Quaternary Science Reviews 197 (2018) 92–111

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Paleoceanographic and climatic implications of a new Mediterranean Outflow branch in the southern Gulf of Cadiz

S.M. Lebreiro [a,*], L. Antón [b], M.I. Reguera [a], A. Marzocchi [c]

[a] IGME - Geological Survey of Spain, 28003, Madrid, Spain
[b] IGME - Geological Survey of Spain, 28760, Tres Cantos, Spain
[c] National Oceanography Centre, Southampton, UK

ARTICLE INFO

Article history:
Received 30 November 2017
Received in revised form
19 July 2018
Accepted 23 July 2018

Keywords:
Quaternary
Paleoceanography
Climate modelling
North Atlantic
Foraminifers
Stable isotopes
Sortable silt
Mediterranean outflow
Morocco contourite drift

ABSTRACT

The presence of contourite drifts in the southern Gulf of Cadiz (GoC) along the Moroccan margin raises questions about the (re)circulation of Mediterranean Outflow Water (MOW) in the GoC and the origin of the currents depositing them. Here, we compare two cores representative of Iberian and Moroccan contourite drifts, covering the last 22 kyr. Although the whole sequence is contouritic in character, it reflects the interaction of distinctive silty-contourite facies (high flow velocity periods) imbedded in muddy-contourite facies (low flow velocity periods). Evidence from benthic foraminifera $\delta^{13}C$, sortable silt grain-size, oceanographic CTD profiles and numerical simulations, indicate the Mediterranean water mass as the source of the southern contourite deposits. Our data, therefore, suggests an additional branch of upper-MOW veering southwards off the Straits of Gibraltar along the Moroccan margin. During MIS-(Marine Isotope Stage) 2, upper-MOW was a sluggish current while in the Holocene upper-MOW dominated as a fast, semi-steady flow. Throughout the deglaciation, silty contourites associated with higher flow speeds were deposited in the northern and southern GoC during cold events such as Heinrich Stadial 1 (HS1) and the Younger Dryas, forced by global millennial-scale climate variability. Millennial variability also appears to drive the deposition of silty-contourites in the Holocene. We estimated an average duration of 1 ka for the process of depositing a fast contourite unit. The case of silty-contourite I6 (within HS1) allows us to illustrate with extremely high resolution a "rapid" sequential change in circulation, with gradual slow-down of dense Mediterranean water while surface was freshening (HS1), provoking injection of high-salinity intermediate waters (via contour-currents) into the GoC, and hence the North Atlantic. The subsequent brief collapse of dense water formation in the Mediterranean Sea triggered a major increase in sea surface temperatures (10 °C/ka) in the GoC, developing into the next interstadial (Bølling/Allerød). The impact of Mediterranean intermediate waters is manifested here by triggering a substantial rearrangement of intermediate and deep circulation in the North Atlantic, which would have further impacted the Atlantic Meridional Overturning Circulation (AMOC).

1. Introduction

The Mediterranean Outflow Water (MOW), a water mass flowing mainly at intermediate depths in the eastern North Atlantic, plays an important role in the development of Contourite Depositional Systems west of the Gibraltar gateway. Its interaction with the adjacent continental margins determines the evolution of local contourite drifts in the northern side of the Gulf of Cadiz (GoC). While the MOW is considered a well-established source for the Faro Drift contourites deposited on the Iberian margin (Faugères et al., 1984; Gonthier et al., 1984; review in Hernández-Molina et al., 2006; Llave et al., 2001; Nelson et al., 1993; Rogerson et al., 2006; Sierro et al., 1999; Stow, 1985), the nature of the current which is depositing the Moroccan Drift contourites (Suppl. Fig. S1) is poorly understood.

We envisage three possible hypotheses for the occurrence of contourites along the Moroccan margin, at an equivalent depth (550 m) as those found on the Iberian margin (Fig. 1A). First, the upper-MOW splits off Gibraltar and circulates not only along the

* Corresponding author.
E-mail addresses: susana.lebreiro@igme.es (S.M. Lebreiro), l.anton@igme.es (L. Antón), mi.reguera@igme.es (M.I. Reguera), alice.marzocchi@noc.ac.uk (A. Marzocchi).

