VIII Congresso Ibérico
de Geoquímica
XVII Semana
de Geoquímica

Nd ISOTOPE COMPOSITION OF THE TERRIGENOUS COMPONENT OF SEDIMENTS AS A TRACER FOR THE HEINRICH EVENTS: A STUDY IN THE NW IBERIAN CONTINENTAL MARGIN

COMPOSIÇÃO ISOTÓPICA DE Nd NA COMPONENTE TERRÍGENA DE SEDIMENTOS COMO MARCADOR DE EVENTOS DE HEINRICH: ESTUDO DE UM CASO NA MARGEM CONTINENTAL NW IBÉRICA

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Abstract

The OMEX core KC 024-19 was studied aiming at to assess the influence of climate changes on the origin and transport of the sediments of the Galician continental slope, in the last 40 ka. The results show that sea level variation played a major role in the supply of the terrigenous sediments coming from the nearby continental areas, whose basement has a Variscan age. Additionally, coarse-grained clastic materials, corresponding to ice-rafted debris (IRD), were deposited through melting of icebergs during the Heinrich events (HE), in the last glaciation. The last four HE were identified in the core. The measured Nd isotope ratios reveal that there was a strong contribution of continental crustal sources significantly older than the Variscan basement for HE 1, 2 and 4. The most likely provenance of the coarse clasts deposited during these three events lie in NE America or Greenland, and the carrier icebergs should be fragments of the Laurentide Ice Sheet. In contrast, the HE 3 layer displays ε_{Nd} values in the range of the compositions of the most common sediments in the core and, therefore, its IRD should have European source(s), which supports previous results obtained in other places of the European Atlantic margin.

Keywords: Galician continental slope, last glaciation, Heinrich events, Nd isotope ratios, sediment sources.

Resumo

O *core* OMEX KC 024-19 foi estudado tendo em vista avaliar o papel das mudanças climáticas nos processos de transporte e nas fontes de sedimentos depositados no talude continental da Galiza, durante os últimos 40 ka. Os resultados obtidos, usando diferentes metodologias, apontam para uma grande influência das mudanças do nível do mar no fornecimento de sedimentos terrígenos a partir das áreas continentais próximas, cujo soco é de idade varisca. Para além disso, nos eventos de Heinrich (HE), ocorridos durante a última glaciação, foram recebidos nesta área materiais detríticos grosseiros transportados por icebergues em fusão (IRD). Foram identificados, neste *core*, os quatro últimos HE. As razões isotópicas de Nd revelam que durante os HE 1, 2 e 4 houve contribuição importante de fontes de crusta continental significativamente mais antiga do que a ibérica. A origem provável dos IRD desses três eventos estará no NE da América ou na Gronelândia, podendo os icebergues que os transportaram ter origem na LIS (*Laurentide Ice Sheet*). Já o HE 3, não se distingue, em termos de ε_{Nd}, dos sedimentos mais comuns no *core*, pelo que os IRD correspondentes deverão ter origem europeia, o que corrobora resultados obtidos noutros locais da margem atlântica europeia.

Palavras-chave: talude continental da Galiza, última glaciação, eventos de Heinrich, razões isotópicas de Nd, fontes dos sedimentos.

1. Introduction

The study area is located in the Galicia Interior Basin, i.e. in the Galician continental slope, near the Galicia Bank (Fig. 1). The Galicia Interior Basin is limited in the east by a narrow continental shelf (30–50 km wide) with the shelf break well-marked at water depths of 160-180 m (Dias et al., 2002).

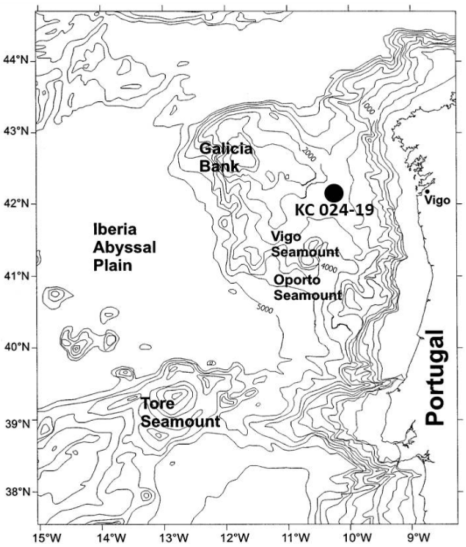

Fig. 1 - Map showing the bathymetry of the Iberian margin and the location of core KC 024-19 (adapted from Hall and McCave, 2000).

