ARTICLE IN PRESS
MARGO-05348; No of Pages 15
Marine Geology xxx (2015) xxx–xxx
Contents lists available at ScienceDirect
Marine Geology
journal homepage: www.elsevier.com/locate/margeo

Reworked tsunami deposits by bottom currents: Circumstantial evidences from Late Pleistocene to Early Holocene in the Gulf of Cádiz

Y. Takashimizu [a,*], R. Kawamura [b], F.J. Rodríguez-Tovar [c], J. Dorador [c], E. Ducassou [d], F.J. Hernández-Molina [e], D.A.V. Stow [f], C.A. Alvarez-Zarikian [g]

[a] Department of Geology, Fac. of Education, Niigata University, Japan
[b] Kamoshida Dai-ichi Elementary School, Yokohama, Japan
[c] Departamento de Estratigrafía y Paleontología, Univ. Granada, 18002 Granada, Spain
[d] Université de Bordeaux, UMR CNRS 5805 EPOC, Allée Geoffroy St Hilaire, 33615 Pessac cedex, France
[e] Department of Earth Sciences, Royal Holloway University London, Egham, Surrey TW20 0EX, UK
[f] IPE, Heriot-Watt University, Edinburgh, Scotland, UK
[g] International Ocean Discovery Program (IODP) and Dept. of Oceanography-Texas A&M University, USA

ARTICLE INFO

Article history:
Received 13 March 2015
Received in revised form 13 September 2015
Accepted 17 September 2015
Available online xxxx

Keywords:
Bi-gradational grading
Bottom current
Contourite
Grain size
Radiocarbon age
Ichnology
Mediterranean outflow water
Tsunami deposits

ABSTRACT

Younger Sand layers (YSLs) have been identified in drill cores of a Late Glacial to Early Holocene muddy contourite succession from the Gulf of Cádiz. In this study, we evaluate the grain size characteristics of the YSL, which display bi-gradational grading, with inverse grading (from silt to fine- or medium-grained sand) followed by normal grading (from fine- or medium-grained sand to silt). Radiocarbon dating shows that the YSL formed at three distinct times: 1) the Bølling-Allerød (sites U1387 and U1386); 2) the Younger Dryas (site U1390), and; 3) the beginning of the Boreal (site U1389). Ichnological analyses and radiocarbon dating of cores from drill site U1389C indicate that the YSLs consist of reworked materials deposited at a high sedimentation rate. The results of sedimentological analyses, ichnological treatment, spatial distributions, and radiocarbon dating of the YSLs suggest that the possibility of an origin of the YSLs is tsunami-related but later reworked by bottom current. However, the source areas of the sandy sediments remain unclear, although our results show them to be variable and area dependent. Some sandy deposits are transported by the Mediterranean Outflow Water (MOW) from the proximal sector of the Gulf of Cádiz Contourite Depositional System (CDS), which is close to the Strait of Gibraltar. However, in other cases it is more probable that local gravity flows, which are the result of instability on adjacent margins, provide the sandy material.

1. Introduction

Contourites are sediments deposited by or significantly affected by bottom current action (e.g., Stow et al., 2002, 2008; Rebesco et al., 2008, 2014). Various contourite facies models have been proposed based on both modern and ancient deposits (e.g., Stow and Lovell, 1979; Faugères et al., 1984; Gonthier et al., 1984; Faugères et al., 1984; Stow and Piper, 1984; Hüneke and Stow, 2008; Stow and Faugères, 2008; Shanmugam, 2012). Recently, Stow and Faugères (2008) proposed an integrated model that recognizes 11 different facies on the basis of their grain size and composition: 1) muddy contourites, 2) silty contourites, 3) sandy contourites, 4) gravel-rich and gravel-bearing contourites, 5) shale-clast or shale-chip layers, 6) volcaniclastic contourites, 7) calcareous muddy and silty contourites, 8) calcareous sandy contourites, 9) calcareous gravel-lag contourites, 10) siliceous bioclastic contourites, and 11) chemogenic contourites. In addition, Stow and Faugères (2008) re-interpreted the Gonthier et al. (1984) original model for contourites, describing five generic contourite sequences based on bioturbated divisions (C1–C5), which include a mud–silt sand sequence characterized by bi-gradational grading. In general, the formation of bi-gradational sequences is thought to be controlled by long-period variations in the mean velocity of the bottom current and by the rate of sediment supply. Rebesco et al. (2014) comprehensively reviewed the study history of contourite facies model from Shanmugam et al. (1993); Martín-Chivelet et al. (2008); Shanmugam (2006a, 2008, 2012), and Stow and Faugères (2008), and introduced examples of the principal sedimentary facies for the contourites recovered during IODP Expedition 339 (Hernández-Molina et al., 2013). Using high-resolution biostratigraphy, oxygen isotope ratios, and radiocarbon data, Stow and Faugères (2008) highlight 2–5 ky cycles of deposition. In contrast, Hüneke and Stow (2008) discuss 2–20 ky cycles, which are possibly Milankovitch in origin. With regard to late Pleistocene Gulf of Cádiz Contourite Depositional System (CDS), Llave et al. (2006) use seismic stratigraphy, long cores, and radiocarbon data to suggest that the formation was linked to Heinrich events

