4DWC EDINBURGH

The 4th Deep Water Circulation Research Conference

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Abstracts

4DWC Edinburgh

The 4th Deep Water Circulation Research Conference

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Abstract Volume

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Organising Committee:
Dorrik, Zeinab, Uisdean, Tom, Debora, Heather, Helen, Nicola, Gayle
Student support: Jiawei, Kachi, Elizabeth, Deron, Ben, Jonathan

Conference Programme

Tues 23rd **Arrival and free time**. Please contact the organisers for any suggestions. The Icebreaker Reception will now be on Wednesday 24th (see below)

Weds 24th **Royal Society of Edinburgh**, 22-26 George Street
08:00-09:00 Registration and set-up of posters
09:00-16:45 Conference keynotes, papers, posters and discussion.
16:45-18:45 Building Stones of Edinburgh tour
18:30-late: Icebreaker reception and buffet, The Dome, George Street

Thurs 25th **Royal Society of Edinburgh**, 22-26 George Street
08:00-09:00 Morning coffee and posters
09:00-17:15 Conference keynotes, papers, posters and discussion.
18:30-late: Conference Dinner, The Heights, Apex Grassmarket Hotel

Friday 26th **Lyell Centre, Heriot Watt University**, Riccarton Campus
10:00-10:30 Arrival and Coffee
10:30-15:30 Workshops and discussion
15:30 Closing drinks, Howff, top floor, Lyell Centre

Discussion Workshops

Deep Ocean Drilling: An IODP Workshop. Facilitated by Uisdean Nicholson

Contourites and ocean hazards: slope instability and tsunami genesis. Facilitated by Dorrik Stow and Naohisa Nishida. Sponsored by JSPS (Japan Society for the Promotion of Science)

Deepwater Sediments, Hybrid Systems and Core Workshop. Facilitated by Zeinab Smillie. Cores supplied by BOSCORF (British Ocean Sediment Core Research Facility)

Keynote Presentations

Elda Miramontes (MARUM, Bremen): *Can internal waves control the formation of channels, contourite drifts and cold-water coral mounds in upper continental slopes?*
Javier Hernandez-Molina (Royal Holloway, London): *Everything You Always Wanted to Know About Contourites (But Were Afraid to Ask)*
Lesli Wood (Colorado School of Mines, Denver): *"Deepwater" processes and deposits in shelfal and upper slope settings: A reconsideration of paradigms*.
Michele Rebesco (OGS, Trieste): *Contourite erosional features: new observations and process implications*

Abstracts

Analogue experiments of mixed turbidite-contourite systems: linking flow dynamics to grainsize trends

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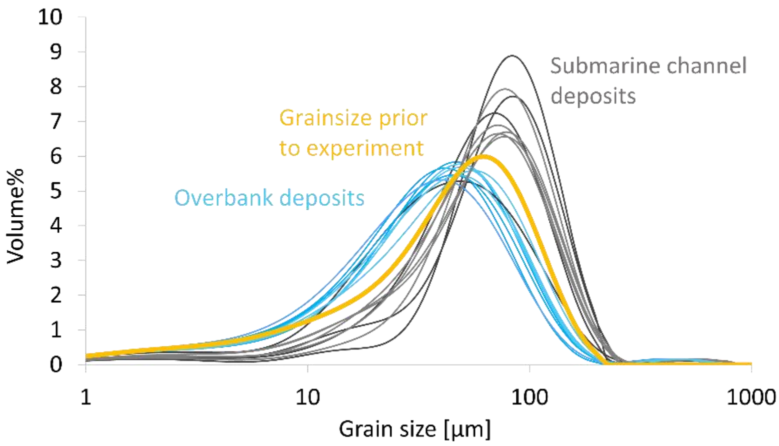
Turbidity currents are the dominant transporting agent of sediment, organic carbon, nutrients and pollutants from the continental shelf to the deep sea. Turbidite depositional models commonly ignore dynamic conditions of ambient water masses in the receiving basin. However, continental slope environments are rich in dynamic processes such as tides, waves and contour currents. Turbidity currents can interact with other water masses, resulting in a combined flow field, forming a mixed turbidite-contourite system. These combined flows deposit large volumes of sediment along the continental slope, hosting important archives of Earth's climate, potential reservoirs for hydrocarbons and a sink for carbon and micro-plastics. Measurements and observations of these flow interactions and resulting sediment transport are scarce and diagnostic criteria linking processes to deposits are not established. Various conceptual models—mainly based on the interpretation of deposits—attempt to explain the flow interaction, but these models remain untested. We present the results of combined turbidity current – contour current experiments conducted in the Eurotank flume facility of Utrecht University. The effect of channel aspect ratios and contour current intensities on the flow field and on the deposits was tested. The combined flow was measured in 3 dimensions at five locations across a submarine channel. The experiments were sampled for concentration above the bed inside the channel and on the down-stream levee. The flow, the channel deposits, and the overbank deposits were sampled for grainsize and deposit thickness was measured with a laser scanner. The experiments show that a secondary flow establishes in the downstream part of the channel flowing against the contour current direction at bed level. The grainsize distributions are coarser in the channel than on both the overbanks. Contour currents increase the down-stream overbank concentration of the flow compared to experiments without a contour current. Channel aspect ratio's determine the connection between the channel and levee concentration profiles. The down-stream overbank deposits are thicker in experiments where contour currents are present than in absence of contour currents.



Contourite stratigraphic models linked to Light Intermediate *versus* Dense Deep Mediterranean Waters flow regime variations (Alboran Sea, SW Mediterranean)

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Few studies have been conducted jointly on sedimentation impact of bottom currents associated with the Light Intermediate (LMW) and Dense Deep Mediterranean (DMW) Water masses in the Mediterranean. In this regard, this work presents an integration and comparison of sedimentology (texture, D50, UP10, sedimentary structures), chronostratigraphy (oxygen isotope and ^{14}C), and composition (sand fraction, carbonate content, Zr/Rb ratio, chemical microanalysis) data from different contourite features formed by the LMW and DMW bottom currents in the Alboran Sea (SW Mediterranean), since the last glacial period to the Holocene. In order to have a good spatial control of their bottom current action, we have studied fourteen sediment cores from continental slope to basin, combined with on an *ad-hoc* support of current meter records.

Eight facies are characterized. They are interpreted as contourites, turbidites and contourite/turbidite mixed sediments, contourites being dominant. These facies are arranged into ten sequences, which define two contourite stratigraphic models (terrace and drift) and a contourite/turbidite mixed model:

(I) The contourite terrace model is an archive of the interplay between the high energetic (paleo-velocities > 23 to 50 cm/s) Atlantic Water-LWM interface and glacioeustasy. It is characterized by coarse-grained sediments (silty sands and sands) rich in glaucony deposited on the contouritic terrace of the upper slope, since the Younger Dryas (YD) to the Holocene.