The Portuguese coastline, in the southern sector of this area, is interrupted by the estuaries of five rivers, which supply the oceanic system with sediment: Douro, Ave, Cávado, Lima and Minho. A large part of the rivers catchment area is underlain by metasediments, derived from Upper Precambrian and Lower Palaeozoic protoliths, and Carboniferous granitoids. Both regional metamorphism and magmatism are related to the Variscan orogeny. The northern sector of this area, in Spain, is characterized by the Lower Galician Rias (from south to north): Vigo, Pontevedra, Arosa and Muros. The rias were formed mainly due to rocky bed modelling processes since the Miocene (Méndez & Vilas, 2005). These valleys were incised during the low sea-level stands of the Quaternary and then drowned during the last transgression (Rey, 1993). The geology of the Spanish sector is also dominated by Variscan basement.

This work is based on the results acquired on the OMEX (Ocean Margin Exchange Project) core KC 024-19 (181 cm long) collected in the Galicia continental slope (south of the Galicia Bank area; at 42°08'98''N, 10°29´96''W, and 2765 m), off Vigo, Spain (Fig. 1).

The sampled sediments are composed mostly by silt and clay, but also include a coarser-grained (sand-sized) fraction, corresponding essentially to foraminifera tests. Another remarkable feature is the occurrence of four depth intervals characterized by abundances greater than usual of relative large terrigenous clasts (considered as ice-rafted debris - IRD), related to melting of massive influxes of icebergs into the North Atlantic (e.g. Heinrich, 1988) during the so-called Heinrich Events (HE). HE layers have already been identified in several places along the Iberian Margin (e.g. Abreu et al., 2003; Schönfeld et al., 2003; Baas et al., 1997; Lebreiro et al., 1996).

The main aim of this study is to use Nd and Sr isotope data acquired in core KC 024-19, relate them with other studies in this core, and assess the effect of climate change on the variation of the sources and on the transport processes of the sediments deposited in the Galician continental slope, during the last 40 ka.

2. Materials and methods

The core KC 024-19 was continuously sampled at 1 cm resolution (corresponding to 180 samples). Samples were dried at 40ºC.

For granulometric analysis, the silt and clay fractions (<63µm) were separated from the coarser fractions by wet sieving and the fine fraction micrometric data were obtained by using a SediGraph 5100 device.

The number of terrigenous grains was counted in splits from the sub-fraction >350 µm of each centimetre.

For stable isotope analysis, ten to fifteen specimens of the planktonic foraminifer *Globigerina bulloides* were picked from the 300 to 355 µm fraction from each centimetre of the core. The oxygen isotope composition was determined with a Finnigan MAT 251 mass spectrometer coupled to an automatic carbonate preparation device (Kiel II) at the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven.

Eight radiocarbon dates of mixed planktonic foraminifera tests (10 mg to 20 mg) were determined from the >125 µm sedimentary size fraction, by AMS method in “Beta Analytic Inc.”, Miami, FL, USA. Radiocarbon ages were calibrated to calendar years Before Present (cal ka BP) using the calibration program Calib 6.0.

The magnetic susceptibility was measured on dried bulk sediment samples (at each 2 cm) using a Bartington Instrument MS2B sensor.

Mineralogical studies were carried out on the <63 µm fraction of the sediments through X-ray diffraction (XRD), in the Department of Geosciences of the University of Aveiro, using samples spaced at each 1 or 2 cm. Qualitative and semiquantitative mineralogical analyses followed the method described by Martins et al. (2007).

Planktonic foraminifera assemblages were identified in the fraction >150 µm, which was split to obtain at least 300 specimens in each sample. The percentage of each planktonic foraminifera species in the assemblage was calculated. In the present work, only the percentage of the species representing polar waters, i.e. *Neogloboquadrina pachyderma*, sinistral (s) is used.

The detrital fractions of 27 samples from various selected levels along the core were analysed for $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$. These ratios were determined by TIMS, using a VG Sector 54 mass spectrometer, in the Isotope Geology Laboratory of the University of Aveiro. The used methodology is described in detail by Ribeiro et al. (2011).

3. General characterization of the core

The core KC 024-19 is composed mostly by hemipelagic sediments with a general homogeneous appearance and with no obvious marks of bioturbation and turbiditic facies. Some levels have ice-rafted debris (IRD) enclosed by a muddy matrix.

The age model of the studied core (Fig. 2) was based on the interpolation of eight calibrated radiocarbon ages BP (2σ calibration).

The granulometry of the studied sediments shows that they are mainly composed of silt and clay-sized particles (Fig. 3). Sand fraction (>63 µm) varies along the core between 2 and 34 %. The proportion of sand fraction increases, from 3% up to 34 % at the first 54 cm (Fig. 3).

