6º Simposio sobre el Margen Ibérico Atlántico **MIA09** *1-5 de diciembre de 2009 Oviedo*

Submarine Cascais Canyon as a sediment conduit to the deep sea: Comparison with adjacent slopes

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Abstract: Submarine canyons are known to be important conduits that trap, accumulate and deliver both natural and anthropogenic sediments from the shelf to the deep sea. Ten multi-cores from the Cascais Canyon and from the neighbour slopes (off Estremadura and Sines) were dated by ^{210}Pb methodologies and analyzed for texture, major and trace metals to evaluate the role of submarine canyons in the transport of anthropogenic metals to the abyssal plains. Higher accumulation mass rates were determined in the upper Cascais Canyon than in the lower canyon and slopes. Enrichment factors (EF) were used to evaluate the level of metal enrichment in the studied areas. EF values exceeding natural background concentrations were obtained for Pb suggesting an anthropogenic and/or diagenetic source for Pb enrichment in the Cascais Canyon, but also, to a lesser extent, in the Estremadura and Sines slopes. Studies of provenance based on the ratio of different stable Pb isotopes can help to determine the origin of such metal in the sediments.

Palabras clave: Cañón de Cascais, tasas de acumulación de masa, elementos mayores, metales pesados, factores de enriquecimiento

***Key words:** Cascais Canyon, mass accumulation rates, major elements, heavy metals, enrichment factors*

1. INTRODUCTION

About 90% of sediments generated on land by erosion are deposited on the continental margins (Brown *et al.*, 2007), which are affected by transport, deposition and resuspension processes before reaching the ocean bottom. Submarine canyons play an important role in the transport of those sediments to the abyssal plains, trapping sediments from the shelf and slope and acting as main conduits that, through different processes, lead the sediments to the deep sea (e.g. Canals *et al.*, 2006, de Stigter *et al.*, 2007, Lastras *et al.*, 2007, Palanques *et al.*, 2008).

The sediments originated in land by erosion are often associated with anthropogenic substances derived from human activities (Loring, 1991). The focusing effect of canyons may induce relatively higher concentration of such substances in canyons relative to surrounding slope areas (Paull *et al.*, 2002).

The Cascais Canyon (CC) is located in the western Portuguese margin, near the Tagus river (TR) mouth. The TR flows through Lisboa, the most populated and industrialized city in Portugal. Studies performed in the Tagus estuary and prodelta indicated the occurrence of anthropogenic metals enrichments (e.g. Paiva *et al.*, 1997, Jouanneau *et al.*, 1998, Mil-Homens *et al.*, 2009). Richter *et al.* (2009) also demonstrated a contribution of anthropogenic metals in surface sediments from the Lisboa-Setúbal Canyon System (LSC).

This work is integrated in the FCT-funded CANYONS project (Sediment transport in the Setúbal and Lisboa submarine canyons), and aims to evaluate the role of the CC in the transport of sediments from the shelf and slope to the abyssal plains through the comparison with multi-cores recovered from adjacent slopes.

2. REGIONAL SETTINGS

The central Portuguese western margin is characterized by a relatively narrow shelf and steep irregular slope, dissected by several submarine canyons such as the Nazaré, Cascais, Lisboa and Setúbal canyons (Fig.1).

The CC is one of the shortest canyons of the Portuguese margin. It is located NW of the LSC, separated from the later by the high ridge of the Afonso Albuquerque Plateau (Vanney and Mougenot, 1981). Its head is positioned on the shelf, near a fine-grained deposit located at the TR mouth – the Tagus Prodelta (Vanney and Mougenot, 1981), at around 175 meters water depth (mwd) and extends down to depths over 4600 mwd with high sinuosity index from its head to the canyon mouth (Lastras *et al*., 2009).

North of Lisboa, the shelf, assigned as Estremadura spur, consists of a nearly flat surface above the 120 m isobath and a slightly dipping outer surface with alternation of faulted and gullies truncation surfaces and sedimentary sheets (Vanney and Mougenot, 1981). South of the area affected by canyons, the shelf consists of a westward gently dipping, slightly convex depositional surface of sediment aggradation linking the inner shelf to the Tagus Abyssal Plain (Terrinha *et al*., 2003).