(II) The contourite drift models are archives of rapid ocean-climate coupled fluctuations since 29 kyr. They comprise coarse-grained (silty dominated) contourites from the shallow drift (lower continental slope) formed under the influence of a relatively fast (23 to 36 cm/s) LMW; and fine-grained (muddy dominated) contourites from the deeper drifts (base-of-slope to basin) formed by a relatively weak (paleo-velocities 4 to 11 cm/s) DMW, except for the Heinrich Stadial (HS) HS3 to HS1 and YD periods when coarse-grained contourites (silt to sand) were deposited.

III) The contourite/turbidite mixed model is another archive of the DMW and glacioeustasy interplay. It is defined on the overbank of the Guadiaro fan by turbidites (sandy silts and silts) during the end of late Pleistocene, contourite-turbidite mixed deposits for the YD, and contourites (muddy predominant) for the Holocene.

The comparison of paleooceanographic records (i.e., sand content, D50, and UP10 fraction and Zr/Rb ratio) with a robust chronology allows us to infer for the first time the relative variability of the LMW *versus* DMW flow regimes in the Alboran Sea, revealing differences and similarities. The similarities indicate that the LMW and DMW fluctuations occur in parallel at a millennial and centennial time scales. The differences refer to: the overall higher velocity of the LMW *versus* DMW; the magnitude changes in velocities that are lower for the LMW and higher for the DMW; the recognition of three short ventilation events (a,b,c) during the HS1 and

HS2 only for DMW; and the distinct LMW and DMW responses to the onset of glacial conditions and return to interglacial conditions during the HSs, YD and Holocene cold periods.

The results of this study leave questions unanswered and also raise for more detailed analysis of the contourite stratigraphy in other margins of the Mediterranean Sea. The outcomes of this study may have broad implications for understanding the complex palaeoceanography of the Mediterranean waters (LMW and DMW). Their distinct impact on sedimentation may provide new insights not only into their different paleoceanographic responses to rapid climatic oscillations (i.e., their ocean-climate coupling) but also to decoding their triggering mechanisms.

Acknowledgements: This study was supported by the Spanish projects FAUCES (CMT2015-65461-C2-R, MINECO/FEDER). Authors from the Continental Margins Group-GMC at the Institut de Ciències del Mar-ICM-CSIC acknowledge to the 'Severo Ochoa Centre of Excellence' accreditation (CEX2019-000928-S).

Numerical simulation of sediment transport by thermohaline bottom currents

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Contour (along slope) and turbidity (downslope) currents actively interacts on the seafloor of the continental margins and control the distribution of seafloor habitats, slope instability, microplastics accumulation and hydrocarbon reservoirs. Numerical simulations that reproduce the sediment transport at the crossroad of these two current types may improve the understanding of this distribution. Nevertheless, the interaction between turbidity and contour currents is problematic to afford with numerical or experimental instruments. The aim of this PhD study is to adapt and develop methods for the numerical simulations to reproduce the effect of this interaction on the sediment transport in order to understand how the finer (suspended) component of the sediment transported by the turbidity flows can be a source of sediment for transport within the contour current.

The first step of the project will be the construction of a pertinent domain. For this purpose, the intention is to use a setting where a straight inclined channel (for the release of the turbidity flow) leads to an expansion table covered by sediment and swept by a transversal contour crossflow. With respect to this case, to better represent our phenomenon, the turbidity current channel will be considered with a thalweg lower than the expansion table. After this first step, we will analyse the two types of currents independently, turbidity and contouritic, using the reference literature for comparison. This will be useful to better understand the critical characteristics of the two currents, and the possible problems posed by their interaction. In the end, as a third step, the turbidity current will be analysed in the case of contour crossflow, with a particular attention to the possible mechanisms of sediment transport. Considering the complexity of the mixing processes of the two currents type and of their interaction, we will take advantage of Large Eddy Simulation (LES) or of Wall-modelled LES (i.e., skipping the solution of the viscous boundary layer). The cases will be analyzed at a time scale related to the turbidity current. The sediment transport, for computational reason, will be probably treated with a Eulerian approach, therefore through the solution of the transport equation for a scalar, with a two - way coupling of the momentum equation through the buoyancy term.

How to characterize the mineralogical composition and provenance of contourites and associated sediments coupling optical microscopy and Raman spectroscopy

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In the last 10 years, Raman spectroscopy has been successfully applied to the study of the mineralogical composition of modern sediments in different depositional environments and geodynamic settings (Andò and Garzanti, 2013). This technique expands the possibilities offered by the polarizing microscope and the classical study of mineralogical optical properties, adding a greater ability to recognize the composition of the investigated species and allowing to quantify the mineralogy of very small particles, down to a few microns.

Single grain high resolution heavy mineral analysis of silt and sand has been applied to investigate modern sediments in continental archive (bedload and suspended load in rivers, beach sediments and sand dunes in deserts) and in marine environments (muddy deposits on the shelf). The same approach is also applied in ancient deposits both in marine and terrestrial depositional environments: loess deposits, fluvial terraces, soils and turbiditic sediments in the deep oceans (Andò et al., 2019). To fill the gap and to further our understanding of the mineralogical composition, and potential provenance, of contourites and associated sediments, we suggest using an integrated approach, merging the classical optical microscopy with the advanced Raman spectroscopy applied to fine sediments. This approach takes advantage from the recent protocols for heavy mineral separation (Andò, 2020) and could be also applied to quantify and characterize the composition of bottom current deposits (contourites) versus density current (turbidites).

In modern sediments the concentration of heavy minerals in sediments is controlled by hydraulic sorting and source rocks fertility for different species (Andò, Garzanti 2007). This quantitative information together with the entire suite of minerals and their relative abundance of mineral, could highlight different depositional environments and help deciphering the source of detritus, identifying local versus distant sources. Tractive currents concentrate heavy minerals in fine sand and silt fraction and these lag deposits represent a phenomenal archive waiting to be explored with single grain methods. The use of Raman spectroscopy could help identifying each single grain in very fine silt, when optical properties are not sufficient, and the expertise of the operator can introduce a bias analysing a such fine sediment. The Raman spectroscopy applied to single group of detrital minerals (Bersani et al., 2009) is a powerful tool to depict the source rocks and distinguishing magmatic versus metamorphic sources. To check our ideas and to squeeze out all the possible information from the sedimentary archive, we would like to use as a natural laboratory, the sediments collected during the IODP expedition 374, at site U1523, in the Ross Sea, Antarctica (McKay et al., 2019), to test the hypothesis that contourites (Lucchi, Rebesco, 2007) can be used as a proxy to define temporal and spatial change of bottom current strength and provenance in relationship with fluctuations of the Antarctic ice sheet, ice shelf and sea-ice during past glacial and interglacial cycles.