The sand-sized particles are mostly foraminifera tests and, therefore, are composed of calcite.

In the finer-grained fractions, calcite (and other carbonate minerals) may still be present but the terrigenous components are largely dominant, especially during the late Pleistocene (Fig. 3). As expected, the most important detrital minerals are phyllosilicates, quartz, plagioclase and K-feldspar. Anatase may also, locally, attain significant proportions.

Heinrich Events are marked by peaks of the number of coarse lithic grains (IRD), values of magnetic susceptibility and proportion of *N. pachyderma* (s) (Fig. 2).

Significant variations in the proportions of *N. pachyderma* (s) indicate a series of rapid sea surface cooling oscillations and the lowering of salinity, which typically accompany the HE (Lebreiro et al., 1996) due to iceberg discharges into the North Atlantic (e.g. Abreu et al., 2003; Salgueiro et al., 2010). Minor peaks of the proportion of *N. pachyderma* (s) may correspond to interstadials of Dansgaard-Oeschger (D-O) events (Bond et al., 1993). D-O events are labelled in Fig. 2 following the numbering system of Dansgaard et al. (1993).

Peaks of magnetic susceptibility are related to high proportion of minerals with magnetic properties, such as magnetite (either as individual grains of as inclusions in other minerals), discharged during the melting of icebergs.

In this core the four last HE (HE1 to HE4) were recognised (Fig. 2). These events show the expected chronological overlap with the correlative layers in other records of the Iberian Margin (e.g. Schönfeld et al., 2003; Abreu et al., 2003; Rey et al., 2008; Salgueiro et al., 2010).

The $\delta^{18}O$ records of this core generally show a general trend that agrees with the variation described for other cores of Iberian Margin (e.g. Abreu et al., 2003; Salgueiro et al., 2010). In core KC 024-19, $\delta^{18}O$ values vary between 0.4 and 3.3 ‰. The lowest average values (0.7 ‰) occur in the Holocene layers. Significantly higher values correspond to the last glaciation, and comprise mainly MIS 2 (average 2.6 ‰) and the four last HE (average 2.7-2.9‰)

The $\delta^{18}O$ stratigraphy, radiocarbon chronology and the identification of the layers deposited during the HE show that this core represents a complete sediment succession spanning the last 40 ka Cal BP and, thus, records Marine Isotope Stages (MIS) 1 and 2, and part of the MIS 3 (Fig. 2).

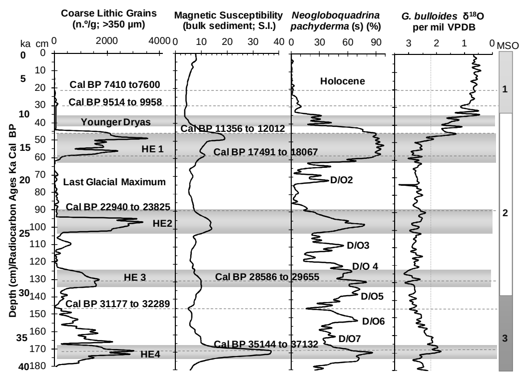

Fig. 2 – Depth plot of coarse lithic grains (n.º/g in bulk sediments; >350 µm), magnetic susceptibility (bulk sediment; S.I.), *N. pachyderma* (s) (%), *G. bulloides* $\delta^{18}O$ (‰). An age scale and radiocarbon calibrated ages are represented; Heinrich events (light grey shade) and some Dansgaard-Oeschger (numbered D-O) events are signalized as well as three last marine stages of oxygen (at right).

4. Sr and Nd isotopes

Sr and Nd isotope ratios were also studied in these sediments. In a previous work (Silva et al., 2010), data on the Sr composition of tests of one planktonic and one benthic foraminifera species, at different depths along the core, were reported. Results obtained on those tests reflect essentially the seawater composition, but, additionally, the $^{87}Sr/^{86}Sr$ ratios of the planktonic species (*Globigerina bulloides*) seem to record a subtle variation related to the distance towards the shoreline (Silva et al., 2010).

In this study, $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios were measured in the detrital fraction of 27 layers, from the topmost to the lowermost levels of the core. The procedures used to exclude the biogenic carbonate component are described by Ribeiro et al. (2011).

