End-member modelling to recognize sediment sources in contourites: a case study in the Alboran Sea

Modelización de los end-members para reconocer fuentes de aporte sedimentario en contornitas: un caso de estudio en el Mar de Alborán

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Abstract: Contourite drifts are one the main morphosedimentary features in the Alboran Sea and their sediments are important archives of the past oceanographic conditions and sedimentary processes. The end-member modelling approach lets to decompose multimodal grain-size distribution into genetically meaningful subpopulation that may be related to different sediment transport mechanisms and source areas. Three end-members have been identified in the contourite drift and moat system located at the southern side of the Dijbouti Ville seamount that have been interpreted in terms of sediment sources. Two end-members point to an eolian source and comprise fine silt (EM1) and coarse silt (EM2) as modal grain-sizes, characterized by high and low contents, respectively, of terrigenous elements (Al, Si, Ti and K). The third end-member (EM3) indicates a fluvial origin and is mainly defined by a clay modal grain-size of intermediate and homogeneous content in terrigenous elements. Downcore variation of the relative proportion of these EMs can be used to decipher paleocenographic and paleoclimatic conditions in the Alboran Sea.

Keywords: *end-member modelling, contourites, sediment source, geochemistry, Alboran Sea*

1. INTRODUCTION

The presence of widespread contourite deposits in the Alboran Sea highlights the importance of these morphosedimentary features in the continental margin (Ercilla *et al.*, 2012). In this area, marine terrigenous sediments are a mixture of particles coming from the river supply and eolian dust deposition (Moreno *et al.*, 2002). The first is related to continental runoff that is highly dependant of humidity conditions. Otherwise, the second may inform about aridity in the source area and even the intensity of the wind transport. Additionally, the imprint of bottom currents over these deposits may also play an important role in advecting and reworking sediments under different oceanographic conditions. Hence, as marine sediments are archives of the past environmental, oceanographic and climate conditions, if we can "unmix" the grain size distributions that characterize each process we will be able to reconstruct the present and past story of the ocean basins that are ultimately related to global changes.

The end-member algorithm was developed by Weltje (1997) in order to decompose multiple-source grain-size distributions into genetically meaningful subpopulations that explain the grain size variance in the dataset. We have applied this approximation to contourite deposits in the Alboran Sea to recognize the main sediment sources and their interplay.

2. PHISIOGRAPHY AND OCEANOGRAPHY

The Alboran Sea is a partially land-locked, east-west-oriented basin in the westernmost Mediterranean Sea between the Spanish and Moroccan margins (Fig. 1). In this basin, the Djibouti-Motril marginal plateau is characterized by several seamounts (Palomino *et al.*, 2011) with reliefs ranging from 500 to 1000 m high and summits at about 200 m water depth. The southernmost seamount is Djibouti Ville that is surrounded by narrow moats and different drifts features (Palomino *et al.*, 2011). This is study is focussed on the elongated separated contourite drift and associated moat located in the southwestern flank of this seamount.

Present day oceanography in the Alboran Sea is highly influenced by the interaction between Atlantic and Mediterranean waters. The Alboran Sea has traditionally been subdivided into three major water masses (Millot, 1999): i) Modified Atlantic Water (MAW) flowing eastwards in a surface layer of 150–250 m, ii) Levantine Intermediate Water (LIW) flows westwards at intermediate water depth (200–600 m), and iii) Western Mediterranean Deep Water (WMDW) that flows below 500-600 m water depth.

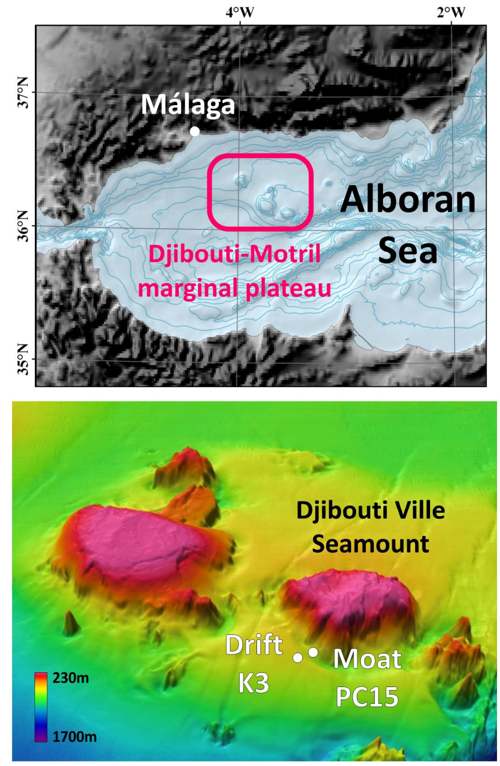

Fig. 1. Location map of the study area and the contourite drift-moat system associated to the Djibouti Ville Seamount where cores K3 and PC15 were retrieved.