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Garzanti E., Andò S. 2007. Heavy mineral concentration in modern sands: implications for provenance interpretation. Dev. Sed.. 58, 517-545.

Lucchi R.G., Rebesco M., 2007. *Glacial contourites on the Antarctic Peninsula margin: insight for paleoenvironmental and paleoclimatic conditions. Geological Society, London, Sp. Publications, 276, 111-127.*

McKay, R.M., De Santis, L., Kulhanek, et al., 2019. *Site U1523. Ross Sea West Antarctic Ice Sheet History. Proceedings of the International Ocean Discovery Program, 374: College Station, TX (International Ocean Discovery Program).*

Controls of Upper Cretaceous to Upper Miocene, deep-sea, shelf and shallow-water carbonate sedimentation in W Cyprus

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Southern Cyprus exposes a thick sequence of Upper Cretaceous to Pliocene marine carbonate rocks that have recently provided additional evidence of contourites. The present research concerns the uppermost Cretaceous to Upper Miocene carbonate sedimentation of western Cyprus, following tectonic amalgamation of the Upper Cretaceous Troodos ophiolite and the Triassic-Cretaceous Mamonia Complex. Extensive fieldwork (over four years) includes sedimentary logging (c. 80 logs), facies analysis and structural data collection (i.e. faults and folds). The fieldwork is supported by new biostratigraphic dating using calcareous nannofossils and benthic foraminifera, and also by Sr isotopic analysis using planktic foraminifera extracted from selected stratigraphic intervals. Laboratory work includes petrographic and XRD analysis to help determine palaeoenvironments and provenance. Here, we present some key sedimentary logs that illustrate the variable sedimentation that characterises western Cyprus. Upper Cretaceous chalk (Lower Lefkara Formation) is patchily exposed in the SE around the periphery of the Troodos ophiolite, and in the NW on the Akamas Peninsula. The basal chalk locally interfingers with polymictic debris-flow deposits (Kathikas Formation) derived from the adjacent basement terranes. Palaeocene chalks and marls (also Lower Lefkara Formation) are thin and only known in the SE. Eocene chalk with diagenetic chert (Middle Lefkara Formation) is thick (100-150 m) and well developed around the ophiolite periphery in the east and SE, with evidence of calciturbidites, debris-flow deposits and slumps. Overlying Eocene chalk without chert (also Middle Lefkara Formation) is relatively thick in the SE (up to c. 60 m), and has mm-scale planar lamination and cross lamination. Oligocene chalk and marl (Upper Lefkara Formation) is restricted to the SE. A structural break exists in the south between the uppermost Cretaceous-Paleogene deep-sea sediments and the overlying shelf-depth Miocene sediments (Pakhna Formation; up to 200 m thick), associated with large-scale folding. Both the Oligocene and the Early Miocene facies are rich in contourites in the south and SE, extending into the Middle Miocene. In contrast, calciturbidites characterise the Middle Miocene in the west. Sapropels accumulated widely during the Mid-Late Miocene throughout the whole region. During the Early Miocene, deposition was strongly influenced by a topographic high in the vicinity of the Akamas Peninsula in the NW, where shallow-water sediments rich in large benthic foraminifera accumulated, associated with downslope redeposition including reef-derived debris-flow deposits (Terra Member). Middle to Late Miocene deposition, including in-situ reefs (Koronia Member), was structurally influenced by the Mid-Late Miocene development of the c. N-S Polis graben, associated with the uplift of the Akamas high and the west periphery of the Troodos ophiolite. Crustal extension affected much of western Cyprus (including the Pissouri basin in the south) during the Mid-Late Miocene, with extension continuing into the Pleistocene in places. Overall, the uppermost Cretaceous-upper Miocene deposition was controlled by the variable interplay of depositional, palaeoceanographic and tectonic processes.

The early retreat of the Western Antarctic Ice Sheet from an ultra-high resolution Holocene paleoclimate record discovered in Edisto Inlet Fjord, northern Victoria Land, Antarctica

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We report for the first time an integrated morpho-bathymetric and seismo-stratigraphic analysis of Edisto Inlet fjord, located on the northern Victoria Land (NVL) coast in the western Ross Sea. Edisto Inlet is a small fjord about 16 km long and 4 km wide, formed by glacial processes and separated from Moubray Bay by a sill.

Bathymetric and seismic reflection data combined with geologic samples and oceanographic measurements indicate that most of the post (Last Glacial Maximum) LGM sedimentation here was influenced by deposition of seasonally flourishing biogenic material (mainly diatom ooze) that was essentially redistributed locally by bottom currents. The interaction of rapid sediment deposition due to high productivity and persistent fjord-like circulation resulted in the formation of a confined drift and the accumulation of a sediment layer up to 110 m thick in the inner fjord.

This indicates that the Edisto Inlet fjord was subject to seasonal sea ice-free conditions with regular warm water intrusions, and the undisturbed acoustic character of sediment drift in the central parts of the fjord suggests that the fjord was not carved by ground ice after the Holocene climatic optimum, when ice ran aground on the fjord margins. The results of this work, based on marine data, suggest that glaciers on the NVL coast retreated by about 11 Ky. This would preclude the presence of extensive ground ice on the north-western Ross Sea continental shelf after the late Holocene.

Microplastics across the Gulf of Cadiz continental slope: evidence for current velocity control

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A significant portion of the global marine plastic budget is unaccounted for in known surface waste patches. It is therefore thought that large volumes of waste are accumulating in the deep ocean. However, little is known of the source to sink cycle of plastics in the environment, particularly in deep marine settings. Recent research has shown that the sediments deposited by deep ocean bottom currents (named contourites) are potential hot spots for deposition and it is now hypothesised that these contourite sediment drifts are the ultimate sink of microplastics in the ocean. However, acquiring data from deep marine settings to understand this is difficult and costly. This study aimed to test if legacy samples can be used to understand microplastic distribution in these settings by assessing if (a) MP concentration is controlled by distance from source (land); and (b) there is evidence for MP concentration being controlled by depositional processes.

Samples from the East Atlantic were collected from legacy cores stored at BOSCORF and from previous CONTOURIBER cruise archives. Of 38 samples requested, only 25 were suitable for MP separation due to sample quality. MPs were separated from sediment using standard settling techniques and host sediment analysed using laser particle analysis. Samples with anomalously high MP concentrations were excluded from analysis due to contamination. Remaining samples showed no correlation between MP/g and water depth, or distance from source. There were however several correlations between MP/g and the sediment textural characteristics. MP/g increased with mean grain size for muds to fine silts. Medium silt and coarser mean grain sizes saw low MP/g concentrations. Samples with poorest sorting have the highest MP/g values and those with very fine skew have the lowest MP/g. Four distinct populations are seen in the textual data. Cumulative frequency curves of each cluster reveal that samples dominated by sediment transported by a mixture of suspension and saltation are most likely to have higher MP/g concentrations. These are the processes characteristic of fine grained contourite settings such as drifts. There is therefore a likely but complex control between depositional process and depositional energy on MP distribution.

