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Contourite erosive features caused by the Mediterranean Outflow Water in the Gulf of Cadiz: Quaternary tectonic and oceanographic implications

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ABSTRACT

Contourite depositional systems have been the focus of much recent research, but still relatively little is known about contourite erosive features and their associated processes. Based on multibeam bathymetry, side-scan imagery and different resolution seismic records, a detailed description and classification of the major erosive submarine valley features of the Contourite Depositional System of the Gulf of Cadiz middle slope is presented for the first time. Four types of erosive features have been differentiated, including *contourite moats*, *contourite channels*, *marginal valleys* and *large isolated furrows*, and interpreted in terms of their tectonic and oceanographic implications during the Quaternary. The study of the distribution and characteristics of erosive features is essential to better understand the present and past interaction of the Mediterranean Outflow Water (MOW) with the middle slope seafloor, and allows us to propose a new and more precise scheme for the MOW circulation patterns. This scheme includes a main along-slope circulation responsible for the excavation of the contourite moat and channels, and a secondary down-slope circulation responsible for the erosion of marginal valleys and isolated furrows. Three evolutionary stages have been observed in the development of the erosive system during the Quaternary, that can be related to changes in the distribution and splitting of the MOW as a consequence of the segmentation of the NE–SW diapiric ridges by neotectonic effects: *1) Early Pleistocene to Mid-Pleistocene*: linear diapiric ridges; *2) Mid-Pleistocene to Late Pleistocene:* diapiric reactivation and *3) Late Pleistocene to Holocene:* main recent phase of diapiric ridges segmentation and rotation. This study provides important regional clues for establishing the evolution of the erosive features in relation with neotectonic effects, and represents a good example of the potential of erosive features as evidences for the reconstruction of the paleoceanography and recent tectonic changes.

1. Introduction

The impact of contour currents on continental margins has received the attention of many studies that have focused on the morphology, seismic and sedimentary products and associated processes (Faugères et al., 1999; Stow et al., 2002; Rebesco, 2005; Viana and Rebesco, 2007). Contour currents may form in a wide variety of oceanographic contexts and are responsible for the generation of contourite deposits of variable dimensions in a range of geological settings (Stow et al., 1986; Ercilla et al., 1998; Gao et al., 1998; Faugères et al., 1999; Stow et al., 2002; Viana, 2001; Maldonado et al., 2003, 2005; Rebesco, 2005; Mulder et al., 2006; Rebesco and Camerlenghi, in press; Stow et al., in press-a,c, among others).

Although there are several recent classifications of contourite deposits (McCave and Tucholke, 1986; Faugères et al., 1999; Rebesco and Stow, 2001; Stow et al., 2002; Rebesco, 2005), the variety of erosive features that develop in relation to the activity of contour currents are still the "ugly duckling" of contourite studies. Knowledge of the distribution and evolution of these features is essential for understanding the oceanographic circulation regarding the direction, velocity of the current, secondary flows, filaments, local turbulence and other local hydrodynamic features. This work characterizes, in particular, the erosive submarine valley features generated by the Mediterranean Outflow Water (MOW) on the Gulf of Cadiz middle slope (Fig. 1) with three aims: a) identification of sedimentary processes associated with the erosive features; b) establishment of a detailed present-day

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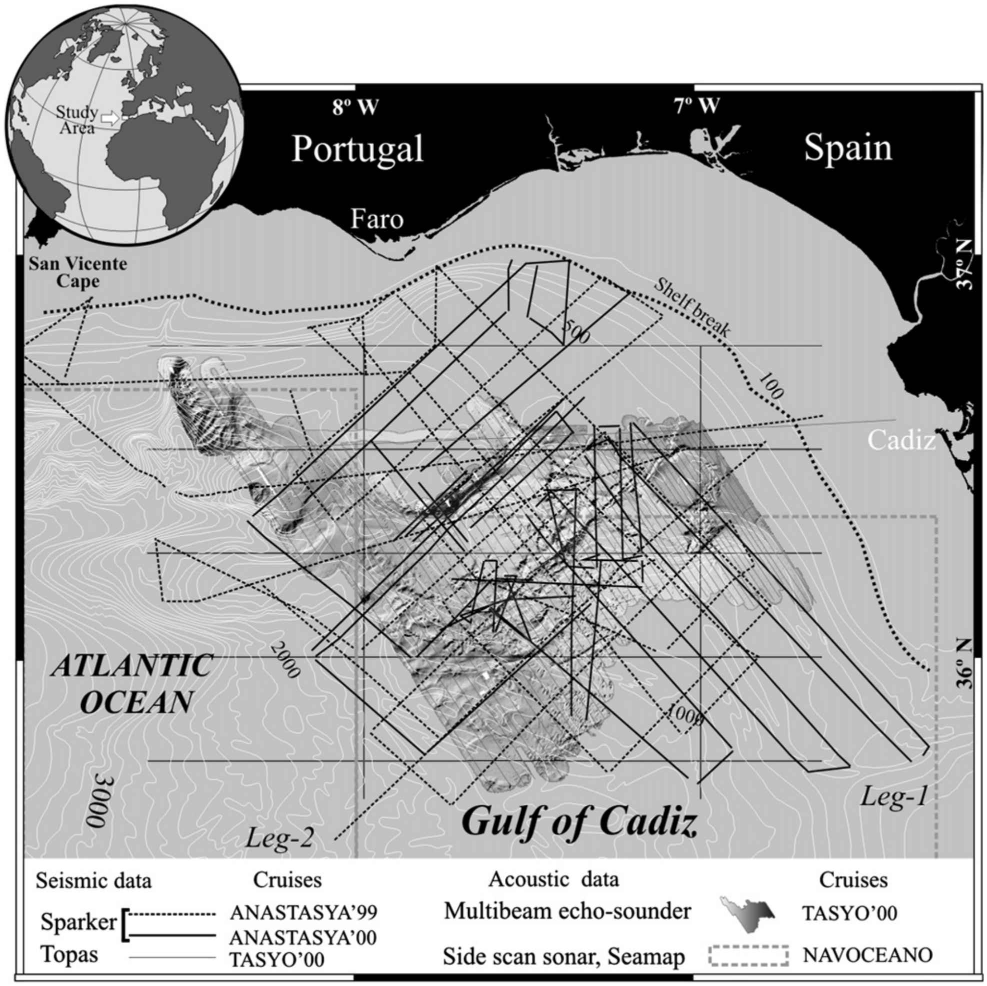