3. MATERIAL AND METHODS

For this study we have analysed two cores, K3 and PC15, that were retrieved along a NE-SW transect of 1.5 km long at water depths of 712 m and 763 m, respectively, in the south-central area of the Djibouti Ville Seamount (Fig. 1) during SAGAS-BIS and MONTERA cruises onboard the R/V Sarmiento de Gamboa. Piston core K3 (451 cm recovery) was located in the elongated separated drift, and gravity core PC15 (589 cm recovery) was situated in the moat.

3.1 Grain-size analysis

Particle size distributions were calculated at 3-8 cm sampling resolution, obtaining 123 samples in total. Duplicate samples for bulk and terrigenous fractions were analysed using a Coulter LS 100 laser particle size analyser (CLS 100). This technique determines particle grain sizes between 0.4 and 900 µm as volume percentages (vol%) based on diffraction laws. The grain size analysis of the terrigenous fraction (carbonate-free) was obtained from previous treatment of the samples with hydrochloric acid (HCl) to remove carbonate content.

3.2 End-member modelling

This statistical approach let to decompose or unmix multimodal high resolution grain size data sets resulting from laser particle size analysis. The modelling algorithm decomposes the multivariate data set into a set of end-member loadings (interpretable as processes) and end-member scores (the contribution of each process to each sample). We have applied this technique to the grain-size distribution of the terrigenous fraction (n=123 samples) of cores K3 and PC15. The minimal number of end members to get the best approximation of the variance is determined by calculating the coefficient of determination (r^2). The value of r^2 represents the proportion of the variance of each grain-size class which can be reproduced by the approximated data (Weltje, 1997). The great advantage of this approach is that it is not deterministic but rather aims to find the best-possible model to explain the dataset.

3.3 Sediment geochemistry

The relative contents (expressed in counts per seconds, cps) of Al, Si, Ti and K were measured on split core sediment sections at 1 cm intervals by the Avaatech XRF core scanner of the University of Barcelona. For the Mediterranean region, the relative content of Si-Ti and K has been extensively used as proxies for terrigenous inputs, to differentiate between eolian dust and fluvial supply, respectively (Moreno *et al.*, 2002).

4. RESULTS

4.1 Sediment facies

The sediment facies of the moat and drift environments of the Djibouti Ville seamount are mainly composed of fine grained sediments. Two main contourite facies are distinguished along the cores: homogeneous muds and mottled silts and muds (Alonso *et al.*, 2014).

4.2 End-member modelling

End-member modelling of grain-size distributions has been carried out to recognize the most significant particle size distribution that help us to infer the main sediment sources, associated transport and depositional processes affecting the contourite deposits. The minimum number of end-member required for a satisfactory approximation of the grain-size data, i.e. the goodness of fit, has been calculated. For the three end-member approximation a mean r^2 of 0.93 was obtained (Fig. 2b). The plot of r^2 versus each grain size class explains the grain-size spectrum from 0.25 to 38 µm with a coefficient of determination of more than 0.6 (Fig. 2c). It is worth mentioning that the four and five end-member models do not improve substantially either the coefficient of determination or the grain-size range, probably due to the model try to also describe "noise" in the dataset (Holz *et al.*, 2007). Hence, the three end-member model has been the one selected to reproduce the grain-size variation in the cores.