https://doi.org/10.1016/j.quascirev.2018.07.036
0277-3791/

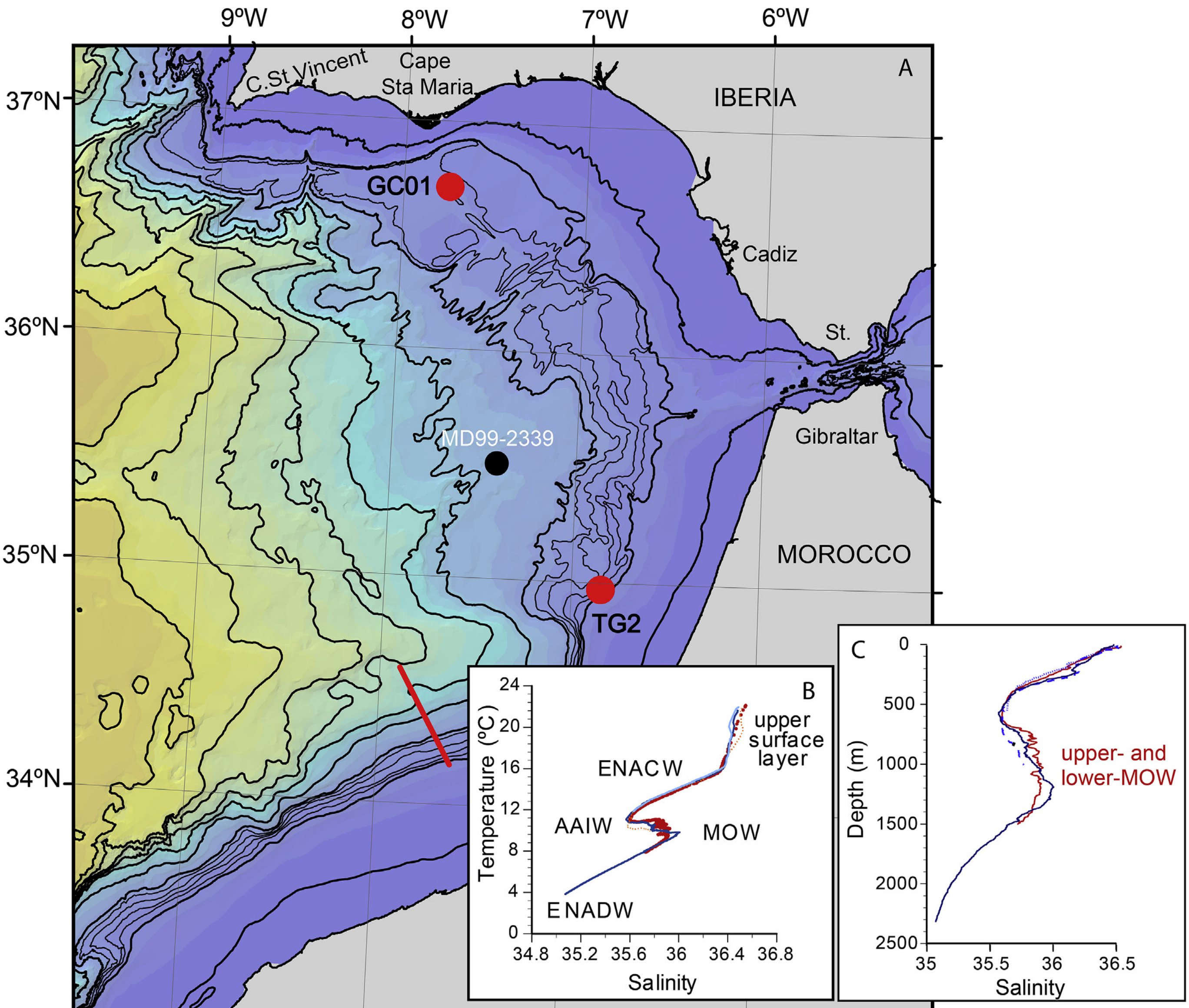

Fig. 1. Location of contourite drift sites in the N and S of the Gulf of Cadiz: GC-01A-PC (36° 42.6257′N; 7° 44.7173′W; 566 m; cored in preparation for IODP site U1386) and MVSEIS08_TG-2 (34° 58.28′N; 6° 50.47′W; 530 m), referred in text as GC01 and TG2, respectively (A). Reference core MD99-2339 (35.88°N, 7.53°W, 1170 m) (Voelker et al., 2006). Note the presence of upper- and lower- MOW in the diagrams of Temperature/Salinity (B) and Salinity/Depth (C) across the red line transect on the southern Moroccan margin, from compilation of stations 674299 (550 m), 674287 (995 m), 674275 (1485 m) and 674263 (2295 m), available from the British Oceanographic Data Centre (BODC) of the Natural Environment Research Council, United Kingdom. ENACW (Eastern North Atlantic Central Water), AAIW (Antarctic Intermediate Water), MOW (Mediterranean Outflow Water), and ENADW (Eastern North Atlantic Deep Water). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Iberian margin, but also in a southward branch along the Moroccan margin (Fig. 2–1). Second, the northern lower-MOW jet turns southwards at Cape St. Vincent, and re-enters the GoC mixed with North Atlantic Central Water (NACW) and modified-Antarctic Intermediate Water (AAIW), in the form of meddies (Mediterranean eddies) as infered in Ámbar et al. (2008), Carton et al. (2002), Iorga and Lozier (1999), and Quentel et al. (2011) (Fig. 2–2). Or third, modified-AAIW flows directly from the South Atlantic along the NW African margin to the southern margin of the GoC, before mixing with MOW (Figs. 2–3).

The verification of hypothesis 1 would imply an underestimation of the influence of MOW on the Atlantic Thermohaline Circulation (Rogerson et al., 2006; Voelker et al., 2006). A number of CTD (Conductivity-Temperature-Depth, BODC-British data, Fig. 1B and C) profiles gathered in oceanographic cruises along the Moroccan margin within the GoC, shows evidence for the presence of modern MOW in the area at a depth of 700–1400 m, as well as further south in the passage between Morocco and the Canary Islands at 29°N latitude (Hernández-Guerra et al., 2003; Knoll et al., 2002; Llinás et al., 2002; Machín et al., 2010; Machín and Pelegrí, 2016), and offshore the Canary Islands (Armi et al., 1989; Richardson et al., 2000; Verdiere, 1992). Zahn et al. (1987), focussing on C and O isotopes, also inferred that the MOW path bathed the NW African margin down to Cape Blanc (21°N latitude) in the past 27 kyr, but shoaled to less than 1000 m between 10 and 14 kyr. Hypothesis 2 would require buoyancy of the lower-MOW and an increased flow velocity, independently of the water mixing, when the current re-enters the GoC and approaches the Moroccan margin. This would imply unconvincing hydro-dynamics, involving meddies converted into strong and/or semi-permanent and confined contour-currents.