Deep-water bottom current dynamics: processes, products & challenges

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Abstract
Contourites are deep-water sedimentary deposits created under the influence of predominantly along-slope bottom currents. They are considered to be excellent deep-water recorders of global climatic change. Over the last decade, the improvement of deep-water survey technology enabled better visualising and understanding their driving processes, recognizing these deposits in more complex areas and in shallower depositional environments (such as shallow seas and lakes). Unfortunately, there still is no uniform and unequivocal classification, since the coupling between geological and hydrographic processes is rather vaguely defined due to the lack of good “in-situ” observations, in contrast to shallow marine and river systems. This paper aims to introduce the challenges and potential benefits that are ahead of us in contourite research, and aspires to open a dialogue between the deep and shallow water sediment dynamic communities.
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1. INTRODUCTION

The ocean basins floor, from their shallow shelf down to the abyssal plains, is swept by a large variety of bottom currents, originating from different processes. Whereas shallow marine and riverine bedforms are (also) influenced on (semi-)diurnal basis, they are however rather poor recorders of the geological or climatic log-book. Conversely, in deeper water, some of the large-scale bedforms or depositional elements driven by along-slope bottom currents are regarded as some of the best sedimentary recorders (Rebesco & Camerlenghi, 2008). Although these deposits, called contourites or sediment drifts, have been known since the 1960’s (Heezen et al., 1966), and their fundamental role in the construction and evolution of continental margins has already been clearly documented (Stow et al., 2002, Rebesco & Camerlenghi, 2008), it is only recently that their importance and relevance is coming back into the spotlights (Hernández-Molina et al., 2011). There is a vast need to improve our understanding of the involved processes, products and controls.

This present paper aims to introduce the challenges and potential benefits that are ahead of us in contourite research, and will show that a lot of knowledge can be gained from their shallow water counterparts and vice versa.

2. PROCESSES & PRODUCTS

Whereas initially the erosive and depositional features associated to contourites where only attributed to the deep thermo-haline circulation, it is now clear that they are formed under the complex interplay oceanographic processes, pre-existing seabed morphology, sediment supply and climate change (Hernández-Molina et al., 2011). Based upon this, the most recent classification of large-scale contourite drifts has been proposed by Rebesco and Camerlenghi (2008), following upon the seismic work of Faugères et al. (1999). Some of these have an elongation of over hundreds km (giant elongated drifts, abyssal sheet drifts), some may be restricted by obstacles or gateways (confined drifts, mounded drifts), or just locally attached to the margin (plastered drifts). All types may occur separately, or combined over space and time in contourite depositional systems (Hernández-Molina et al., 2011). A very wide variety of oceanographic processes, among which the internal tides are gaining importance, will leave characteristic bedforms behind, allowing to reconstruct the along-slope bottom current pattern that is responsible for the shaping of these giant drift bodies. A compilation has been made by Stow et al. (2009), based upon seabed imagery and bottom current measurements (Fig. 1).

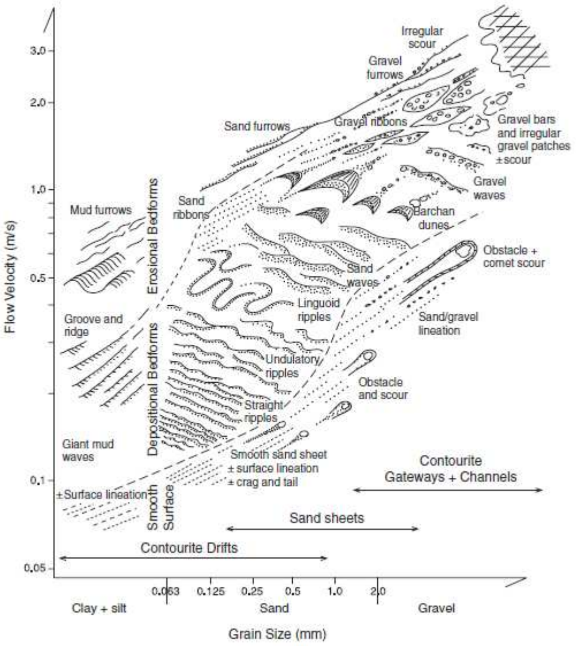

Figure 1. Bedform-velocity matrix for deep-water bottom current systems, showing mean grain size of sediment versus flow velocity at or near seafloor, with schematic representation of bedforms present under specific velocity-grain-size conditions (Stow et al., 2008).

However, they only indicate the present day current direction and strength, whereas during the depositional history of the entire sediment body, both direction as intensity may have changed significantly. On a larger scale, 3D seismic geomorphology may assist in better visualizing palaeotopographic features, whereas only through coring and drilling the fine-scale bottom current intensity changes may be deciphered. Unfortunately, the contourite sedimentary record only sporadically leaves behind traces of the wealth of present-day bedforms.

Although their study has been one of the most active lines in marine geoscience research over the last decades, necessitating an interdisciplinary approach that encompasses sedimentology, physical oceanography, stratigraphy, bio-geochemistry, geophysics, palaeoceanography and paleoclimatology, the visualising and under-standing of their driving processes is largely dependent of (and restricted to) the improvement of deep-water geophysics, coring and drilling facilities and oceanographic monitoring tools (Faugères et al., 1999; Rebesco, 2005; Hernández-Molina et al., 2011).

3. RELEVANCE & CHALLENGES

Contourite processes cover a specific part of all bottom currents, actively distinguished from the better studied downslope processes, forming turbidite deposits, organised in deep-sea fans. It is largely the economic interest of the latter that pushed research to bottom-parallel currents into the shade. Ironically, it is a renewed economic interest (Viana et al., 2007) that has put the spotlight on these deposits. Besides this, the relevance of contourite studies to science and society is manifold, despite their presence is little known and even less understood.