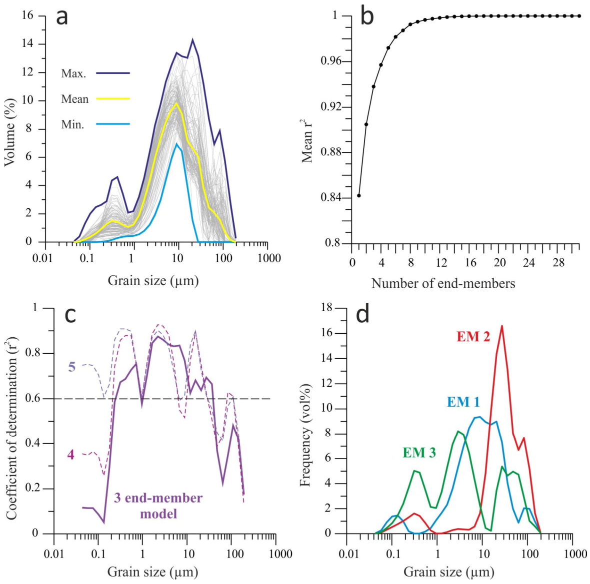

Fig. 2. End-member modelling results of K3 and PC15 cores: a) maximum, mininum and mean values of the original grain-size dataset (n=123, grey lines), b) mean coefficient of determination for the different end-member solutions, c) coefficients of determination for each size class of 3, 4 and 5 EM models, and d) modelled end-members grain-size distributions.

Three end-member (EM) grain-size distributions are characterized by fairly polymodal shape (Fig. 2d). If we do not take into account particle fractions of less than 2 vol%, then EM1 and EM2 are almost unimodal with a modal size of ~10 µm (fine silt) and ~32 µm (coarse silt), respectively. The rather polymodal EM3 grain-size distribution is characterized by 3 modal sizes of ~3 µm (coarse clay), ~32 µm (coarse silt) and < 1 µm (very fine clay).

Along the cores, the relative proportions of the three EM display some difference between the moat (PC15) and drift (K3) environments. The average value of the three EM is similar in the moat, ranging from 23% (EM2) to 40% (EM1). Otherwise, the drift is clearly dominated for EM3 with an average value of 53% while EM2 is only present the 9% of the time. In general, dominance of EM1 is quite similar in both environments with an average value of 38% (Fig. 3).

4.1 Geochemical composition of end-members

For this study, only the relative content of representative core intervals corresponding to samples where individual EMs (i.e., EM1, EM2 and EM3) represents more than 80% of the variance, have been considered. Biplots of Al *vs* Si, Ti and K are shown in Fig. 4 to represent compositional changes in the terrigenous fraction of each EM. There is a clear lineal positive correlation among Al with Si (R^2=0.98), Ti (R^2=0.87) and K (R^2=0.96). EM1 shows the highest contents in all analyzed elements while EM2 displays the lowest values. The content in terrigenous elements is quite homogeneous in EM3 that is characterized by an intermediate composition between EM1 and EM2.

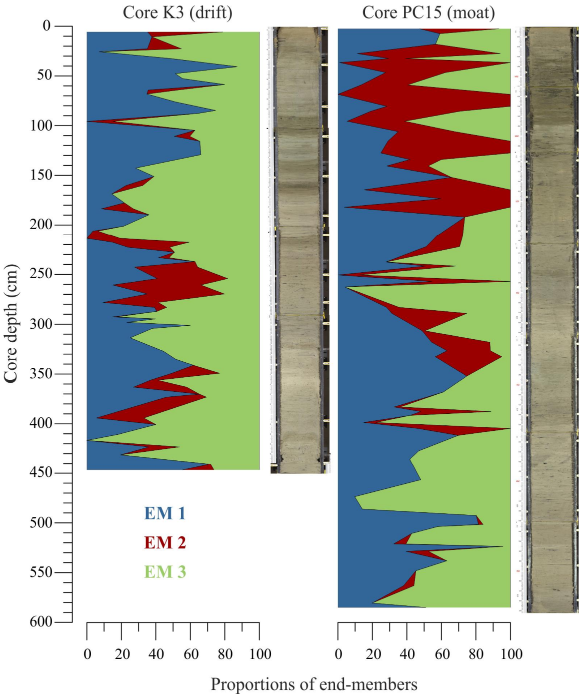

Fig. 3. Downcore proportions (%) of the three end-members and high resolution photograpy of the sediment cores.

