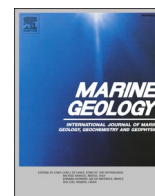


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Preface

Introduction: Special issue on bottom currents and contourites: Processes, products and impact



This special issue of *Marine Geology*, published following the 4th Deepwater Circulation (4DWC) Conference held in Edinburgh, 2023, represents a state-of-the-art perspective on oceanographic processes and their depositional products, broadly referred to as contourite systems. With over seven years since the last major compilation of studies on contourite systems (Van Rooij et al., 2016) and the last major review paper (Rebesco et al., 2014), there are numerous developments in this field of research that are documented here. This includes the integration of physical oceanographic observations and measurements with numerical modelling; documentation of previously undescribed active systems, and their influence on the seafloor; new Pleistocene-Holocene sedimentary records of contourites documenting changes in current dynamics on centennial to millennial timescales; ancient (Cenozoic) contourite systems and their record of the evolution of tectonically controlled ocean gateways; mixed turbidite-contourite (hybrid) depositional systems; and new integrated perspectives of geohazards in contourite systems (Fig. 1). These case studies cover all of Earth's major oceans at different latitudes, as well as smaller marginal seas and fjord systems, giving a unique perspective on these different marine environments and oceanographic conditions. These individual contributions are described below according to the main focus of each paper, although many contribute to multiple different themes.

1. Integrated oceanography and geology/geophysics

Direct measurements and numerical modelling of oceanographic processes and their interaction with complex seafloor topography has advanced significantly in recent years, with several case studies documented in this special issue. Wilckens et al. (2021) use measurements from Acoustic Doppler Current Profilers (ADCP) and outputs of a hydrodynamic model to understand the local variability of bottom currents associated with the Malvinas Current and their interaction with seabed topography across the La Plata and Ewing Terraces. Miramontes et al. (2021) use a similar modelling approach in the Mozambique Channel, in combination with seismic stratigraphic observations and oceanographic measurements, and propose a new simplified classification of contourites. They note that the highest bottom current velocities occur in moats and abraded terraces above drift deposits, and that internal waves play a critical role in the development of erosional features and bedforms in contourite terraces. Likewise, Chen et al. (2022) document terraced plastered drifts in the South China Sea that have developed in response to hydrodynamics at the interface of water masses and show that contourite systems are highly dependent on the interaction of topography and water masses. Rebesco et al. (2021) use numerical models, current velocity measurements and seismic observations to

show that sediment waves at the Malta Escarpment are controlled by south-flowing bottom currents along the foot of the escarpment. In a very different oceanographic setting, Porz et al. (2021) combine observational data, seismic data and numerical modelling in the Baltic Sea to document episodic, wind-drive inflows of dense, saline water from the North Sea, producing strong, cascading bottom currents in this marginal sea.

2. Modern systems

This Special Issue highlights several other active, or modern, contourite systems, in very different geographic and oceanographic settings. Nishida et al. (2022) provide one of the first detailed studies of contourites associated with the Kuroshio Current, the major wind-driven surface current of the Pacific. This system includes the largest documented contourite sand sheet and subsidiary bedforms in the Okinawa-Ryukyu region, where there is substantial interaction between the complex island arc-backarc topography and current systems. The importance of large surface currents in controlling contourite geometry and sediment composition is also highlighted by Davies et al. (2021) who show for the first time the importance of the East Greenland Current and the East Greenland Spill Jet on the formation of the Eirik Drift. On the South American Atlantic margin, de Mahiques et al. (2022) document pronounced changes in slope morphology that occur as a result of opposing current vectors at different water depths, with currents interacting with the complex seafloor topography in the region.

Several case studies also document contourite systems further away from continental slopes, where most classic contourite studies have focused. Wils et al. (2021) document drift systems forming in Patagonian fjords, on the west coast of South America. Here the Antarctic Circumpolar Current (ACC) drives episodic surface water flow into the fjords, a process that started after earthquake-induced subsidence along this active margin. Porz et al. (2021) document similar, periodic inflow to the Baltic Sea. At the other end of the ocean spectrum, in the abyssal plain of the Atlantic Ocean, Ivanova et al. (2022) document contourite drift systems formed by bottom currents flowing through the Vema Gap. The studied contourite drifts are composed of terrigenous and calcareous biogenic material, with the latter only forming above the Carbonate Compensation Depth (CCD) at ~3.5 km. Lüdmann et al. (2022) document carbonate contourites in the Maldives, where currents also interact with the topography of the archipelago, producing distinctive patch and sheeted drifts on the platform interior and around the atolls.

