Earth and Planetary Science Letters 489 (2018) 228–240

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Controls on the global distribution of contourite drifts: Insights from an eddy-resolving ocean model

Amanda C. Thran [a,*], Adriana Dutkiewicz [a], Paul Spence [b,c], R. Dietmar Müller [a,d]

[a] *EarthByte Group, School of Geosciences, University of Sydney, Sydney NSW 2006, Australia*
[b] *Climate Change Research Centre, University of New South Wales, Sydney NSW 2052, Australia*
[c] *ARC Centre of Excellence for Climate System Science, University of New South Wales, Sydney NSW 2052, Australia*
[d] *Sydney Informatics Hub, University of Sydney, Sydney NSW 2006, Australia*

ARTICLE INFO

Article history:
Received 6 December 2017
Received in revised form 25 February 2018
Accepted 27 February 2018
Available online xxxx
Editor: M. Frank

Keywords:
contourite
sediment drift
ocean modelling
meridional overturning circulation
eddy
bottom current

ABSTRACT

Contourite drifts are anomalously high sediment accumulations that form due to reworking by bottom currents. Due to the lack of a comprehensive contourite database, the link between vigorous bottom water activity and drift occurrence has yet to be demonstrated on a global scale. Using an eddy-resolving ocean model and a new georeferenced database of 267 contourites, we show that the global distribution of modern contourite drifts strongly depends on the configuration of the world's most powerful bottom currents, many of which are associated with global meridional overturning circulation. Bathymetric obstacles frequently modify flow direction and intensity, imposing additional finer-scale control on drift occurrence. Mean bottom current speed over contourite-covered areas is only slightly higher (2.2 cm/s) than the rest of the global ocean (1.1 cm/s), falling below proposed thresholds deemed necessary to re-suspend and redistribute sediments (10–15 cm/s). However, currents fluctuate more frequently and intensely over areas with drifts, highlighting the role of intermittent, high-energy bottom current events in sediment erosion, transport, and subsequent drift accumulation. We identify eddies as a major driver of these bottom current fluctuations, and we find that simulated bottom eddy kinetic energy is over three times higher in contourite-covered areas in comparison to the rest o.f the ocean. Our work supports previous hypotheses which suggest that contourite deposition predominantly occurs due to repeated acute events as opposed to continuous reworking under average-intensity background flow conditions. This suggests that the contourite record should be interpreted in terms of a bottom current's susceptibility to experiencing periodic, high-speed current events. Our results also highlight the potential role of upper ocean dynamics in contourite sedimentation through its direct influence on deep eddy circulation.

1. Introduction

Contourite drifts (or "sediment drifts") are anomalously high accumulations of deep-sea sediment that are largely found around prominent bathymetric obstacles. These features have become frequent ocean drilling targets, as they can preserve high-resolution sedimentological evidence of major paleoceanographic and/or paleoclimatic change (Rebesco et al., 2014). In a series of seminal papers, Heezen et al. (1966) were among the first to propose bottom currents as the main driver for their formation, and the link between contourite drifts and the world's most powerful bottom currents steadily became apparent as more contourite drifts were discovered (Hollister and Heezen, 1972). However, causality between bottom current activity and contourite drift occurrence can be difficult to demonstrate in situ for all cases; these features are often highly inaccessible, and investigators have had to rely on sparse current meter measurements or oceanographic transects to gauge the regional hydrodynamic setting of their survey area (Rebesco et al., 2014). Such methods, though essential for ground-truthing, may not adequately represent the oceanographic processes that lead to drift formation. The use of ocean circulation models can help address these shortcomings, as they simulate these processes on larger scales while abiding by the physical restrictions imposed by fluid dynamics.

In bridging the gap between physical oceanography and the deep-sea sedimentological record, it is becoming more common to present simulation results in tandem with site survey data (e.g., seismic reflection profiling, core analyses, bathymetry

---

* Corresponding author.
E-mail address: amanda.thran@sydney.edu.au (A.C. Thran).

https://doi.org/10.1016/j.epsl.2018.02.044

data, backscatter intensities, current meter measurements, etc.) as an additional independent line of evidence used to demonstrate a given contourite's formation mechanisms (Chen et al., 2016; Hanebuth et al., 2015; Hernández-Molina et al., 2011; Uenzelmann-Neben et al., 2016). Interestingly, numerical simulations have been used to resolve and investigate lesser-known oceanographic processes (e.g., internal waves and dense shelf water cascading) that could be responsible for the formation of many shallow-water, smaller-scale drifts and their associated bedforms (Bonaldo et al., 2016; Droghei et al., 2016; Martorelli et al., 2010; Stow et al., 2009). Nevertheless, a numerical approach to drift occurrence has only been implemented on a regional scale (Bonaldo et al., 2016; Chen et al., 2016; Droghei et al., 2016; Hanebuth et al., 2015; Haupt et al., 1994; Hernández-Molina et al., 2011; Martorelli et al., 2010; Salles et al., 2010), and regional simulations are accompanied by their own set of limitations. Regional computational domains can produce boundary artefacts (Haupt et al., 1994) and generally have trouble realistically representing critical global-scale processes (e.g., Atlantic meridional overturning circulation – AMOC) that are thought to exert first-order control on contourite drift distribution throughout the world's oceans (Rebesco et al., 2014). To date, the absence of a global, cohesive contourite database has prevented the link between large-scale ocean circulation patterns and contourite drift occurrence to be demonstrated. In this paper, we present a census of the world's known contourite features, and we use this database to assess the relationship between simulated bottom current activity and contourite distribution throughout the ocean. This work represents one part of a growing effort to unite numerical methods with observations from the geological record.

