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Microstructure of muddy contourites from the Gulf of Cádiz

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ABSTRACT

In deep-sea sediments, contourites deposited from bottom currents mainly along slopes are associated with hemipelagites, pelagites, and sediment gravity-flow deposits. The major sedimentary facies of contourites are characterized by bioturbation and mottling and bigradational grading. However, it is difficult to discriminate muddy contourites from hemipelagites by using only these features of the lithofacies, particularly in core samples. Therefore, the present study focused on microstructure as an additional potentially diagnostic characteristic for identifying muddy contourites. Microstructures of muddy contourites, mainly from the Gulf of Cádiz, and of hemipelagites from off the West Iberian margin collected by IODP Expedition 339 were examined, along with their magnetic fabric and grain-size distribution. The results showed that the muddy contourites were composed mainly of silt grains, including plate-like silt particles that were oriented parallel or sub-parallel to the bedding plane. Some samples were composed of silt grains up to 100 μm in apparent size. In contrast, the hemipelagites were composed of calcareous nannoplankton or silt grains and randomly oriented clay particles. The magnetic fabric, as indicated by the anisotropy of magnetic susceptibility, and the grain-size distribution of the muddy contourites also differed from those of hemipelagite. On the basis of these features, the plate-like silt particles parallel or sub-parallel to the bedding plane characterizing the muddy contourites were interpreted to reflect rapid deposition from a low-concentration suspension of fine-grained particles in a weak bottom current. Although microstructural features used alone are insufficient, used in conjunction with magnetic fabric and grain-size distribution, they are expected to be a useful tool for discriminating muddy contourites from hemipelagites.

1. Introduction

In deep-sea environments, hemipelagites and pelagites are formed by fall out of fine-grained suspensions and episodic-event deposits are formed by sediment-gravity flows such as turbidity currents, whereas contourites are deposited from bottom currents, mainly along slopes (e.g., Rebesco et al., 2014). Bottom currents, which are a major means of sediment transport and deposition in deep-sea environments, are affected by both local and global factors, including climate, sea level, and tectonics (e.g., Faugères and Mulder, 2011). Therefore, to reconstruct fluctuations of bottom currents controlled by other factors, it is important to discriminate contourites from other deep-sea sediments and to understand their spatial and temporal distribution patterns.

Many studies have described the lithofacies of specific contourites in various regions (e.g., Stow and Lovell, 1979; Stow and Holbrook, 1984; Stow and Piper, 1984; Pickering et al., 1989; Faugères and Stow, 1993; Gao et al., 1998; Faugères et al., 1999; Llave et al., 2006; Øvrebø et al., 2006; Shanmugam, 2006; Stow and Faugères, 2008; Shanmugam, 2012, 2013; Stow et al., 2013). Gonthier et al. (1984) proposed a standard facies model for contourites based on those found in the Gulf of Cádiz, where they are characterized by a bigradational grading: the sequence first coarsens upward from mud to sandy silt and then fines upward from sandy silt to mud. Stow and Faugères (2008) have more recently proposed variations on this model. Although the numerous studies on contourite facies are useful for recognizing contourites in other regions, the diagnostic features of contourites are still controversial (e.g., Rebesco et al., 2014). In particular, the features of contourites composed of clay- and silt-sized materials (herein called muddy contourites), which are characterized mainly by mottling caused by bioturbation by benthic organisms and rare or no lamination (e.g., Gonthier et al., 1984; Stow and Holbrook, 1984), are similar to those of hemipelagite. Thus, it is often difficult to discriminate muddy contourites from hemipelagites, especially in core samples, which only allow limited observation of the deposit.

The focus of the present study was the microstructural characteristics of muddy contourites. In general, a fabric characterized by randomly oriented clay particles has been interpreted to be ubiquitous in hemipelagites, which are deposited from low-concentration suspensions of mud under quiescent bottom-water conditions in marine and transitional marine environments (e.g., Bennett et al., 1981, 1991; O'Brien, 1987; Kawamura and Ogawa, 2004). In contrast, the microstructure of muddy contourites has yet to be clarified. Therefore, the present study investigated the microstructure of muddy contourites

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from the Gulf of Cádiz collected by IODP Expedition 339, focusing on potentially diagnostic characteristics that would be useful for discriminating muddy contourites from other deep-sea deposits.

2. Regional setting: Gulf of Cádiz

The Gulf of Cádiz is located along the southwestern coast of the Iberian Peninsula (Fig. 1). Mediterranean Outflow Water (MOW) from the Strait of Gibraltar flows along the middle slope (500–1400 m water depth) of the gulf, which generally lacks submarine canyons, and then along the West Iberian margin (e.g., Hernández-Molina et al., 2006). The current speed of the MOW is as high 300 cm/s near the Strait of Gibraltar, and it decreases to around 80 cm/s around Cape São Vicente (e.g., Cherubin et al., 2000). This remarkable bottom current generates the well-known contourite depositional system in the Gulf of Cádiz and around the West Iberian margin; this depositional system is characterized by both large depositional and erosional features that vary spatially (e.g., Hernández-Molina et al., 2003, 2006). Various types of contourite drift have accumulated with a high sedimentation rate since the opening of the Strait of Gibraltar at 5.3 Ma; thus, they provide a high-resolution record of past climate associated with MOW fluctuations (e.g., Voelker et al., 2006). Recently, IODP Expedition 339 drilled cores in the contourite drifts and showed that the evolution of the MOW was closely related to global shifts of ocean circulation and climate, as well as to regional tectonics (Hernández-Molina et al., 2014).