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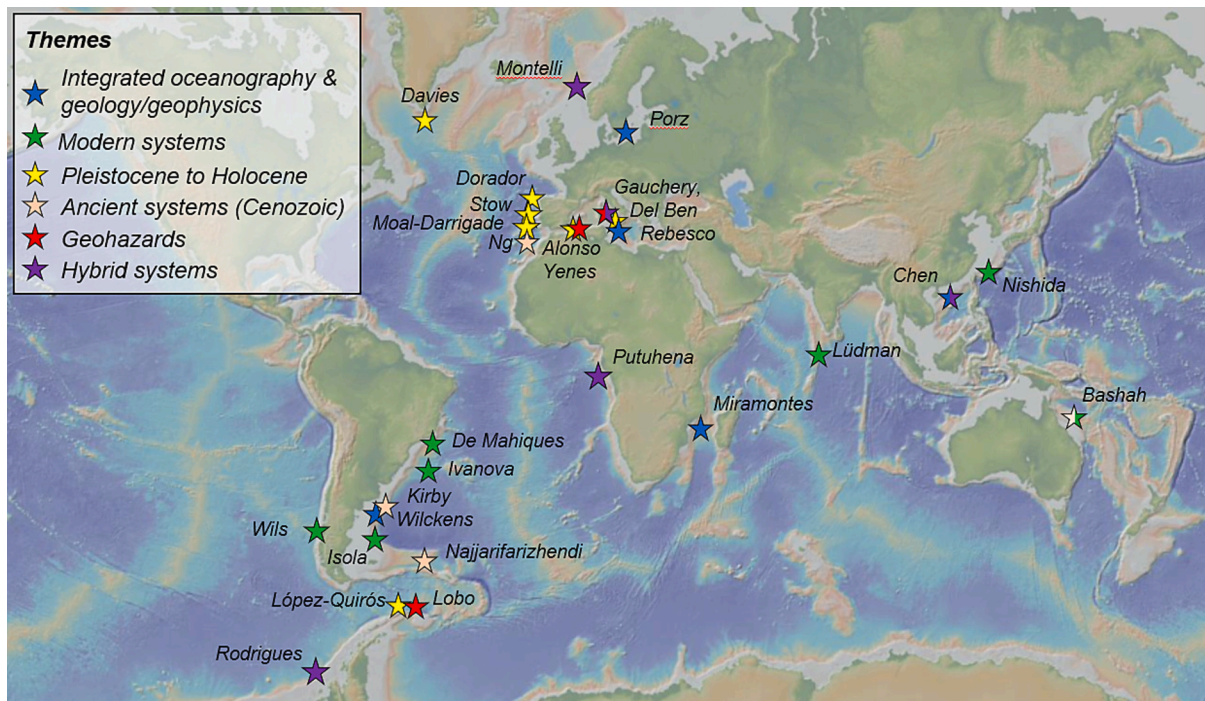


Fig. 1. Map showing the geographic distribution and main themes of the papers in this Special Issue. Lead authors highlighted for ease of reference. The underlying topography and bathymetry map was generated using GeoMapApp.

3. Pleistocene-Holocene systems: centennial to millennial-scale current dynamics

The importance of large surface currents in controlling contourite geometry and sediment composition over long (10^2 – 10^6 year) timescales is highlighted by several papers in this special issue. [Alonso et al. \(2021\)](#) use high-resolution paleoceanographic and paleoclimate archives to document changes in Western Mediterranean Deep Water (WMDW) dynamics on millennial timescales, with four distinct phases of current dynamics since 25 ka. Also in the Mediterranean, [Alonso et al. \(2021\)](#) show the contrasting responses of the velocities of light intermediate Mediterranean (LDW) and dense deep Mediterranean water (DMW) to changing climatic conditions on a centennial to millennial timescale, with important implications for deconvolving individual water mass components in contourite systems. [Stow et al. \(2023\)](#) document bi-gradational contourites in the Gulf of Cádiz to show the covariation of several textural and compositional characteristics through a single sequence, closely linked to changes in current speed and, to a lesser extent, sediment supply. These changes alternate over millennial and longer timescales reflecting relatively higher to lower current speeds. [Moal-Darrigade et al. \(2022\)](#) show that clay minerals in contourite drifts in the Gulf of Cádiz not only document a change in the strength of Mediterranean Outflow Water (MOW) on glacial-interglacial timescales, but they are also affected by sediment supply from river systems and wind-blown dust, which are profoundly affected by paleoclimate. In the same region, [Dorador et al. \(2021\)](#) use ichnofacies to document similar (intermittent) changes in contourite deposition in the NW Iberian Margin over the last 60 kyr. At higher latitudes, [López-Quiros et al. \(2021\)](#) use high-resolution seismic stratigraphy and core data to document changes in the intensity of Antarctic Circumpolar Current (ACC) and Weddell Sea Deep Water (WSDW) from glacial to interglacial timescales.

4. Ancient systems

Although this Special Issue is focused primarily on recent systems, several case studies address ancient contourite systems that record

major current reconfigurations associated with changing tectonic boundary conditions. [Najjarifarizhendi and Uenzelmann-Neben \(2021\)](#) use new 2D seismic reflection data around the Maurice Ewing Bank to document the onset of proto-ACC in drift systems as old as Paleogene. They also document a major increase in current strength at the Eocene-Oligocene boundary, emphasising the importance of the tectonic evolution of the Drake Passage in controlling current intensity. [Kirby et al. \(2021\)](#) also document drifts of Eocene and younger age on the Uruguay margin of South America, with a significant increase in deep-water circulation intensity through time. [Ng et al. \(2021\)](#) use offshore and onshore 2D seismic data in the Gulf of Cádiz to characterise outflow through the Late Miocene gateway between the Mediterranean Sea and the Atlantic Ocean. [Bashah et al. \(2024\)](#) show that major changes in contourite drift architecture have taken place since the Middle Miocene, linking these to changes in eustatic sea level (e.g. onset of northern hemisphere glaciation) and restriction of Indonesian Throughflow between the Pacific and Indian oceans. These case studies highlight the importance of tectonic boundary conditions and opening and closure of ocean gateways on contourite systems.