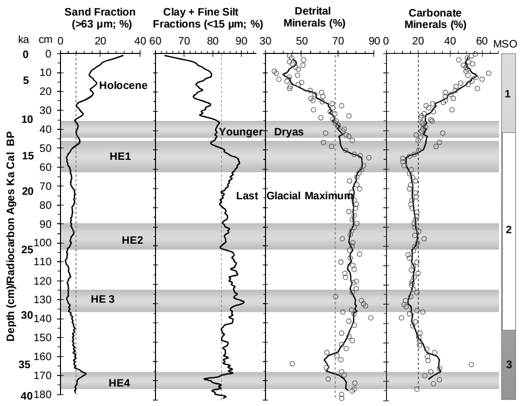

Fig. 3 – Depth plot of sand fraction (>63 µm; %), clay + fine silt fractions (<15 µm; %), detrital minerals (including phyllosilicates, quartz, plagioclase, K-feldspar and anatase; %) and carbonate minerals (calcite, dolomite, rhodochrosite; %). An age scale and radiocarbon calibrated ages are represented; Heinrich events (light grey shade). Marine stages of oxygen (MSO) are represented (at right).

In the studied samples, $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ ratios vary from 0.512072 to 0.511604 and from 0.732273 to 0.725140, respectively. These values fit into the range of values expected in terrigenous material derived from the erosion of a sector of the continental crust with no relevant addition of mantle derived magmas in the Meso-Cenozoic (Taylor & McLennan, 1985). Although the $^{143}Nd/^{144}Nd$ values may be as low as 0.511604 (corresponding to ε_{Nd}=-20.1), most of the Nd isotope ratios are clustered between 0.512013 (ε_{Nd}=-12.2) and 0.512072 (ε_{Nd}=-11.0). Significantly, the lowest values were all obtained in samples from HE layers, namely in HE1, HE2 and HE4 (Fig. 4).

$^{143}Nd/^{144}Nd$ values in terrigenous sediments depend on the average Sm/Nd ratio and on the average age of the crustal reservoirs that supply the basin. This relationship can be established, taking into account that the Sm/Nd ratio does not strongly fractionate during intracrustal processes (Taylor et al., 1984; Moorbath & Taylor, 1986). Since Sm/Nd values are typically lower in the continental crust than in the mantle, $^{143}Nd/^{144}Nd$ will tend to be lower in portions of the continental crust that remain stable since the Precambrian than in sectors of the crust that underwent addition of juvenile material during the Phanerozoic.

Detrital material transported to the studied area comes dominantly from NW Iberia, as a result of the erosion of Variscan basement. Therefore, the range of ε_{Nd} values between -12.2 and -11.0 may be seen as the signature of the dismantling of that basement.

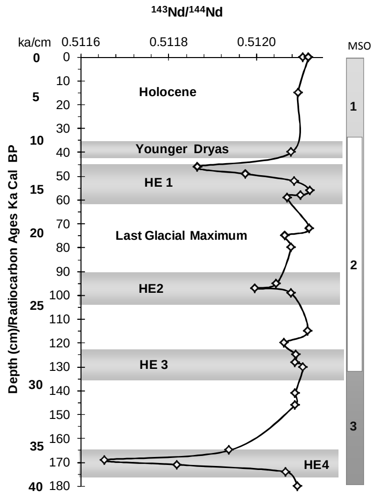

Fig. 4 – Depth plot of $^{143}Nd/^{144}Nd$. An age scale and radiocarbon calibrated ages are represented; Heinrich events (light grey shade) are signalized. Marine stages of oxygen (MSO) are represented (at right).

Lower ε_{Nd} values are found only in IRD layers (Figs. 4-5), which suggests that, during those episodes, other source(s) had also a relevant role. Taking into account that those layers incorporate clasts dropped by icebergs, their sources must be located further North in the circum-Atlantic area. In North-East America, Greenland or Scandinavia, Precambrian orogens are extensively represented and, therefore, the sources of the IRD with the strongest negative ε_{Nd} values lie probably in some of those areas.

HE3 layer contrasts with the other studied HE layers, and displays Nd isotope ratios that can not be distinguished from the signature of the detrital component supplied by the Variscan crust.

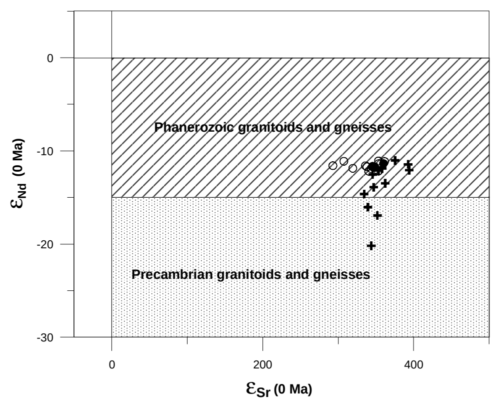

Fig. 5 – ε_{Nd} *vs.* ε_{Sr} diagram for present day values. Open circles – whole terrigenous fractions of layers with no IRD. Closed circles - whole terrigenous fractions of HE3 layer. Crosses - whole terrigenous fractions of HE1, HE2 and HE4 layers. Fields for granitoids and gneisses according to Faure & Mensing (2005).