* Corresponding author.

http://dx.doi.org/10.1016/j.margeo.2015.09.009
0025-3227/

Please cite this article as: Takashimizu, Y., et al., Reworked tsunami deposits by bottom currents: Circumstantial evidences from Late Pleistocene to Early Holocene in the Gulf of Cád..., Marine Geology (2015), http://dx.doi.org/10.1016/j.margeo.2015.09.009

and the Younger Dryas. Although similar observations are made by Voelker et al. (2006); Toucanne et al. (2007), and Bahr et al. (2014), the detailed origin of facies-scale sedimentation through time in this region, and the role of bottom currents remains debated.

Between November 2011 and January 2012, the Integrated Ocean Drilling Program (IODP) Expedition 339 drilled five sites in the Gulf of Cádiz, along with two additional sites off the western Iberian margin. They recovered 5.5 km of sediment cores with an average recovery of 86.4%. The Gulf of Cádiz was targeted because it represents a key location for investigating the Mediterranean Outflow Water (MOW), which travels through the Gibraltar Strait and impacts on global circulation and climate (Expedition 339 Scientists, 2012; Hernández-Molina et al., 2013, 2014a, 2014b; Stow et al., 2013b).

In this study, we use grain size analysis, ichnological treatment and accelerator mass spectrometry (AMS) carbon-14 (^{14}C) radiocarbon dating to evaluate younger sand layers (YSLs) found within the Gulf of Cádiz CDS. These units are located below the present-day seafloor sand (PSS), and are intercalated in the Holocene sedimentary successions.

Understanding an origin and features of bi-gradational graded sequence contributes to development of contourite science in the future. YSLs are one of well preserved contourite layer with bi-gradational sequence. For this reason, the main targets of this study are YSLs through Gulf of Cadiz collected by IODP expedition 339. We present a detailed sedimentary stratigraphy that includes a description of bottom current-related sandy deposits. The results of this study will facilitate the more accurate identification of similar deposits in ancient contourites.

2. Regional setting

The southwestern Iberian margin is located near the Azores–Gibraltar Fracture Zone, which is a section of the convergent plate boundary between Eurasia (the Iberian sub-plate) and Africa (the Nubian sub-plate). Plate convergence currently occurs at a rate of ~4–5 mm/y in a WNW-ESE direction. Counter-clockwise rotation along the margin is accommodated by a series of thrust and dextral strike-slip faults (Zitellini et al., 2009; Duarte et al., 2011), active since at least 1.8 Ma. The area is characterized by low–moderate magnitude seismicity (Udías et al., 1976; Grimson and Chen, 1986; Buforn et al., 1995, 2004; Stich et al., 2003, 2005). A number of earthquake-induced tsunami events of historical or pre-historical age are recorded in the sediments of offshore Portugal or in the coastal lowlands of the Gulf of Cádiz (e.g., Gràcia et al., 2010; Lario et al., 2011; Rodríguez-Vidal et al., 2011).

IODP Expedition 339 revealed that the sedimentary evolution of the Gulf of Cádiz, located off the western coast of Portugal, records a detailed history of MOW evolution, extending back to the opening of the Strait of Gibraltar at 5.33 Ma (Hernández-Molina et al., 2014a, 2014b). At present, the MOW results from the mixing of Mediterranean Levantine Intermediate Water and Western Mediterranean Deep Water within the Strait. Upon exiting the Strait, the MOW cascades downslope as a warm saline water overflow (0.67 ± 0.28 Sv; Rogerson et al., 2012) before flowing northwestwards and settling as an intermediate bottom current along the middle slope. Along the middle slope, at water depths of 400–1400 m, two differentiated cores are observed: the Upper Core (MU) and the Lower Core (ML).