This study highlights interesting future lines of investigation, however we note that legacy cores for MP analysis is problematic due to lack of control on contamination and limitations in sample availability and size. Future MP work should acquire fit-for-purpose samples to overcome these issues.

3D Seismic Sequence Stratigraphy, Erosional Surfaces, and Implications for Hydrocarbon Prospect Generation in the N'kapa Formation, Douala Sub-Basin, Cameroon

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A precise definition of environment of sediment deposition from seismic signatures is imperative for characterizing and providing measures for enhancing hydrocarbon reservoirs. This study set out to utilize seismic sequence stratigraphic techniques and qualitative seismic attribute analysis to identify various sequences and seismic facies, delineate significant stratigraphic surfaces and establish their implications in hydrocarbon prospect generation in the Douala Basin. 3D SEG normal standard seismic volumes (2800 km^2) together with well log and lithological information were utilized for the seismic stratigraphic studies. Identified bounding surfaces, unconformities and prospective bright spots were mapped as horizons on 3D seismic record. In addition, subsurface time elevation maps were generated, and amplitude variation surface seismic attribute analysis carried out to aid in geometry delineation of depositional channels. Five sequences and seven associated seismic facies were identified, and detailed analysis was focused on Sequences 1 and 2 and Facies SF6 and SF7. SF7 presented semi parallel thick sporadic high amplitude, diagnostic of turbidite reservoirs. Sequence 1 represents the N'kapa Formation characterized by erratic distribution of SF7 within a predominant mesh of SF6. Three seismic surfaces corresponding to reservoir body, major erosional surface and an Eocene Unconformity were identified, and their seismic attribute character portray high amplitudes revealing channel sand or levee reservoir bodies distributed on the erosional surface cutting across the N'kapa Formation, signifying a channelized system that acted as sites for shallow marine aprons or reservoir formation. This study has revealed channel turbiditic stratigraphic plays which should guide future well location.

Keywords: seismic stratigraphy, seismic facies, surfaces, channel reservoirs, Douala Basin.

Sedimentology and Geochemistry of Carbonate Bearing-Argillites on the Southeastern Flank of Mount Cameroon (Likomba)

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Sedimentological, geochemical and petrographic studies were carried out on carbonate-bearing argillites outcropping at the southeastern flank of Mount Cameroon (Likomba) to determine the lithofacies and their associations, major element geochemistry and mineralogy. This was in an attempt to establish the relationship between the carbonate-argillites sequence and the Cameroon Volcanic Line (CVL), determine their provenance and predict a depositional model of the environment of deposition.

Outcrops and rock samples were carefully observed and described in the field. Major elements of the rocks were analysed using XRF technique. Thermal analysis and thin section studies were carried out accompanied with the determination of insoluble components of the carbonates.

The carbonates are classed as biomicrites with siderite being the major carbonate mineral. Clay, quartz and pyrite constitute the major insoluble components of these rocks. Geochemical results depict a broad variation in their concentrations with silica and iron showing the highest concentrations and sodium and manganese with the least concentrations. In an attempt to account for the source of the iron, origin of siderite and the sediments, R-Mode analysis was used to discriminate the elemental associations, and two elemental associations were revealed: Fe_2O_3-MgO-Mn_2O_3 (72.56%) and TiO_2-SiO_2-Al_2O_3-K_2O (23.20%), indicating both Fe-enrichment event, the subsequent formation of the siderite and the contribution of the continental sediments to the formation of these rocks.

The rocks consist of cyclic iron-rich carbonates alternating with sideritic-shales and might have been formed as a result of variations in the sea conditions as well as variation in sediment influx resulting from transgression and regression sequences occurring in a shallow to slightly deep marine environments. The rocks lie unconformably beneath the CVL and are highly fractured due to the overburden of the overlying igneous rocks.

Key words: Sedimentology, Geochemistry, Petrography, Iron carbonates, Likomba

Characterization of channel-related contourites at Bight Fracture Zone (North Atlantic Ocean).

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Contourite drifts are relatively frequent in the North Atlantic due to the interactions of different North Atlantic Deep Water (NADW) branches with the bottom topography, particularly the Mid-Atlantic Ridge (MAR). The main elongated contourites bodies around the northern sector of the MAR, the Reykjanes Ridge, are Bjorn, Gardar and Snorri Drifts. These contourites are relatively well known and characterised. However, channel-related contourites deposited in the deep-ocean passages, as the fracture zones, are relatively poorly known. The two main fracture zones in the North Atlantic are the Bight Fracture Zone (BFZ, 57ºN) and the Charlie-Gibbs Fracture Zone (CGFZ, 52ºN). These ones are key areas for the Atlantic Meridional Overturning Circulation (AMOC) because they constitute the main routes for the Iceland-Scotland Overflow Water (ISOW), connecting the eastern and western North Atlantic basins (Iceland and Irminger basins, respectively).

In this work, we present multiproxy analysis obtained on core BFZ21-GC01, which was retrieved from the westernmost end of the BFZ (57º 7.06N; 35º 16.354W; 2746 mbsl; 4.80 m long). The combination of tomographic, compositional, textural, grain-size and planktic foraminifera oxygen isotope analyses together with 18 AMS 14C allow us to record the main climate and oceanographic fluctuations during Marine Isotope Stages 2 and 3 (MIS2 and MIS3). Contourite and turbidite facies and diatom mats intervals appear repetitively along the core, suggesting an association between sedimentary processes, the Subarctic Front oscillations and ISOW intensity changes.

Sediment waves as a tool to understand deep-water current evolution, Senegal Basin, NW Africa

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Sediment waves can be formed by the action of bottom-water and/or turbidity currents on the seafloor and can form an important part of deep-water depositional systems. Mapping of a 2030 km2 3D seismic dataset offshore Senegal has allowed detailed description and classification of sediment wave fields developed within a Cretaceous deep-water basin. The Cretaceous stratigraphy contains five distinct deep-water sediment wave fields aging from Valanginian to Late Cretaceous, with varying morphologies and geometric parameters. Three different sediment wave types are identified; 1- Sediment waves, characterised by a crescentic shape in planform, high amplitude on crest and upslope flank, steeper slope on the downslope flank and downslope decrease of both wave height and wave length on cross sections. They have wave length ranging between 1.3 and 2.4 km, wave height between 8 m to 31 m and crest length between 2.9 and 12.7. These are interpreted to be turbidity current induced. 2- Linear waves with longer crest lines (16.6-20.5 km), exhibiting a random to constant distribution of wave length (1.2-4.4 km) and height (15-67 m) and no systematic amplitude changes, interpreted to be caused by bottom water currents. and; 3- Waves characterised by high-amplitude seismic response on their crest and upslope flank, with a downslope decrease in wave dimensions, and longer crest compared to turbidity current related equivalents. They are measured 55 to 117.5 m high, 1.3 to 5.4 km wide and 11 to 24 km long. These wave forms exhibit changes in crest orientation and are interpreted to be produced by mixed bottom water and turbidity currents. The recognition of mixed current related sediment waves during late Valanginian indicates that the bottom water currents were initiated during that time, with a constant interaction between turbidity and bottom water currents. This is observed until Turonian, from when sediment waves are absent in the study area. A late Cretaceous sediment wave field is observed on a regional 2D line located NW of the study area in offshore Senegal basin but 100 km away from the 3D data location. This might be related to the slope becoming gentler and bottom water currents spreading to the deep basin rather than being concentrated at the toe of slope. This study records the morphology, geometry, and distribution of sediment waves that offer an insight into the deep-water circulation in the Cretaceous mixed turbidite-contourite system and discusses their timing, mechanism of formation, and evolution through a proposed depositional model.

