI-LABIN *et al.*, 2000; FONTANIER *et al.*, 2003; RIJK *et al.*, 2000
Cassidulina teretis	GOODAY & LAMBSHEAD, 1989; ALTENBACH, 1992; SARNTHEIN & ALTENBACK, 1995
Eggerella like species	DUIJNSTEE *et al.*, 2004; including *Eggerella bradyi* and *Eggerelloides scaber*
Epistominella vitrea	GOODAY, 1988; HEINZ *et al.*, 2002;
Fursenkoina spp.	LEUTENEGGER & HANSEN 1979; GOODAY, 1993; KAIHO 1994; 1999; OHGA & KITAZATO, 1997; including *Fursenkoina loeblichi.*
Globobulimina spp.	Den DULK *et al.*, 1998; KAIHO 1994; 1999; JIAN *et al.*, 1999, CORLISS, 1985, 1991
Nonionella spp.	DONNICI & BARBERO, 2002
Nonionella iridea	MACKENSEN *et al.*, 1990; ISHMAN & DOMACK, 1994; GOODAY & HUGHES, 2002
Nonionella stella	PHLEGER & SOUTAR, 1973; GOODAY, 1993; SILVA *et al.* 1996
Nonionella turgida	JÖRISSEN, 1987; CORLISS & EMERSON, 1990; Van der ZWAAN & JÖRISSEN, 1991; ALVE & BERNHARD, 1995; BARMAWIDJAJA *et al.*, 1995; DUIJNSTEE *et al.*, 2004
Rectuvigerina phlegeri	DEBENAY & KONATE, 1987; ALAVI, 1988
Stainforthia spp.	LEUTENEGGER & HANSEN 1979; GOODAY, 1993; ALVE, 1994; OHGA & KITAZATO, 1997
Stainforthia feylingi	KNUDSEN & SEIDENKRANTZ, 1994
Stainforthia fusiformis	ALVE, 1990, 1994, 1995; ALVE & BERNHARD, 1995; ALVE & MURRAY, 1995, 1997; MURRAY, 1995; BARMAWIDJAJA *et al.*, 1995; ERNST, 2002.
Trochammina spp.	FONTANIER *et al.*, 2003
Uvigerina peregrina	MILLER & LOHMANN, 1982; LUTZE & COULBOURN, 1984; DEBENAY & KONATE, 1987; ALTENBACH, 1988; HERMELIN & SHIMMIELD, 1990; Van der ZWAAN & JORISSEN, 1991; RATHBURN & CORLISS, 1994; LOUBERE, 1996; MIAO & THUNELL, 1996; RIJK *et al.*, 1999, 2000; ALTENBACH *et al.*, 2003; FONTANIER *et al.* 2003; JIAN *et al.* (1999)
Valvulineria bradyana	ALAVI, 1988; Van der ZWAAN & JÖRISSEN, 1991; JÖRISSEN, 1987.

Taxa	References
Asterigerinata spp.	MURRAY (1991). **Note**: including *Asterigerinata mamila*
Cibicides spp.	MURRAY 1991; KAIHO, 1994; MURRAY & ALVE, 1994; SCHÖNFELD, 1997, 2002 a, b; BEAULIEU, 2001; RASMUSSEN *et al.*, 2002; Den DULK *et al.*, 1998
C. ungerianus	BARMAWIDJAJA *et al.*, 1995; ALTENBACH *et al.*, 2003
C. gerthi	MURRAY, 1991; BARMAWIDJAJA *et al.*, 1995; SCHÖNFELD, 1997; ALTENBACH *et al.*, 2003
Discorbis spp.	MURRAY, 1991; GERAGA *et al.*, 2000
Elphidium spp.	like *E. macellum var. aculeatum*, *E. crispum*, *E. fichtellianum*, in this work *E. jenseni*; MURRAY, 1991 (keeled *Elphidium spp.*); LANGER *et al.*, 1989; SAFFERT & THOMAS, 1998; GERAGA *et al.*, 2000
Gavelinopsis praegeri	MURRAY, 1991; BARMAWIDJAJA *et al.*, 1995; SCHÖNFELD, 1997; ALTENBACH *et al.*, 2003
Glabratella spp.	MURRAY, 1991
G. subglobosa	ALTENBACH, 1992; LINKE & LUTZE, 1993
Hanzawaia nitidula	(as *H. concentrica*), BARMAWIDJAJA *et al.*, 1995; SCHÖNFELD, 1997; ALTENBACH *et al.*, 2003
Hyalinea balthica	GERAGA *et al.*, 2000
Lepidodeuterammina ochracea	SCHÖNFELD, 2002 a, b (as *Deuterammina ochracea*)
Lobatula lobatula	(identified frequently as *Cibicides lobatulus*) CORLISS, 1991; LIPPS, 1983; WILLIAMSON, 1985; MATHIEU, 1986; SCHRÖDER-ADAMS *et al.*, 1990; BANNER *et al.*, 1994; SCHÖNFELD 2002 a, b
Paumotua terebra	De STIGTER *et al.*, 1998 (as *Eponides* sp. 1)
Planorbulina mediterranensis	MURRAY, 1971; COPPA & DI TUORO, 1995
Quinqueloculina spp.	BARMAWIDJAJA *et al.* 1992; KAIHO, 1994; Den DULK *et al.*, 1998; GERAGA *et al.*, 2000
Spiroplectinella sagittula	SCHÖNFELD, 2002 a, b
T. angulosa	SEJRUP *et al.*, 1981; JÖRISSEN, 1987; SCHRÖDER-ADAMS *et al.*, 1990; ALTENBACH, 1992; LINKE & LUTZE, 1993; RATHBURN & CORLISS, 1994; De STIGTER *et al.*, 1998; MACKENSEN *et al.*, 1985, 1990; 1995; SCHÖNFELD, 2002 b
Textularia spp.	SCHÖNFELD, 1997; GERAGA *et al.*, 2000; ALTENBACH *et al.*, 2003
Trochammina ssp.	SCHÖNFELD, 2002 a, b