Fig. 1. Study area and datasets studied in this work, including mono-channel reflection seismic data (Sparker and TOPAS), multibeam echo-sounder mosaic and side-scan sonar imagery.

circulation model of the MOW cores and branches; and c) interpretation of the Quaternary tectonic and oceanographic evolution responsible for the generation of the erosive features.

2. Methodology

The present study is based on an extensive database of bathymetric and seismic reflection profiles (Fig. 1). Regional bathymetric maps by Heezen and Johnson (1969) and Serrano et al. (2005) were used for the regional morphological study. High-resolution swath bathymetry and backscatter data were obtained with the Simrad EM12S-120 multibeam echo-sounder system and the Seamap Side Scan Sonar system operated by the NRL and Naval Oceanographic Office (NAV-OCEANO). Seismic reflection profiles were obtained with a Sparker system. The seismic emission frequency was between 100 and 1500 Hz, giving an average vertical resolution of 1.5 m. Global Positioning System (GPS) and GPS-Differential systems were used for the data positioning.

3. Geological and oceanographic setting

The Gulf of Cadiz is located at the SW margin of the Iberian Peninsula (Fig. 2A). Since the late Miocene, different tectonic regimes have affected this area, from compressive to transtensional regimes. The emplacement of a giant “olistostrome” (the Cadiz Allochthonous Unit or Cadiz Nappe) during the Tortonian induced very high rates of basin subsidence and strong diapiric activity (Maldonado and Nelson, 1999; Maldonado et al., 1999; Somoza et al., 1999; Medialdea et al., 2004). The olistostrome has been alternatively defined as an actively deforming accretionary wedge originated by the ongoing W-SW shortening in a scenario of active subduction in a compressive tectonic regime (Gutscher et al., 2002). Salt- and shale-tectonics resulting from extensional events from Late Tortonian to Late Messinian and from Early Pliocene to Late Pliocene affected the olistostrome and induced large-scale mass wasting events (Maestro et al., 2003). Neotectonic reactivation in the Gulf of Cadiz is indicated by the occurrence of mud volcanoes, diapiric ridges and fault reactivation (Maestro et al., 1998; Díaz del Río et al., 2003; Lobo et al., 2003; Maestro et al., 2003; Somoza et al., 2003; Fernández-Puga, 2004; Fernández-Puga et al., 2007; Llave et al., 2007a,b).

The continental slope of the Gulf of Cadiz is composed of three domains: *upper*, *middle* and *lower* slope (Fig. 2B) based on the gradient and morphological features (Heezen and Johnson, 1969; Maldonado and Nelson, 1999; Hernández-Molina and Lobo, 2005). The *upper slope* occurs from 120–140 to 500 m water depth. The *middle slope* occurs at depths of about 500–1200 m, with a maximum width of 100 km and low gradients of 0.5–1°. The *lower slope* is 50–200 km wide and connects with the abyssal plains at 4300–4800 m water depth.

A Contourite Depositional System (CDS) has been characterized within the Gulf of Cadiz middle slope region (Llave et al., 2001; Hernández-Molina et al., 2003, 2006; Llave et al., 2006) and is composed of five morphosedimentary sectors (Fig. 2D): p*roximal scour and sand ribbons; overflow sedimentary lobe; channels and ridges; contourite drifts* and *submarine canyons sectors*. Amongst several different types of erosive features, those designated as submarine valleys include *contourite channels, large isolated furrows, marginal valleys* and *moats*