5. Geohazards

Contourites, particularly plastered drift deposits, are recognised as being susceptible to submarine mass failure due to their characteristic geometric and geotechnical properties, potentially making these systems an important submarine geohazard. [Lobo et al. \(2021\)](#) present a new case study of recurrent landslides derived from drift deposits on the South Scotia Ridge, where bottom currents precondition the slope for failure. [Yenes et al. \(2021\)](#) present a detailed geohazard analysis of contourite deposits in the Alboran Sea, combining in-situ geotechnical data with lab measurements to determine the physical properties of these drifts. They highlight that the drifts have high safety factors, and are likely not prone to failure, because of high consolidation induced by earthquakes or internal waves. [Gauchery et al. \(2021\)](#) also note the presence of several mass transport deposits in contourite drifts in the Mediterranean Sea, preconditioned by a phase of short-lived intense bottom currents in the region.

6. Mixed turbidite-contourite systems

Mixed turbidite-contourite systems, or hybrid systems, are generated by the interaction of along-slope bottom currents with downslope gravity currents (Mulder et al., 2008). Our understanding of the interactions of these systems has increased significantly in recent years, and this Special Issue highlights a number of new case studies addressing this theme. In West Africa, Putuhena et al. (2021) use 3D seismic data to image complex ridge and furrow structures on the continental slope. These form oblique to slope and are inferred to be formed by sediments cascading from the shelf and from canyon overflow, as well as by the regional currents flowing along slope. Rodrigues et al. (2022) document a hybrid system on the Antarctic Peninsula, where downslope systems are strongly dependent on glacial dynamics and sediment delivery to the continental margins, but also by significant changes in along-slope bottom current on glacial-interglacial timescales. Isola et al. (2021) demonstrate the effect of bottom currents on the Piedra Buena Terrace (SW Atlantic Ocean), including the generation of patchy mounded drifts and asymmetric sedimentation along submarine channels due to the interaction of bottom currents with turbidity currents on the Patagonian continental slope. In the North Atlantic, Montelli et al. (2022) show that contourite drift deposition is controlled by sediment flux during glacial periods, reworked by bottom currents during interglacials, highlighting the importance of these interacting depositional systems. At mid-latitudes, Gauchery et al. (2021) show that downslope sediment supply in the Strait of Sicily has changed significantly since the last glacial maximum, and that changes in bottom current velocity have also significantly impacted sedimentation rates and drift formation.

7. Perspectives on future development

This special issue, and research presented at the 2023 4DWC conference, highlight the significant advances that have taken place in contourite research over the last 5–10 years. Oceanographic data, including global databases of temperature, salinity, and density, are now routinely used when describing and interpreting modern contourite systems. Field measurements of current velocities from observational arrays such as RAPID and OSNAP provide critical new long-term measurements of current dynamics across ocean basins. ADCP systems are increasingly becoming available for many regions, despite the challenges of acquiring such data in the deep ocean. Numerical models have advanced significantly, particularly resolving the interaction between bottom currents and seafloor topography.

However, there are still significant uncertainties in our understanding of the dynamics of bottom currents that are not captured by current models or observational arrays. Most integrated studies of numerical models and seabed geomorphology only use *average* flow properties for currents, and do not capture the dynamic variability present in natural systems, particularly associated with mesoscale and sub-mesoscale processes. A number of papers in this Special Issue do model discrete events and maximum current speeds (e.g. Porz et al. (2021), Miramontes et al. (2021)), but these do not yet capture the full temporal and spatial variability of these bottom currents. Mesoscale eddies and associated oceanographic processes have been recognised to play an important role in sediment suspension and redistribution for decades (e.g. Gardner and Sullivan, 1981) but these are not fully captured in integrated oceanographic-sedimentological models. Recent oceanographic observations of intense seabed turbulence associated with mesoscale eddies (e.g. Evans et al., 2022) provide important new constraints for such models. Direct, long-term measurements of currents using ADCP systems have revolutionized our understanding of sediment gravity flows in submarine canyons (e.g. Azpiroz-Zabala et al., 2017) but these have not yet been extensively employed for bottom current systems, which are typically not as well confined. Thus, the impact of bottom currents on sediment transport and deposition in contourite systems is not well understood. We anticipate that future developments in these areas in

particular – numerical modelling, integration of oceanographic datasets, and direct measurements of bottom-current controlled depositional systems – will transform our understanding of these systems in the near future.

Declaration of competing interest

None.

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