Appendix B
Benthic foraminifera high productivity proxy

Appendix B (cont.)
Well oxygenated bottom waters/low concentrations of organic carbon indicators
Note: some species this sub-group were separated on the basis of morphological criteria (e.g., Corliss & Chen, 1988; Murray, 1991); because planoconvex taxa are considered to be epifaunal, whereas biconvex or more elongate taxa are considered as shallow infaunal. So in well oxygenated bottom waters were also include other planoconvex species like: Eoeponidella pulchella, Lamarckina haliotidea, Neoconorbina parkerae, Patellina corrugata, Remaneica helgolandica, Rosalina sp.

Taxa	References
Bolivina ordinaria	HERMELIN & SHIMMIELD, 1990; AHARON *et al.*, 2001
Brizalina pacifica	DOUGLAS & HEITMAN, 1979
B. subaenariensis	PUJOS-LAMY (1973)
Bulimina aculeata	MACKENSEN *et al.*, 2000
Bulimina marginata	ALVE, 1990; Van der ZWAAN & JÖRISSEN, 1991; ROHLING *et al.*, 1993; ALVE & BERNHARD, 1995; ERNST, 2002
Buliminella tenuata	HARMAN, 1964; DOUGLAS & HEITMAN, 1979; BERNHARD, 1986; QUINTERNO & GARDNER, 1987; BERNHARD & SEN GUPTA, 1999
Chilostomella spp.	MULLINEAUX & LOHMANN, 1981; ALAVI, 1988; BERNHARD & SEN GUPTA, 1999; RIJK *et al.*, 1999
Chilostomella oolina	SEN GUPTA & MACHAIN-CASTILLO, 1993; BERNHARD *et al.*, 1997; Den DULK *et al.*, 1998
Chilostomella ovoidea	JIAN *et al.*, 1999
Fursenkoina spp.	LEUTENEGGER & HANSEN 1979; KAIHO 1994; 1999; JÖRISSEN, 1999; HOLBOURN *et al.*, 2001; including *Fursenkoina loeblich*
Globobulimina spp.	MULLINEAUX & LOHMANN, 1981; MILLER & LOHMANN, 1982; WILLIAMSON *et al.*, 1984; CORLISS, 1985; 1991; MOODLEY & HESS, 1992; BERNHARD, 1993; SEN GUPTA & MACHAIN-CASTILLO, 1993; KAIHO 1994; 1999; RIJK *et al.*, 1999; GOODAY *et al.*, 2001
Nonionella spp.	BARMAWIDJAJA *et al.*, 1992; HOHENEGGER *et al.*, 1993; RATHBURN *et al.*, 2001
Nonionella stella	PHLEGER & SOUTAR, 1973; BERNHARD & REIMERS, 1991; MOODLEY *et al.*, 1997; BERNHARD & SEN GUPTA, 1999; BERNHARD & BOWSER, 1999; Van der ZWAAN *et al.*, 1999
Stainforthia spp.	LEUTENEGGER & HANSEN 1979; JÖRISSEN, 1999
Stainforthia complanata	KAIHO 1994; 1999 (as *Fursenkoina*)
Stainforthia feylingi	KNUDSEN & SEIDENKRANTZ, 1994
Stainforthia fusiformis	ALVE, 1990, 1994; MURRAY, 1995; ALVE & MURRAY, 1997; MOODLEY *et al.*, 1997; BERNHARD & SEN GUPTA, 1999; Van der ZWAAN *et al.*, 1999.

Dysoxic Indicators

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