2. Methods

2.1. Distribution of modern contourites

An exhaustive review of the literature was conducted to assess and refine the known coverage of modern sediment drifts. Two major existing databases were used as a basis for compiling the distribution of contourites used in this study. The first database was presented by Rebesco et al. (2014) in their recent review of contourites, and this was merged with a second online database curated by the Flanders Marine Institute (Claus et al., 2017). Additionally, more recently reported features were added to these merged databases (see Supplementary Table S1). The spatial extent of each feature was carefully re-assessed and modified by georeferencing maps provided in the original publications, as a particularly high level of granularity was required for the application of a high resolution, eddy-resolving ocean circulation model. We relied heavily upon the interpretations of the original authors, where distinct contourite geometries and morphologies (e.g., asymmetrical mounds, moats, sediment waves, erosional bedforms) were interpreted from sub-bottom profiles, multibeam and side-scan sonar data, backscatter data, and seafloor photographs. Features were omitted if they were identified solely based on core descriptions or if they are presently buried beneath turbidites or uniform hemipelagic drapes. Although aimed to be exhaustive, this compilation of known sediment drifts is a work in progress as we anticipate that many more features will be reported in the future.

2.2. Global ocean sea-ice model

To simulate present-day bottom current activity, we use a global ocean–sea ice model (MOM01) that is based on the Geophysical Fluid Dynamics Laboratory (GFDL) CM2.6 coupled climate model (Griffies et al., 2015). The model has a mesoscale eddy resolving 0.1° Mercator horizontal resolution with 75 vertical levels, where the vertical grid was engineered to resolve deep ocean eddies (Stewart et al., 2017). The model was equilibrated for 70 years to reach a dynamically steady state. The atmospheric forcing is prescribed from version 2 of the Coordinated Ocean–ice Reference Experiments (CORE) data (Griffies et al., 2009). The model accurately represents global bathymetric features and realistically simulates the critical drivers of bottom flows (e.g., global meridional overturning circulation – MOC, wind-driven shallow-water circulation, etc.) associated with sediment drift formation (Rebesco et al., 2014).

Simulated bottom current metrics (e.g., time-mean and maximum current speeds, and speed standard deviation) were then examined in relation to the distribution of contourite drifts. Simulated eddy kinetic energy in the model's bottom layer was also considered, where eddy kinetic energy was computed by decomposing daily velocity field outputs into their mean and eddy components, following the methods of Stewart et al. (2017). For each metric, values were extracted from all contourite-covered areas (i.e., points that lie within the bounds of the contourite polygons) using a Hierarchical Equal Area isoLatitude Pixelization (HEALPix) mesh of similar resolution to the computational domain at the equator (Gorski et al., 2005). Extraction of these bottom current metrics was repeated for all points that comprise the global ocean.

When discussing modelled bottom currents, where possible we provide the current name or alternatively specify the large-scale water mass classification on the basis of previous work. Identifying regional-scale intermediate and deep-water masses requires a rigorous examination of the computed vertical stratification of the water column, and thus lies beyond the scope of this study.

3. Results

3.1. Bottom current activity and global contourite distribution

The most energetic bottom currents are simulated along the western boundaries of ocean basins, near deep water creation sites, and in areas that are tightly constricted by topography. Such regions are associated with higher computed bottom current metrics (i.e., mean and maximum annual bottom current speed and bottom current speed standard deviation). There is substantial overlap between these metrics; generally, areas of the ocean with the highest mean annual bottom current speeds (U_{mean}; Fig. 1A) also exhibit the highest maximum simulated speeds (U_{max}; Fig. 1B) and standard deviation values (U_{std}; Fig. 1C).

Areas with stronger simulated bottom current activity closely correspond to the global distribution of 267 contourite features compiled from published literature (Fig. 1, see Supplementary Table S1). The average mean annual bottom current speed computed for all contourites (130,685 total computed points, ~6.3 km resolution) is 2.2 cm/s. This double that of the total global ocean, where mean annual bottom current speeds are 1.1 cm/s on average (based on 8,789,594 total computed points). Violin plots show similar kernel density distributions for computed mean annual speeds in both contourite-covered areas and the total global ocean (Fig. 2A). There is variation between the kernel density distributions when contourite coverage is grouped by region. Naturally, regions with particularly intense bottom currents exhibit a wider range of mean annual current speeds. Southwest Pacific contourites experience the highest speeds on average ($U_{mean} = 2.7$ cm/s) while contourites in the eastern North Atlantic (i.e., the Iberian Peninsula) experience the lowest ($U_{mean} = 0.7$ cm/s). Overall, contourites are found in areas of the seafloor where simulated mean annual bottom currents speeds are less than 10 cm/s.

In contrast to the mean annual bottom current speed, simulated maximum annual bottom current speeds achieve higher values in contourite-covered areas as compared to the global ocean