Sediment drifts in the continental slope in front of the Cook, Ninnis and Mertz Glaciers (East Antarctica)

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The Cook and Ninnis Glacier drain most of the Antarctic, marine-based ice sheet, covering the Wilkes Subglacial Basin (WSB), with an ice volume equivalent to a global sea rise of approximately 3-4 m. Long-term climate projections and ice records suggest that in this area, hitherto considered colder and more stable, a retreat of the ice sheet can be triggered in response to the intrusion of warm ocean waters. However, neither the morphobathymetry of the continental shelf facing the Cook glacier, nor the present and past oceanography of the area is known.

During the Programma Nazionale delle Ricerche in Antartide (PNRA) campaign of 2022 with the ice breaker L. Bassi, the COLLAPSE (Cook glacier-Ocean system, sea LeveL and Antarctic Past Stability) project mapped two systems of canyons and embankments located at the mouth of the inferred glacial valleys off the Cook and of Ninnis glaciers. A transect of sediment cores was collected across these slope features. The preliminary results show evidence of slope instability in front of the main glacial troughs. Bottom current-controlled sediment drifts growth channel-levees and slope terraces. They formed under the action of the westward flowing Antarctic Slope Current and locally of high dense water forming on the continental shelf and descending the slope. The combination of geomorphological, seismic, oceanographic and sediment data allowed to identify a large variety of processes, active on the seabed today and in the late Quaternary. This information, albeit indirectly, will contribute to reconstruct the dynamics of the different glaciers as a function of climatic variations and ocean circulation and estimate their respective contribution to global sea level rise.

The PNRA COLLAPSE involves a large international science party from Univ. of Bordeaux and LOCEAN, Paris (F), CSIC (E), Colgate Univ. (USA), Australian National University and Univ. of Tasmania (AUS), Russian FSBI VNIIOkeangeologia, (RU), Alfred Wegener Institute (D), GNS (NZ), Univ. Utrecht (NL).

The use of linear and circumferential laminography for ichnological analysis of deep-sea sediments research: somewhere between 2D and 3D analysis

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Radiographs have been traditionally used for the study of deep-sea sediment cores as a technique which provides a 2D view of the study cores, deeper and more extensive than the exposed surface. In the last decades, their use has diminished due to the implementation of Computed Tomography (CT) scanning, that allows to get 3D reconstruction of the internal structures after processing. Nowadays, this is frequently used in cores research for sedimentological and ichnological analysis, when CT scanning is possible, but it has some weaknesses. When working at core scale, the resolution of CT scanning is usually a limiting factor and the amount of data is huge. Somewhere between 2D (i.e., radiographs) and 3D (i.e., CT) analyses is the laminography; this is able to take focused radiographs from different depths and angles, allowing to get a 3D view with a smaller amount of data and a higher resolution. This technique is frequently used in material science and other disciplines but is not common in geoscience.

Here we show the use of laminography for the study of biogenic structures from deep-sea box cores collected at the Porcupine Abyssal Plain (northeast Atlantic). A comparison between linear and circumferential laminography is conducted to determine which is the most efficient and useful technique for the ichnological analysis of cores from deep-sea sediments. This study is focused on the application to ichnological research but can be also applied to sedimentological analysis and any other study which is commonly conducted using either radiographs or CT data.

Decoding the evolution of the Equatorial Atlantic Gateway: evidence of mid-Cretaceous deep-water circulation from sediment waves and contourite drifts, offshore Guinea (initial results)

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Plate tectonics is the dominant driver of ocean gateways opening and closure, which in turn have had significant impacts on global climate and ocean circulation through Earth's history. During the mid-Cretaceous, the opening of the Equatorial Atlantic Gateway (EAG) led to the first interhemispheric deep-water exchange within the Atlantic, dramatically changing oceanic depositional environments especially in the Central Atlantic. The major rearrangement of the global ocean circulation impacted global climate, deep-ocean oxygenation and marine biotic evolution. The opening and deepening of the EAG took place in several stages, along the oblique rift and transform margins of Africa and South America, gradually connecting isolated Central Atlantic basins into one system. Despite the importance of the EAG, the temporal evolution of this gateway remains poorly constrained, especially the onset and intensification of deep-water exchange through the EAG.

This work uses a regional 2D seismic reflection dataset, tied to the stratigraphy of DSDP Site 367 (Cape Verde Basin), to describe bottom-current related features developed off the Guinea Plateau, on the northern part of the EAG during the Aptian – Albian age interval. Detailed seismostratigraphic interpretation revels the occurrence of several morphosedimentary features that indicate changes in deep-water circulation: *i)* small-scale sediment waves (< 1.5 km-wide), topped by a regional unconformity that separates it from, *ii)* well-developed field of up-slope migrating giant sediment waves (~5 km-wide) that evolve into more aggradational geometries upward, and *iii)* contourite mounded drift, eroded at the top by the Albian Unconformity (~100 Ma). These observations suggest that the first connection between the South Atlantic and the Central Atlantic occurred during the Aptian, creating the small sedimentary waves at the NW end of the gateway. This evolved into the giant sediment waves, interpreted as a sign of enhanced and more continuous ocean circulation during the Late Aptian to Early Albian, most likely representing water masses flowing through a narrow gateway. The Guinea Plateau was an important structural barrier in the tropical NW African sector that locally enhanced the velocity of northbound bottom currents. Later, with the widening and deepening of the EAG, contourite drifts formed around the plateau under the influence of continuous northwards-flowing currents. This was followed by pelagic sedimentation from the late Albian onwards, as bottom current velocities were further reduced due to the continuous widening of the gateway.

These initial results provide evidence for an early Aptian – Albian gradual opening of the EAG, with the type of the morphosedimentary features changing according to variations in water-mass exchange across the gateway. It emphasizes the spatial and temporal evolution of the EAG, highlighting the importance of understanding past ocean gateways for predicting future large-scale climate and environmental change linked to reconfiguration of ocean current dynamics.