5. Sediment transport and palaeoclimatic evolution

Core KC 019-24 is a continuous sediment column which may record the effect of climatic change in the sediment transport processes and sources in the Galician continental slope, during the last 40 ka. The grain size and composition of the terrigenous component of sediments of this core allows the identification of two main sources.

The transport of sediments from the nearby continental areas may be a mixture of across- and along-slope margin processes that involve river inputs, seasonal upwelling and downwelling events, along-slope currents, internal waves, shelf-break tides and submarine canyons fluxes. All these processes are influenced by climate conditions.

Climatic oscillations caused sea level changes. The retention of water in continental glacial ice sheets gave place to sea level drop. At ≈18 ka BP sea level was about 140 m lower than at the present day and, as a consequence, the shoreline was closer to the shelf-break (Dias et al., 2000). At that time, the terrigenous load transported by the rivers was almost directly discharged into the continental slope (Dias et al., 1997); the extremely narrow shelf was then a very energetic environment due to sea bottom inclination and to a very limited long wave refraction (Dias et al., 2000). These conditions favoured the transport of fine-grained terrigenous materials to the studied area, causing dilution of the biogenic carbonate component (Fig. 2). The sea transgression was very rapid in the beginning of the Holocene, i.e. in the period between 11 ka cal BP and 5 ka cal BP (Dias et al., 2000). With the sea level rise, the terrigenous contribution diminished, leading to an increase in the proportion of biogenic component of the sediment, as recorded by the upper 30 cm layers (Fig. 2).

However, during the last glaciation the area where the core KC 019-24 is located also received allochthonous materials, during the Heinrich Events.

Glacial winds during the HE, exhibiting anticyclonic circulations over the ice sheets, show a strong cyclonic circulation over the northwest Atlantic basin, enhancing a westerly flow over the Iberian coast (e.g. Roucoux et al., 2001; Daniau et al., 2007) favourable for the transport of water and icebergs from high latitude areas.

For most of the HE layers, several lines of evidence suggest that ice-rafted debris were related to icebergs coming, at least in part, from northeastern America (Laurentide Ice Sheet) and western Greenland (e.g.: Grousset et al., 1993, 2000; Kirby & Andrews, 1999; Auffret et al., 2002). Both areas are characterized by the occurrence of Precambrian basement and, thus, they may explain the low ε_{Nd} values obtained in HE1, HE2 and H4 layers. In contrast, the Nd isotope signature of the HE3 layer is similar to the normal terrigenous component of the core. The results obtained in this study agree well with previous works on cores from different places along the European Atlantic margin (e.g.: Grousset et al., 1993, 2000; Auffret et al., 2002; Snoeckx, 2002), which have shown a strong Laurentide influence in the IRD of the HE1, HE2 and H4 layers, whilst the terrigenous material of the HE3 is dominantly from an European provenance. The periods of arrival of Laurentide icebergs to the Iberian margin are likely related to extremely cool climatic conditions, as pointed out by several authors (Seidov et al., 1996; Auffret et al., 2002).

6. Conclusions

Results of this work show that sediment composition in the studied area was controlled by the variation, through time, of the relative contributions of (i) biogenic (carbonate) component, (ii) proximal detrital material, ultimately derived from the erosion of Iberian Variscan crust, and (iii) allochthonous detrital material.

Sea level lined the configuration and extension of river basins and the position of the coastline, thus controlling the proximal terrigenous supply to the Galician continental slope. The higher deposition rate of detrital material occurred during the last glaciation, when the sea level was lower, causing dilution of the carbonate component (especially foraminifera tests). During the subsequent sea level rise, the terrigenous supply to the Galician continental slope decreased progressively.

The allochthonous input of sediments is chiefly manifest in layers deposited during the Heinrich Events. Nd isotope ratios not only confirmed other type of evidence obtained in this core about the peculiarities of those layers, but also allowed to conclude that during HE1, HE2 and HE4 a significant amount of the detrital material came from Precambrian basement area(s). This fits into an origin of the icebergs responsible for the ice-rafted debris, during those three episodes, in the Laurentide ice sheet

Acknowledgements

The authors would like to thank Sara Rodrigues, Cristina Sequeira, Denise Terroso, Lisa Schönborn and Günter Meier, for technical support, and FCT, for the fellowship SFRH/BPD/26717/2006.

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