Marine Geology xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Marine Geology

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

Near-bottom current speed maxima in North Atlantic contourite environments inferred from current-induced bedforms and other seabed evidence

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ARTICLE INFO

Article history:
Received 27 May 2015
Received in revised form 20 October 2015
Accepted 9 November 2015
Available online xxxx

Keywords:
North Atlantic
Contourite
Current-induced bedforms
Maximum near-bottom speed

ABSTRACT

Seabed acoustic data (e.g. deep-tow side scan sonar) together with information from seabed photography is presented for estimating near-bottom current speed maxima in North Atlantic contourite environments. These include the southern Iceland–Faroe Ridge flank, the southeast and southwest Greenland Margin, and the Greater Antilles Outer Ridge in the southwestern part of the North Atlantic. Geomorphological response to North Atlantic deep water circulation is expressed in a variety of dynamic bedforms and other current-controlled seabed features. Various types of dynamic bedforms reflect different hydraulic energy levels. Maximum near-bottom flow speed of almost 1.0 m/s, or more, is illustrated by 'infinite' sand ribbons found on lag sediment, while a much lower maximum of near-bottom water flow speed (<0.5 m/s) can be inferred for fine-grained sediment environments where small erosional furrows and small-scale ripple marks occur. These various dynamic bedforms notably are indicators of (past) extreme current events often not captured by current measurements, which is due to decadal-scale variability in deep-ocean circulation. The results from our study demonstrate that at (multi)decadal time scale near-bottom current speed may in some areas reach values well in excess of what is known from current measurements.

Introduction

Ocean deep convection has a major impact on the environmental conditions and ventilation of the deep ocean basins. In the northern North Atlantic deep convection occurs in the Nordic Seas and Labrador–Irminger Sea basin, from where North Atlantic Deep Water (NADW, Fig. 1) flows south along the North American continental slope (Dickson and Brown, 1994) concentrated in the high-energy Deep Western Boundary Current (DWBC). Deep convection and associated bottom water flow have been found to display significant variations, both at annual, decadal and at longer time scale (Sy et al., 1997; Bacon, 1998). In addition, several studies indicate a negative correlation between deep convection activity in the Nordic Seas north of the Greenland–Scotland Ridge (GSR) and processes in the Labrador Sea region (e.g. Lavender et al., 2000; Oka et al., 2006). At a much shorter time scale, i.e. several days, large energy pulses possibly transferred from the surface have been observed which can lead to acceleration of deep-water flow of the DWBC, so-called 'benthic storms' (Gardner and Sullivan, 1981; Aller, 1989). Benthic storms have also been recorded in the central part of the Greenland Sea deep basin, where they may be associated with sediment plumes descending from the East Greenland slope (Woodgate and Fahrbach, 1999). Significant deep-water transport from the Nordic Seas into the North Atlantic Basin via the GSR has been found responsible for the formation of most of the North Atlantic contourite drifts (Wold, 1994). Many studies have meanwhile documented climatic control of these overflow processes that appear significantly reduced or virtually ceased during glacial climate conditions (e.g. Kuijpers et al., 1998a). Contourite drifts result from prolonged current activity with prevailing mean velocities generally less than 0.5 m/s. However, these large sedimentary bodies also display evidence of episodes of (erosional) high-energy bottom current activity (Stow et al., 2009). Previous studies of the relationship between bedforms, current velocity and sediment types have been published (Stow et al. 2009; Stow et al. 2013). These studies underline the complexity of these relationships, particularly the poor definition of the height of current measurements above the seafloor.

In our contribution we will focus on three different contourite settings in the northern North Atlantic controlled by GSR cold water overflow and/or Labrador Sea Water (LSW, i.e. upper NADW) flow. In addition, seabed observations from a site in the southwestern North Atlantic located further south along the DWBC flow path will be presented. This paper is notably emphasised to represent not only an overview and compilation of various previously published data, but provides also new seabed information and results from other, recent oceanographic research relevant to the subject of our study. The main

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http://dx.doi.org/10.1016/j.margeo.2015.11.003

Please cite this article as: Kuijpers, A., Nielsen, T., Near-bottom current speed maxima in North Atlantic contourite environments inferred from current-induced bedforms and other seabed..., Marine Geology (2015), http://dx.doi.org/10.1016/j.margeo.2015.11.003