Interaction between active tectonics and bottom-current processes: a unique example in the NW Moroccan Margin, Southern Gulf of Cadiz

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The NW Moroccan Margin has a complex geological evolution, being located close to the transition zone between the Azores – Gibraltar Fracture Zone and the western front of the Betic–Rif collisional orogen. The interaction between tectonic, diapiric and fluid flow processes with bottom-current activity shapes the seafloor and influences the distribution of seafloor biologic communities (such as the cold-water coral mounds) and deep-water sedimentation. The aim of this work is to study the interaction of (paleo)oceanographic and morpho-tectonic processes. To achieve this, high-resolution multibeam bathymetry and parasound seismic data acquired during the "ALBOCA II" - M167 cruise were used, complemented by high-resolution 2D seismic reflection data and the EMODnet bathymetric compilation.

The study area is located on the continental upper and middle slope, at water depths ranging between 108 and 1153 m. Several morphological features were identified during the analysis of the data, related to different processes: *i)* sedimentary (contourites and sediment waves), *ii)* structural (faults and diapirs), *iii)* gravitational (slide scars, mass transport deposits), *iv)* fluid migration (mud volcanoes and pockmarks) and *v)* biogenic (exposed and buried coral mounds).
The distribution of these features discloses the interplay between tectonic and oceanographic processes in the NW Moroccan Margin during the Quaternary period. The sedimentation is dominated by bottom-current related deposits (contourites), with an extensive contourite terrace and associated sheeted (plastered) drifts and sediment waves. Mounded to confined drifts and erosive contourite features were also recognised. In addition, mass transport deposits are locally observed. The distribution and the type of the deposits are closely influenced by the morpho-structural reliefs (e.g., SWIM strike-slip faults and mud volcanoes). We suggest that contourite deposits and terraces were developed due to the interaction of the Eastern North Atlantic Central Water (eNACW) and the modified Antarctic Intermediate Water (mAAIW) with the morpho-structure of the seafloor. Moreover, the data hints that the water masses have fluctuated during glacial and intra-glacial periods, and these changes have been shaping the morphology and the sedimentary stacking pattern of the slope.

This work reveals the important of the tectonic and oceanographic processes in shaping the NW Moroccan Margin. It emphasizes the importance of understanding how the deep-water depositional systems and characteristics of seafloor features to characterise continental margins worldwide.

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Carbonate contourites and hemipelagites off the Bahamas

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The Bahama Banks are environments almost exclusively dominated by carbonate sediment. Minor terrigenous particles settling in these environments are essentially brought in by currents and occasionally by winds. The various oceanographic campaigns CARAMBAR (2010, 2014, 2016) allowed us to collect sediment and acoustic data (multibeam bathymetry, backscatter imagery, high and very high resolution seismic) from the slopes off Little Bahama Bank (LBB), Great Bahama Bank (GBB) and Exuma Valley. Detailed sedimentological and stratigraphical analyses carried out on several tens of cores, coupled with acoustic data, have allowed us to understand the critical role of surface and bottom currents acting along the slopes of this archipelago, which are partially isolated from siliciclastic supplies.

Sedimentological analyses include grain-size and elemental (XRF core scanner) measurements and petrographic identification of particles. Chronological proxies integrate 18O, radiocarbon ages and biozones of planktic foraminifers and calcareous nannofossils. Based on these results, variability of sediment supplies has been demonstrated, both at spatial and time scales over the last 450 kyr.

Surface currents, such as the Florida Current and Antilles Current, influence sedimentation from the upper slope to 800 m water depth, and form large elongated sediment accumulations, similar to drifts defined in the siliciclastic context (e.g. LBB drift). However, they are supplied differently in time, with three main periods as follows: (1) when banks are flooded, such as today, with a relative sea level (RSL) > -6 m (MIS 1, 11 and 5e), characterized by the highest sedimentation rates (10-30 cm.ka-1) and the finest grain-size particles, exported from the bank via off-bank processes ; (2) during interglacials (-90 < RSL < -6 m) when bank edges are flooded, with intermediate sedimentation rates (< 10 cm.ka-1) ; and (3) during glacials (RSL < -90 m), corresponding to exposure of the whole bank and upper slope, with the lowest sedimentation rates (mm.ka-1) and the coarsest grain-size particles. Indurated nodules can develop during these glacials and sediment transport via currents favours deposition of bi-gradational and bioturbated sequences along the middle slope (650-800 m deep), so called contourites. Despite this very similar facies compared to contourites described in siliciclastic environments, Bahamian carbonated contourites show specifically very condensed sequences, with very low sedimentation rates over all glacial periods.

The Deep Western Boundary Current (DWBC), the southern part of the North Atlantic Deep Water (NADW), flows along the seafloor below 800-1000 m water depth, essentially along and at the toe of the escarpment bordering the Bahamian slopes and canyons eastward. This current is replaced at the seafloor by Antarctic Bottom Water (AABW) during glacials. DWBC, especially its upper part (upper NADW), plays a significant role in sedimentation of Bahamian internal deep plateaux (e.g. Blake Plateau, terraces in Exuma Valley), generating hemipelagites enriched in siliciclastic particles but winnowing aragonite needles coming from carbonated banks.

Keywords: modern carbonated contourites, hemipelagites, periplatform drifts, Bahamas, Quaternary

Deep-water sedimentation controlled by interaction between bottom current and gravity flow: A case study of Rovuma Basin, East Africa

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As the main depositional process that transports terrigenous material into deep-water areas, turbidity flows are commonly the focus of deep-water sedimentology. However, increasingly, studies are showing that bottom currents also play important roles in deep-water terrigenous deposition.

By using 3D seismic dataset recently acquired in offshore Mozambique, we address the distribution pattern of a Cenozoic channel-levee-lobe complex in deep-water of Rovuma Basin. The results show that the unique levee of this complex asymmetrically developed only on one side of the channel course. We attribute this asymmetric levee development to the interaction between the western slope bottom current from south to north and the gravity flow from west down slope. Due to the winnowing and sorting by the western slope bottom current, the sorted fine grain sediments of the gravity flow were blown and deposited to aside remaining clean sand from the gravity flow deposited within the channel. The lateral deposits steepened northern channel banks and forced the southward migration of channel axes.

On the other hand, reservoir quality variations for 5 main lithofacies have been analyzed combined with core and well-log data. Some medium- to coarse-grained sandstone cores with parallel- to cross-stratification show higher permeability compared to the massive ones, which may imply the existence of bottom current can develop laminated sandstones and improve the reservoir quality.

Keywords: turbidity current, bottom current, channel migration, Rovuma Basin.