The interaction between the MOW and the middle slope of the Gulf of Cádiz generated an extensive CDS, which is divided into five morphosedimentary sectors (Hernández-Molina et al., 2003, 2006; Llave et al., 2006): 1) the proximal scour and ribbons sector, 2) the overflow sedimentary lobe sector, 3) the channels and ridge sector, 4) the contourite depositional sector, and 5) the submarine canyons sector. The development of each of these five sectors relates to the systematic deceleration of the MOW, caused by its interaction with margin bathymetry, as well as the effects of the Coriolis force. In general, the drifts consist mainly of muddy, silty, and sandy sediments with a mixed terrigenous (dominant component) and biogenic composition (Gonthier et al., 1984; Stow et al., 1986, 2002). In contrast, sand and gravel are found in the large contourite channels (Nelson et al., 1993, Nelson et al., 1999; Stow et al., 2013a), along with numerous erosional features (Hernández-Molina et al., 2006; García et al., 2009).

In this study, we use samples from sites U1388, U1389, U1390, U1387, and U1386 (Fig. 1) to document the detailed sedimentological characteristics of the late Pleistocene to Holocene Gulf of Cádiz CDS. Sites U1388, U1387, and U1386 are located under the MU, and sites U1389 and U1390 are distributed within the pathways of the ML. Site U1388 is located ~50 km southwest of the Spanish city of Cádiz in waters with a depth of 663 m. The site lies within the extensive Cádiz sandy sheeted drift and is the closest site to the Strait of Gibraltar. Sites U1389 and U1390 are located within the middle sector of the CDS. Site U1389 is located ~90 km west of Cádiz in waters with a depth of 644 m. It sits on a relative topographic high, which is currently elevated 50–250 m above the flanking contourite channels, ~4 km northwest of the Guadalquivir diapiric ridge. Site U1390 is located ~130 km west of Cádiz in waters with a depth of 992 m. It sits near to the western end of a sheeted drift, which is adjacent to the Guadalquivir Bank and the Guadalquivir contourite channel. It is located 300 m above the channel floor and a little less than 20 km northwest of the of the Guadalquivir diapiric ridge. Site U1387 is located on an elongated mound and is separated from the Faro-Albufeira Drift (hereafter referred to as Faro Drift). It is positioned ~29 km south-southeast of the Portuguese city of Faro in waters with a depth of 559 m. Site U1386 is located at the eastern end of the Faro Drift, less than 25 km south-southeast of Faro, in waters with a depth of 561 m. This site, which lies just 4 km northwest of Site U1387, is the most distal from the Strait of Gibraltar, and represents the most depositional sector within the Gulf of Cádiz CDS.

3. Methodology

3.1. Core descriptions

Sedimentary logs for each drill hole were compiled using a visual core description and high resolution photographs made by scientists on board the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) Resolution vessel (Expedition 339 Scientists, 2012; Stow et al., 2013b). Core descriptions are based on sediment textures, composition, type of bed contact, grain size, facies changes, fossil assemblages, and degree of bioturbation.

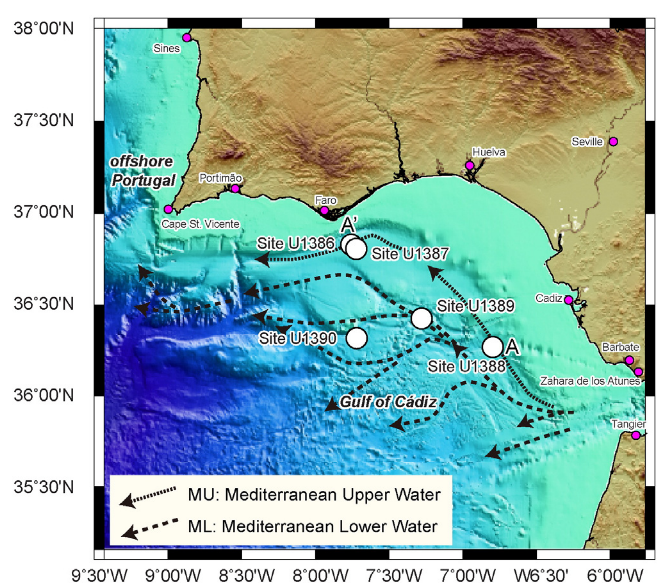

Fig. 1. Index map of the study area. White circles denote drilling sites.