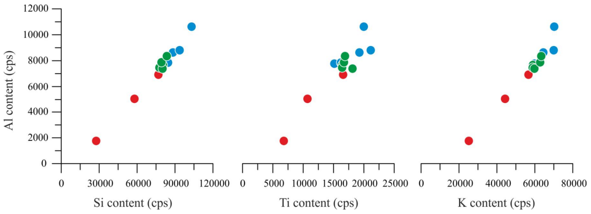

Fig. 4. Relative content variations of individual EM1 (blue dots), EM2 (red dots) and EM3 (green dots).

5. DISCUSSION

The fine silt EM1 with a modal size of ~10 µm represents eolian supply. This end-member coincides with EM1 of eolian dust input previously reported by Moreno *et al.* (2002) for the Alboran Sea and present-day Saharan dust with a modal size of 10-15 µm. This is also consistent with mean modal grain sizes of transported Saharan dust that can range between 8 and 48 µm (Stuud *et al.*, 2005).

Similarly, the coarse silt EM2 displays a modal size of ~32 µm and is likely related to eolian supply. EM2 displays a subsidiary coarser modal grain size of ~97 µm (fine sand) that may correspond to the coarse fraction transported punctually by currents or deposition of pelagic foraminiferal test. Although the end-member algorithm has been applied to the terrigenous fraction, some of the coarser biogenic particles may not be totally dissolved.

Clay-sized EM3 with modal sizes of ~3 and < 1 µm is interpreted as representing sediment contributions from riverine input. This is in good agreement with studies suggesting that finest sediments with a median size of < 6 µm likely represent river supply (Moreno *et al.*, 2002; Holz *et al.*, 2007). Moreover, EM3 is also related with eolian supply as suggested by the third modal size of ~32 µm, although this fraction only represents 26% of the distribution. Fine-grained dust particles may result of wet deposition but as consequence of the relatively short distance to the source area, the wind-blow sediment fraction is much coarser than the sediment supplied by rivers (Holz *et al.*, 2007). This supports our interpretation of two eolian end-members (fine EM1 and coarse EM2) and one derived form fluvial input (EM3).

There is not a straightforward relation between the geochemical proxies with either EM3 (fluvial input) or EM1-2 (eolian supply) which suggest that observed polymodal grain-size distribution also reflect a mix of sediment sources. As mentioned before, fluvial EM3 is characterized by fine (clay-sized) and coarse (silt-size) modal sizes which may correspond to terrigenous input of both K- and Ti-bearing minerals from fluvial origin (Moreno *et al.*, 2002). Likewise, the eolian end-members may have also been composed by K-enriched minerals (e.g. kaolinite, pallygorskite, K-Na silicates) as suggested Larraroaña *et al.* (2008).

The variation of relative EM proportion with time is shown in Fig. 3. In general, the core K3 record is dominated by the interplay of fine eolian EM1 and fluvial EM3 supply. This is in good agreement with the coeval presence of sustained fluvial sediment input and the frequent eolian events suggested by Moreno *et al.* (2002) in the Alboran Sea. The high proportions of EM2 are restricted to events of increased wind strength. Similarly, cold periods of enhanced eolian supply are also indicated by abrupt increasing in fine EM1. The most remarkable change between the two eolian records occurs around 240-280 cm in core K3, and from 150 to 190 cm in core PC15, although some sharp fluctuations are also observed until the last top 20 cm in core PC15. The contribution of fine eolian particles (EM1) is strongly reduced and replaced by the increasing of coarser wind supply (EM2). By this time, a considerable reduction in the fluvial supply (EM3) is also observed reaching minimum values. The presence of two dominant grain-size of eolian dust suggests different strength in wind transport and deposition. Hence, the finer EM1 indicates weaker velocities while the coarser EM2 is related with enhanced flow-speeds.

6. CONCLUSIONS

The end-member approximation may be related with two main processes. 1) Mixing of sediments transported by independent mechanisms and/or supplied from different sources, which in our case are mainly of eolian and fluvial origin. 2) Selective mechanisms operating during unidirectional transport and deposition, producing sediments whose grain-size distributions change systematically with distance from the source. Two main mechanisms are superimposed in the contourite drift and moat system of the Dijibouti Ville seamount, i.e. bottom current and eolian transport. Further studies will be required to correctly interpret these processes in terms of paleoclimate and paleoceanographic changes.

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