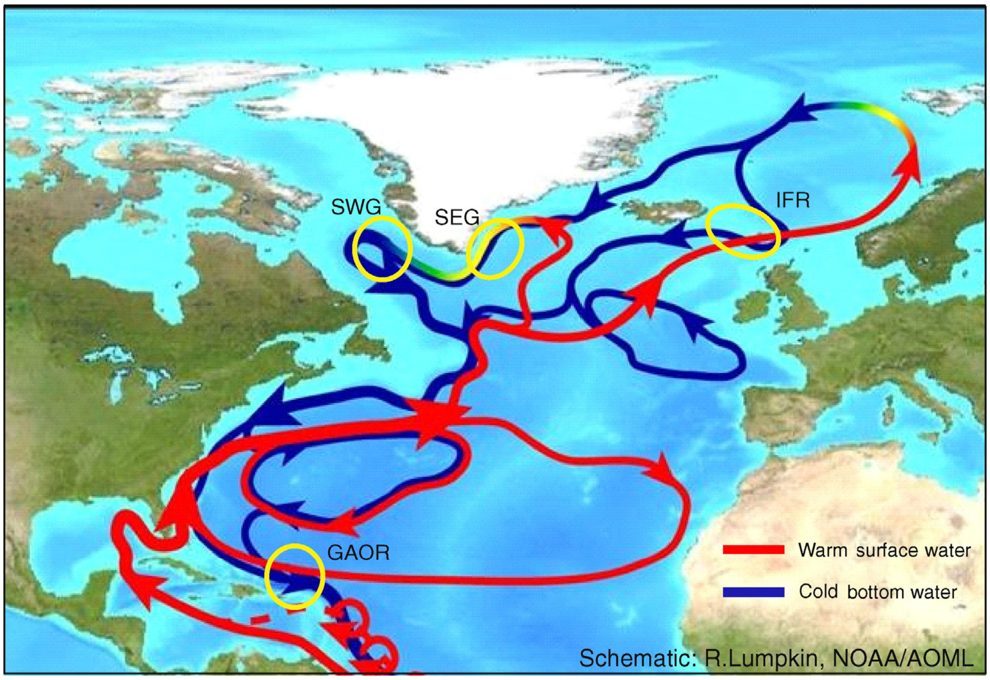

Fig. 1. Study areas (yellow circles) with North Atlantic thermohaline circulation pattern. Red and blue arrow lines indicate warm surface and cold bottom water currents, respectively (from NOAA). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

aim of our study is to compare available near-bottom current data from the selected contourite regions with seabed evidence of (past) extreme current action. As outlined above, with decadal scale variations in deep water circulation, such extreme current events may often not have been captured by current measurements.

Methods and data

Numerous studies have described different current-induced bedforms (ripples, sand waves, sand ribbons, etc.) found in shallow water, and assigned these to specific hydraulic stability fields (e.g. Dalrymple et al., 1978; Young and Southard, 1978; Werner et al., 1980; Langhorne, 1982; Kuijpers, 1985; Whitmeyer and Fitzgerald, 2008). These studies have been based not only on shallow water field measurements, but partly also on laboratory flume experiments. Values found for the hydraulic stability field and maximum near-bottom current speed of respective bedforms reported in above studies are summarised in Table 1. It is evident that similar measurements in deep-ocean environment are limited due to much larger operational costs and technical requirements. A recent compilation of deep-water bedforms and velocity relationships has been published by Stow et al. (2009), illustrating still many uncertainties of the hydraulic stability fields of various bedforms in deep-water environments. The above shallow water hydraulic information is therefore used here as a tool for estimating the approximate magnitude of extreme bottom current events having affected various North Atlantic contourite environments.

Seabed information from the Faroe GSR study area includes deep-tow side scan sonar data acquired with a dual-channel EG&G 990S model equipped with two 59-kHz transducers (Kuijpers et al. 2002), whereas side scan information from the SE Greenland margin was acquired using a deep-tow ORETECH dual channel 30-kHz side scan sonar devise with a 3–7 kHz profiler system (Kuijpers et al., 2003). Bottom photography in the canyon west of Fylla Bank off SW Greenland was carried out during deployment of a giant video-controlled (Preussag) grab (Nielsen et al., 2004). Bottom photography on the lower rise of the Greater Antilles Outer Ridge (GAOR) was carried out using a Benthos deep-sea camera triggered by bottom contact (Kuijpers and Duin, 1986).

Table 1
Dynamic bedforms and hydraulic stability field (various studies, see Methods and data).

Dynamic bedform type	Maximum near-bottom current speed (m/s)
Sand shadows	0.25–0.50
Small 'comet' marks	
Small furrows/ripples in fine-grained sediment	
Megaripples/sand waves ('dunes')	0.60–0.90
'Infinite' sand ribbons & 'comet' marks	>0.90

For further seismic and acoustic data from the Faroe study area (see Fig. 1) is referred to Bowles and Jahn (1983), Dorn and Werner (1993), Kuijpers et al. (1998b), and Kenyon et al. (2003). Relevant seismic information describing the contourite setting of the SE Greenland margin has been published by Clausen (1997) and Rasmussen et al. (2003), while Nielsen et al. (2011) has documented the existence of a large drift complex off SW Greenland. The contourite environment of the GAOR and adjacent Nares Abyssal Plain has been described by Tucholke and Ewing (1974) and Kuijpers and Duin (1986).

Results and discussion

Within the context of this study it is important to note that high-energy current events may be ascribed to several possible mechanisms. Maximum current activities can be reached under conditions of a favourable combination of barotropic and tidal current forces (Stow et al. 2013). Furthermore, within a system of permanent slope currents, regularly high-amplitude current events may occur, the so-called solibores (Hosegood and van Haren, 2004;Yttervik and Furnes, 2005). Solibores are high-frequency internal waves that display the properties of turbulent internal bores while being accompanied by short-period, intense, pulse-like internal waves that display the characteristics of solitons or internal solitary waves. The latter authors report that strong wind events connected with the passage of low-pressure systems can cause rapid perturbations in the thermocline which may then trigger the formation of near-bed solibores. A similar linkage between perturbations in the upper water masses and deep-water dynamics was found in the HEBBLE study area on the Nova Scotian continental rise

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