Deep-water sedimentation in Ordos Basin, NW China

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The Ordos Basin is China's second largest sedimentary basin with a total area of 370,000 km^2, bounded in the east by the Lüliang Mountains, north by the Yin Mountains, west by the Helan Mountains, and south by the Qinling Mountains. Deep-water sedimentation of all ages and lithologies are commonly found in Ordos Basin, mainly in ancient sedimentary successions from Precambrian to Mesozoic. In many cases, they form important subsurface sources, reservoirs and seals for hydrocarbons. They include a very wide range of deposit types, from sediment gravity flow deposit (turbidites, debrites, liquefied/fluidized flow and grain flow), mass transport deposit (slide and slump), deep-water dark shale and mudstone and deep-water slope facies carbonates. Liquefied/fluidized flow and grain flow are not covered in this article due to a much more limited application and we prefer to discuss the new terms of muddy and sandy debris flows. Based on a considerable plenty of earlier work, as well as more recent studies, we have used data gathered from outcrops and cores to synthesize their principal characteristics in Ordos Basin.

Key Words: Turbidites; Debrites; Mass transport deposit; deep-water systems; facies; sediment textures

Insights into fine-grained sedimentary facies at deep-sea: Identification, characterization and discrimination

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Downslope (e.g., turbidity currents and sediment mass failures) and alongslope processes (i.e., bottom currents) coexist and interact in the deep sea, yielding complex sedimentation patterns recorded in the deep-water sedimentary systems. It is thus crucial to identify each sedimentary facies for a better understanding of depositional mechanisms. However, many uncertainties remain when distinguishing fine-grained sedimentary facies in sediment cores. Based on the analysis of X-ray images of sediment cores from the SW Grand Banks Slope off Newfoundland (eastern Canada), this study identifies fine-grained sedimentary facies through the distribution of ice rafted detritus (IRD) and further investigates the characteristics of each facies. The observed interbedded mud lacking planktonic foraminifera and well-defined coarse silt or sand deposits without IRD are distinctive characteristics of turbidites, as they resulted from episodic events with high sedimentation rates. The thickness of each single turbidite layer ranges mostly from 0.5 mm to 3 cm, which is a typical "by-passing" lag deposit on the upper slope. Normal grading is only identifiable when the bed thickness reaches 5 cm, and beds with higher sand content tend to have clearer boundaries. Muddy contourites (sand content <10%) show homogeneity except where cm-scale bioturbation is visible. These features are similar to hemipelagites but the regional variation in thickness clearly favours a current-related origin. Silty contourites (10-28% sand), with gradational contacts at the top and base, have relatively distinct lamination generated by a current speed sufficient to sort silt at the bed. Their laminae differ from those generated by turbidity currents by the general irregularity (wavy and/or wedge-shaped), discontinuity character and the presence of IRD. A specific type of glacial silty contourites was found with distinct rhythmic laminae, within which IRD are more uniform in size and well-aligned, with their long axes roughly parallel to the wavy-parallel bedding. Sandy contourites (30-45% sand) are mostly massive, occurring either as lenses or as part of the ideal bi-gradational vertical sequence with mottled silt-mud. Vertically flaky mottled features are observed in muddy contourites mainly resulting from bioturbation, and also in silty contourites related to changes in grain size. Hybrid deposits are produced when a turbidity current and a bottom current interact; such sediments tend to be homogeneous, with sedimentation rates at an intermediate level and abundant bioturbation throughout (> 5 m in continuity). A comparison was made to present the key elements that would be comparable to similar fine-grained facies in other regions.

Keywords: Fine-grained facies, Contourite, Turbidite, Hybrid deposits, Ice-rafted detritus

Reconstruction of intermediate and deep water circulation patterns in the Eastern Bransfield Basin (Antarctic Peninsula) from high-resolution acoustic data

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This work aims to understand the link between the seafloor morphology and sub-seafloor stratigraphy of the Eastern Bransfield Basin (EBB; Antarctic Peninsula) with the water masses circulation established since the opening of the basin at around 3.3 Ma. Bottom currents (contourite) features identified from swath bathymetry data and parametric echo-sounder profiles acquired in the DRAKE2018 and POWELL2020 cruises are correlated with published information about water masses circulation and hydrological data.

The EBB is the easternmost sector of the Bransfield Strait, oriented SW-NE and bounded by the Antarctic Peninsula to the southeast and the South Shetland and Elephant islands to the north and northwest. Contourite features are identified based on their sedimentary stacking pattern and morphological characteristics. They locate at distinctive depth levels in the EBB. A large mounded drift has been identified in an intra-slope platform in the SE margin, at water depths of 1000-1500 m. It is 35 km long and 20 km wide and is bounded by erosional contourite moats. These features are interpreted to result from the southwestward flow of the East Basin Deep Water (EBDW) at intermediate depths, formed by a mix of water masses from the Weddell Sea. Plastered drifts topped by contourite terraces occupy depths of 1100-1200 m along the SE margin of the basin, and are related to the high-energy oceanographic regime formed at the transitional boundary between the EBDW and the East Bransfield Bottom Water (EBBW). Contourite features on the deep, flat seafloor of the EBB at 2000-2300 m water depth are also formed by the EBBW. Mounded contourite drifts prograde and thin towards the outer limits of the basin, where contourite moats are interbedded with mass transport deposits. These contourite features have been generated by the episodic entrance of bottom water masses from the Central Basin and their mix with deep water masses flowing from the NE.

This work reveals the highly dynamic oceanographic circulation in the Bransfield Strait, which has been established as tectonic processes led to the opening and deepening of gateways in the narrow basins at the tip of the Antarctic Peninsula and South Scotia Sea. Understanding the onset and temporal variability of the oceanographic pattern is of key importance to study the impact of deep-sea gateways in global oceanographic and climatic models.

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Frasnian contourite channel-drift system: Dense shelf-water cascading of anoxic water from the northern Gondwana Epeiric Sea (Tafilalt, Morocco)

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Analysis of Devonian cephalopod limestones in the eastern Anti-Atlas of Morocco (Tafilalt) reveals the formation of a contourite terrace on the uppermost slope of the northern passive margin of Gondwana (Hüneke et al. 2023). The inner terrace was bounded by an alongslope contourite channel and a small mounded drift at its downslope margin. The Eifelian-Frasnian record of pelagites and bioclastic carbonate contourites includes shell concentrations (coquinas) of mainly planktonic and nektonic organisms, which are identified as integral parts of bi-gradational contourite sequences showing inverse and normal grading. Hiatal lag concentrations of carbonate intraclasts, ferromanganese nodules and phosphatic conodonts often drape hardgrounds and erosional surfaces at the midpoint of these frequently incomplete sequences. Contourite deposition was mainly controlled by oxic clear-water currents.