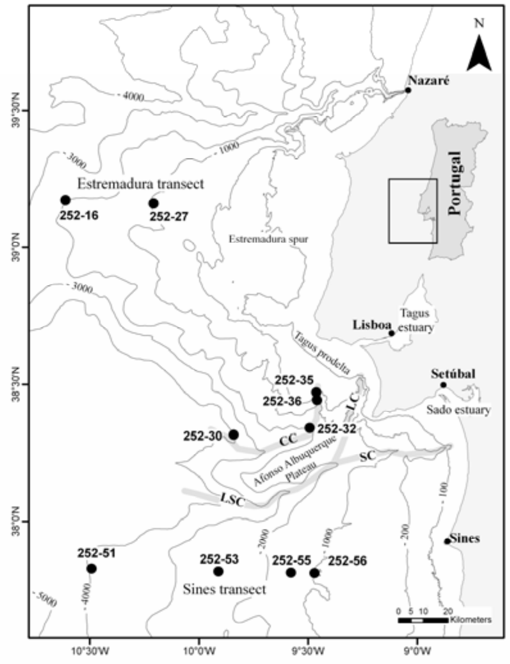

Fig. 1. Location of the 10 multi-cores recovered by the Pelagia 252 cruise in the Cascais Canyon and the Estremadura and Sines slopes. CC – Cascais Canyon; LC – Lisboa Canyon; SC – Setúbal Canyon; LSC – Lisboa-Setúbal Canyon System.

3. MATERIALS AND METHODS

Ten multi-cores collected along the CC and Estremadura and Sines slopes were studied (Fig.1). Those cores were retrieved during the cruise Pelagia 252, in 2006. In this work, cores will be referred by the cruise name and station number (e.g. 252-32).

Grain-size distribution was measured using the Coulter Laser LS230 and following the methodology used at Marine Chemistry and Geology department of the Royal Netherlands Institute for Sea Research (NIOZ-MCG).

^{210}Pb activities were measured by α-spectrometry using the granddaughter isotope ^{210}Po (Boer *et al*., 2006) following the internal method used at NIOZ-MCG. Mass accumulation rates (MAR) were determined using the model of Constant Flux and Constant Sedimentation Rate (CF/CS; Appleby and Oldfield, 1992 in Boer et al., 2006) and the model of Constant Flux and Constant Sedimentation Rate including a Surface Mixed Layer (SML) on the top (CF/CS^{SML}; Carpenter *et al*., 1982; Boer *et al*., 2006).

Major elements (SiO_2, Al_2O_3, Na_2O, CaO, Na_2O, K_2O, TiO_2 and MnO) were determined by wavelenght dispersive X-ray fluorescence spectrometry. Total trace elements (Zn, Cr, Li, Ni and Cu) were measured by flame atomic absorption spectrometry and Pb by graphite furnace atomic absorption spectrometry, after an acid decomposition. Both methodologies were used following in-house methods from LNEG-LAQ.

In order to eliminate effects of grain-size variability and to identify anomalous concentrations in metal contents, the geochemical data were normalized using Li as reference element (e.g. Loring, 1991).

Enrichment factors (EF) were used to evaluate the metal enrichment in each sample taking into account a background level. The background value is assumed as the deepest concentration value determined in each core, with exception for cores 252-35 and 252-36 which, due to fast accumulation rates, do not reach local pre-industrial background values. In this case, the background values were obtained from the concentration values average of the deepest samples of cores 252-30 and 252-32. EF were calculated based on Li-normalized values to reduce the influence of grain-size variability. Zhang and Liu (2002) consider EF higher than 1.5 as a result of enrichment through non-crustal sources such as anthropogenic, diagenetic and/or biogenic sources.

4. RESULTS AND DISCUSSION

Grain-size

All the studied cores present silt as the dominant grain-size fraction followed by clay and sand. Cores do not show important changes with core depth excepting cores 252-32 and 252-36 which reveal an increase in sand towards the bottom of the core.

Mass accumulation rates

MAR vary from 0.02 g $cm^{-2}y^{-1}$ in the studied transects to 0.40 g $cm^{-2}y^{-1}$ in the upper CC (Fig. 2). ^{210}Pb activity at the surface show variable values among 400 and 1500 mBq g^{-1} decreasing to values from 15 and 45 mBq g^{-1} in the core base.

All cores reveal a regular exponential decrease with depth where excess ^{210}Pb is only detected in the first 10 cm, with exception for the cores 252-35 and 252-36, both not reaching the ^{210}Pb background values, reflecting high accumulation rates due to the proximity to the TR mouth. Cores 252-35, 252-36, 252-53 and 252-56 present a SML in the first centimetres (Fig. 2). MAR for these cores were determined using the CF/CS^{SML} model while for the other cores MAR were determined through the CF/CS model. Cores 252-27, 252-30, 252-32, 252-36, 252-51, 252-53 and 252-55 show high ^{210}Pb values at certain depth (Fig. 2). Those high values were considered as result of bioturbation in all cores with exception for core 252-36 where the ^{210}Pb high values are associated with increase of sand contents in bottom levels suggesting a turbidite layer. These values were not used to MAR determinations.