3.1 Palaeoceanography & global change

In the first place, both deep and shallow water circulation is driven by climate. Hence, continuous contouritic deposits, accumulated under enhanced sedimentation rates, are excellent recorders of past climate change (either local or global) and assist in better understanding the modulating role of the deep ocean in our climate's system (Rebesco, 2005). However, deconvolving the different signatures (bottom current intensity, bottom water temperatures & salinities, source fingerprinting,…) from these records is not straightforward. A multidisciplinary approach is required for better relating ocean circulation and bottom currents to their deposits and therefore for determining how best to read the palaeoceanographic or palaeoclimate signatures from contourite deposits.

3.2 Geohazards

Contourite deposits are observed all over the Earth's continental margin, predominantly as vast sheets of fine-grained material (Rebesco & Camerlenghi, 2008). The combination of these deposits, together with oversteepened slopes, (isostatic) seismicity, oversedimentation, free gas and overpressure may lead to geo-hazards, especially in polar continental margins. They lie at the origin of major slope instabilities, leading to catastrophic slope collapse and consequent damage to subsea installations and cables. Slope collapse can lead directly to major tsunami events and likely devastation to coastal regions (cfr. Storegga Slide (Bryn et al., 2005)), whereas high velocity bottom currents can erode subsea structures, undercut seafloor pipes and chafe submarine cables (Rebesco, 2005).

3.3 Earth resources

Similar to turbidite systems, also contourites may generate well-sorted deep-water sands (Stow et al, 2009). They occur in nearly any complex environment where sandy contourites are a new reservoir play for subsurface oil and gas; muddy contourites may act as potential source rocks, reservoir seals or unconventional reservoirs. Moreover, the role of deep-water circulation on the growth and distribution of ferromanganese nodules is still under debate.

3.4 Ecosystems & environmental change

Over the past decade it has become clear that most of the deep-water ecosystems (cold-water corals) are highly influenced by the presence of deep-water circulation (Hernández-Molina et al., 2011). These deep-water bottom currents are essential for the construction and maintenance of entire deep-water habitats, some of which are still little known to science and some of which provide ideal nurseries for several fish species. A better understanding of the role of bottom currents in the continued "health status" of such ecosystems will help our appreciation of the impact of climate change (long term) or oil spills (short term).

3.5 Oceanographic processes

Although the contourite paradigm has existed for over 40 years, there still seems to be a missing dialogue between physical oceanography and sedimentary observations. Nevertheless, contourite studies may greatly contribute to reconstruct past oceanographic regimes in great detail. However, in order to perform this, we first need to better understand the true interface between the "sediment processes" and "water processes".

3.6 Challenges

Despite the increasing relevance of contourite studies, many challenges lie ahead (Hernández-Molina et al, 2012). There still is no uniform and unequivocal classification, since the coupling between geological and hydrographic processes is rather vaguely defined due to the lack of good "in-situ" observations. However, there is further good potential for achieving a fundamental break-through in our understanding of ocean circulation and how the associated physical processes relate directly to sedimentary processes and their products (e.g. contourites). This area at the boundary between the often disparate disciplines of physical oceanography and sedimentology has been relatively neglected. Associated to this, more unambiguous diagnostic criteria, based upon a better integration of geophysical, sedimentological and geochemical observations may assist in better recognizing land sections, which are poorly documented and fully underrepresented.

Contourites have previously passed beneath the radar when it comes to the assessment of potential economic resources along continental margins and in deeper basin settings. However, as a principal constituent of deep-water sedimentary systems, they must constitute an essential element in the exploration of progressively deeper waters by the hydrocarbon industry. During IODP Expedition 339, for the first time, several 100 m of sandy contourites with reservoir quality were drilled (IODP Expedition Scientists, 2012).

Furthermore, palaeoceanographers are developing more advanced geochemical proxies to better reconstruct the physical and (biogeo)chemical properties of the water-masses. The most challenging task, however, is to identify, document and understand shallow-water contourites, observed in shallow seas and lakes. In terms of geometry, a lot of similarities are observed with respect to their deep-sea counterparts, but since they are predominantly dependant of (near-) surface wind-driven currents, the responsible processes and the palaeoceanographic potential are poorly known. Ultimately, no real definition has been defined where the “upper” boundary of the contourite occurrence is located, and where this (almost literally) flows over to sandbank and dune dynamics.

4. CONCLUSIONS

It is not by chance that this paper is presented during the “Marine and River Dune Dynamics” conference. The previously stated challenges have recently lead to the initiation of both the IGCP project n° 619, entitled “Contourites: geological record of ocean-driven paleoclimate, accomplice of submarine landslides and reservoir of marine geo-resources” and INQUA project n° 1204 “The Quaternary Contourite Log-book: a deep-water record(er) of variability in palaeoclimate, palaeoceanography and deep-water ecosystems”. Both projects, which basically represent research networks, are grouped under the website http://www.contourites.org, aspire to bring together scientists from over the entire marine (geo)science community in order to try to bridge the knowledge gaps. The association of bedforms and their responsible oceanographic processes is key to both the contourite as shallow water community. In contrast to shallow marine and river systems, good and frequent “in-situ” observations are scarce, due to the demanding logistic challenges of deep-water research. Nevertheless, both communities can significantly contribute to each other. Therefore, the major aim of this paper is to aspire and promote an open dialogue between the deep and shallow water sediment dynamic communities.

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