3. Materials and methods

3.1. Samples

A total of 45 samples of muddy contourites obtained from five sites (U1386, U1387, U1389, U1390, U1391) in the Gulf of Cádiz and the West Iberian margin by IODP Expedition 339 were examined (Table 1). These samples are representative of the finest interval of specific bigradational grading sequences (Gonthier et al., 1984) within the core samples, which were collected by using the Advanced Piston Core system (APC). Disturbed parts of the core (e.g., flow-in, fall-in) were avoided. The muddy contourite lithofacies were characteristically mottled (Fig. 2A). Some muddy contourites from Site U1391 showed faint lamination (Expedition 339 Scientists, 2012). Shipboard X-ray diffractometry (XRD) analyses showed that the samples were composed of quartz, calcite, and illite, with minor plagioclase, dolomite, K-feldspar, and other clay minerals (chlorite, kaolinite, and smectite) (e.g., Expedition 339 Scientists, 2013a,b). The bulk sedimentation rate of the APC cores from these five sites ranged from ~25 to ~75 cm/ky (Expedition 339 Scientists, 2012).

In addition to the muddy contourite samples, 15 samples of hemipelagite obtained from site U1385 ("Shackleton Site") on the West Iberian margin by the same expedition were also examined (Table 1). All core samples from the site were collected with the APC, and disturbed parts of the core samples (e.g., flow-in, fall-in) were avoided. The hemipelagite lithofacies also showed mottling (Fig.2B), which was associated with bioturbation (Expedition 339 Scientists, 2013c). Shipboard XRD analyses showed that the samples were composed of quartz and calcite with minor dolomite, K-feldspar, plagioclase, and clay minerals (smectite, illite, and kaolinite) (Expedition 339 Scientists, 2013c). The bulk sedimentation rate at this site was ~10 cm/ky (Expedition 339 Scientists, 2012).

Subsamples for measurement of the anisotropy of magnetic susceptibility (AMS) and for microstructural observations by scanning electron microscopy (SEM) were obtained from the split working half of each core using 7 cm^3 plastic cubes that are generally used to collect samples for paleomagnetic analysis. In addition, subsamples for grain-size analyses were collected in 10 cm^3 cylinders from

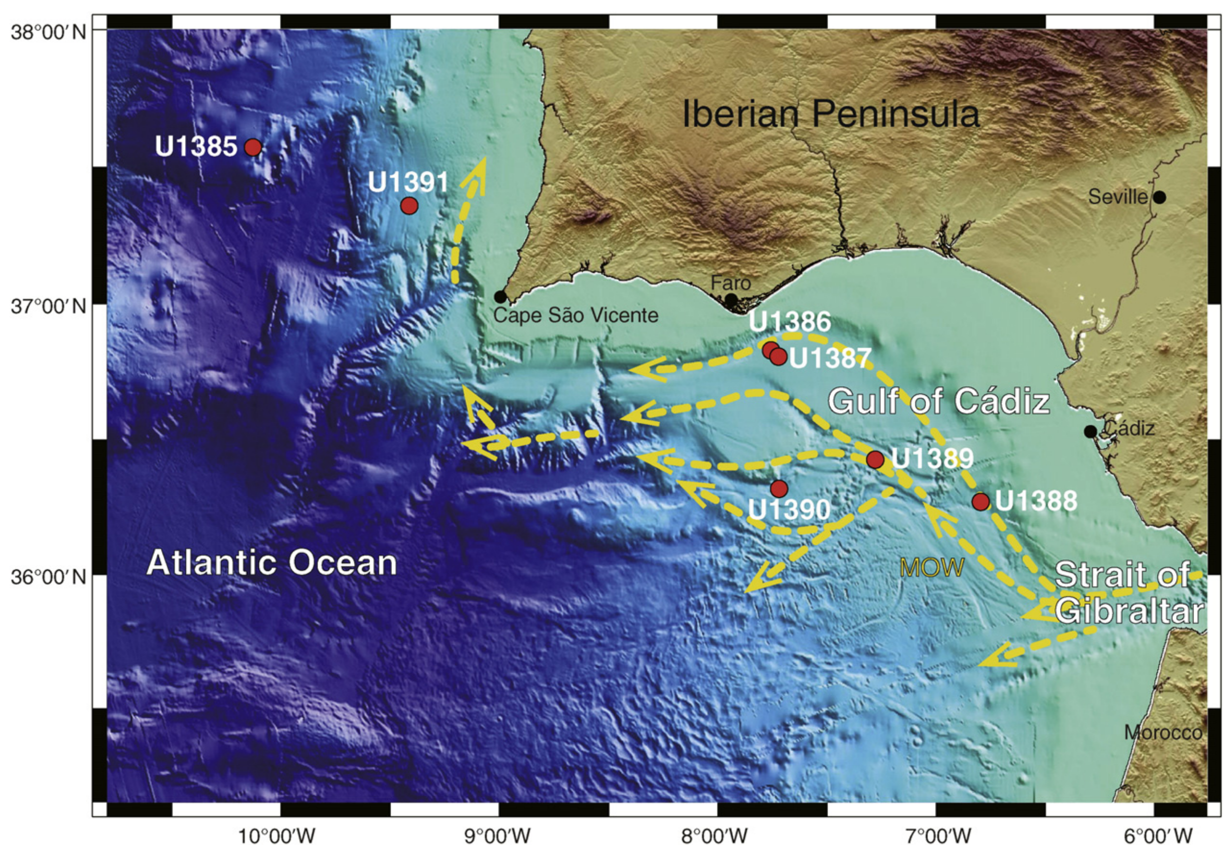

Fig. 1. Map showing drilling sites of IODP Expedition 339 and main pathways of the Mediterranean Outflow Water (MOW) in the Gulf of Cádiz and the West Iberian margin. Modified from Expedition 339 Scientists (2012).