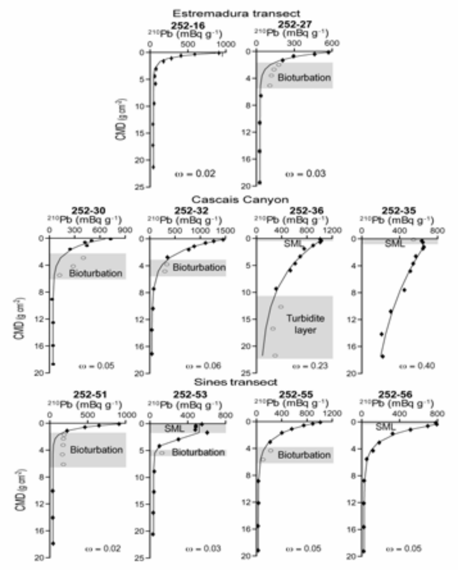

Fig. 2. Total ^{210}Pb activity vs. cumulative mass depth (CMD) and best-fit curve for determination of MAR. Open circles were not considered to the determination of MAR. MAR are given in g cm^{-2}y^{-1}.

Sources of elements in the sediment

The CC shows the highest content in elements associated with the aluminosilicate fraction (SiO_2, Al_2O_3, MgO, Na_2O, K_2O, TiO_2). This fact is probably related to the proximity to the Tagus prodelta (Fig. 3). TR is characterized by a large flow (Fiúza, 1984) where periodic floods and abrupt discharges of suspended load were known to happen (Vale and Sundby, 1987). The Tagus prodelta, localized in the shelf adjacent area of the TR mouth, has been the target of previous studies (e.g. Jouanneau *et al.*, 1998, Mil-Homens *et al.*, 2009) that demonstrated the occurrence of anthropogenic metal enrichments.

The highest content in CaO is found in the Estremadura transect as a result of higher concentration of biogenic particles relative to detrital material. In this transect the supply of detrital material is limited due to reduced river discharges. Furthermore, it is also located between the Nazaré Canyon (north; Fig. 3)) and the CC and LSC (south) that probably help to remove sediment from the area. These canyons may act as conduits of particulate material transported from land by rivers, cutting its supply to the Estremadura slope.

The Sines transect, also located in an area with limited input of detrital material, presents the highest content in Cr and Ni. The enrichment in those metals can be related to the proximity of the Sines Intrusive Massif (Fig. 3), whose weathering assemblage can provide a source of clastic material abundant in Cr and Ni (Salomons and Förstner, 1984).

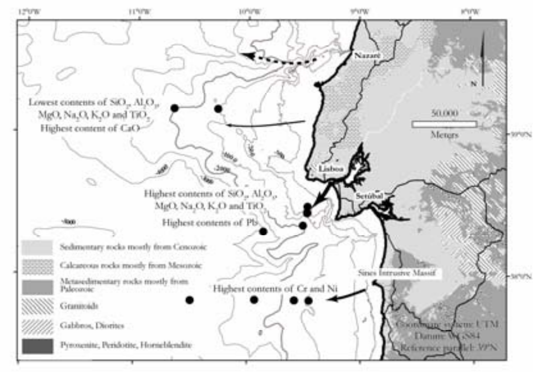

Fig. 3. Simplified geological map and associated metals found in the studied area. Full lines represent the input of terrigenous material (thickness represents relative quantity). Dashed lines represent the probable principal pathway of terrigenous material in the Estremadura slope.

Pb enrichment

In all cores, only Pb shows EF>1.5. Nevertheless, the occurrence of a continuously increasing EF trend towards the present suggests that anthropogenic contributions are being recorded in marine sediments at deeper areas of the Portuguese margin. Stable Pb isotope ratios can distinguish between natural and anthropogenic sources of Pb. Such studies were performed on two cores from the CC (results presented in Mil-Homens et al., this volume) suggesting a major Pb anthropogenic contribution in core 252-35 due the proximity of the Tagus estuary and prodelta.

5. CONCLUSIONS

Higher MAR determined in the CC than the adjacent slopes can suggest that canyons are preferential and active conduits that transport the sediments from the shelf and slope to the deep sea. However, the difference between MAR in the upper and the lower canyon indicate that actually the CC is accumulating sediments in the upper segment while remains almost inactive in terms of sediment transport in the middle and lower canyon.

In the CC and the Estremadura and Sines transects, sediments seem to reflect not only detrital and diagenetic components but also enrichments in metals associated with urban activity.

Acknowledgements

This work was financially supported by the FCT-funded CANYONS project (PDCT/567841/2004). All cores were recovered by the RV Pelagia from the

Royal Netherlands Institute for Sea Research (NIOZ) within the projects “Lead in Canyons” (814.01.018 of the NOW) and HERMES (GOCE-CT-2005-511234). Acknowledgements go also to NIOZ, LNEG-UGM and LNEG-LAQ for all the laboratory technical support.

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