Of particular palaeoceanographic interest are widespread erosional hiatuses and organic-rich calcarenitic contourites (black styliolinid coquinas), many of which formed penecontemporaneous with Devonian evolutionary crises (Joachimski & Buggisch 1993, Becker et al. 2020). The deposits reveal intensified bottom currents coeval with the expansion of a dysoxic-anoxic water mass. Facies- and drift-scale contourite features provide evidence for (northwest-directed) along-slope circulation and additional secondary circulation oblique to the main flow (towards north). We attribute these palaeocirculation events to repeated overflows of anoxic water from the North African Epicontinental Sea, through the Ougarta trough, probably driven by dense (more saline) shelf water formed on the northern Gondwana margin. The overflows cascaded downslope until they reached the level where the interior waters had the same density, probably intermediate water. This evidence of dense shelf-water cascading confirms the photic-zone eutrophication (top-down) model proposed for the Frasnes Event and related Devonian anoxic events (Carmichael et al. 2019). Consequently, we propose a direct link between the dysoxic-anoxic overflows and the Devonian evolutionary events.

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Recent intensification of bottom water over the southern entrance sill of the Western Gap, NE Atlantic

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Although bottom waters flowing over the abyssal plain are generally quite sluggish, these flows may be enhanced around topographic highs or morphological constrictions i.e. deep-sea gaps and gateways. Within these particular areas, the potentially increased deposition and erosion of sediment may result in valuable sedimentary archives of past fluctuations in current intensity, providing insight into the palaeoceanographic setting. Despite this, deposits in deep marine gaps are understudied and so uncertainty remains about the deep water palaeocirculation over abyssal plains.

This study, therefore, seeks to understand the bottom water circulation between the Madeira and Iberia abyssal plains (NE Atlantic) by determining the current pathways and the influence on deposition of sediment in the "Western Gap", a deep marine gap connecting the two abyssal plains. Although some work has looked at the general hydrology in the gap, the sediments in this gap have not been studied and so the role of this gap in paleo-bottom water exchange is unclear. Present bottom water pathways through the gap were determined using hydrological data along with the results of numerical modelling. Evaluation of their erosional and depositional potential, particularly over the southern Entrance Sill to the gap, was done using sea floor videos.

The results of numerical modelling point to two bottom currents entering the southern Entrance Sill from the south. One from the southeast and one from the south, which is in general agreement with the previously determined distribution of the Antarctic Bottom Water (AABW) over the sill. Sea floor videography revealed the presence of large "comet and scour" sedimentary structures over the central part of the sill. These structures are the result of significantly higher bottom current velocities compared to both the numerical model and direct LADCP measurements. However, there is a slight accumulation of fine-grained sediment on some of the exposed boulders and gravel. Therefore, it is likely that, at times in the recent past, the current velocities of this southern source water have exceeded 50 cms-1. Given that such velocities, and the volume of transported water, are much higher than those inferred for the other gap in the Azores-Gibraltar Fracture Zone (Discovery Gap), it is possible that the Western Gap may have been the main conduit of AABW to the NE Atlantic in the recent past. Further ongoing work on the sediments from this gap will provide greater insight into the timing of this event and the spatiotemporal extent of current intensification through the gap and, hence, contribute to our understanding of AABW flow over and between the abyssal plains of the NE Atlantic and deep circulation in this area as a whole in the recent past.

Keywords: Western Gap; AABW; bottom current intensification.

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Fast growing cold-water coral mounds are fed by fine sediments missing from the contemporary coarsest contourite sequences

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Under ideal environmental conditions, cold-water coral mounds can grow by several meters per kiloyear over periods of several centuries to millennia. Since the mound deposits usually consist to less than30% of coral fragments, the majority of the mound material is composed of typical hemipelagic sediments. During intense mound formation phases, siliciclastic sediments can accumulate with rates exceeding 500 g cm^{-2} kyr^{-1} on these mounds. The question is, where this huge amount of sediments is coming from? The answer is probably just around the corner at the seabed near the mounds. A detailed study of sediment cores from a coral mound and from an adjacent contourite in the western Mediterranean Sea revealed that a contourite sequence with the coarsest sediments, representing maximum current velocities, temporally coincides with the fastest aggradation of the mound (Wang et al. 2021, doi:10.3389/fmars.2021.760909). Strong bottom currents are of great relevance for the corals, as these sessile organisms depend on an efficient lateral food supply. Thus, while on the one hand the strong bottom currents triggered intensive coral reef formation on top of the mounds, on the other hand they kept fine sediments in suspension or even re-suspended deposited sediments in the region. The (re)suspended sediments, however, are effectively baffled by the coral reef framework on top of the mounds leading to the deposition of high amounts of fine-grained sediments. At the same time, non-deposition or even winnowing caused a significant coarsening of the sediments at the surrounding seabed. When the bottom currents eventually weakened again, sedimentation of fine sediments at the open seabed resumed and coral growth on the mounds largely ceased. The open seabed record then documents a perfect contourite sequence. The same pattern has now been documented from a contourite-coral mound setting on the Moroccan Atlantic margin, documenting the principal nature of this process (Vandorpe et al. 2022, doi:10.1002/dep2.212. Both studies address past coral mound formation phases and complete contourite sequences. On the Irish margin, this process is nowadays caught in the act. Since the onset of coral growth and, thus, coral mound formation, at the Irish margin during the early Holocene, sedimentation at the open seabed has largely ceased and fine-grained glacial sediments are overlain by a thin layer of coarse Holocene sediments (Wienberg et al. 2020, doi:10.1016/j.quascirev.2020.106310). These observations not only underline the close relation of cold-water corals (and mounds) and contourites, but also provide a clear link between coral mound formation and contourite deposition under strong bottom water hydrodynamics.

Everything You Always Wanted to Know About Contourites* (*But Were Afraid to Ask)

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Along-slope bottom currents and a series of secondary oceanographic processes interact at different scales to form sedimentary deposits referred to as contourite and mixed (turbidite-contourite) depositional systems. Recent proliferation of both academic and industry research on deep-marine sedimentation documents significant advances in the understanding of these systems, but most non-specialists remain unaware of the features in question and how they form. Contourites and mixed depositional systems represent a major domain of continental margin and adjacent abyssal plain sedimentation in many of the world's oceans. They also appear in Palaeozoic, Mesozoic and Cenozoic stratigraphic sections. The growing interest in these systems has led to a refined but still evolving understanding of them. In addition to resolving their exact origins and evolutionary trajectories, research must also continue to ascertain their role in deep-sea ecosystems, geological hazards, environmental policy and economic development. Key gaps in understanding persist regarding their formation, their function in oceanographic systems and their evolution over time.

This talk aims to answer Everything You Always Wanted to Know About Contourites* (*But Were Afraid to Ask) based on my own experience collaborating with both in industry and academia in recent years. In addition, the most controversial issues on the subject will be raised, proposing some considerations for future research. It summarises current conceptual paradigms for contourite and mixed depositional systems, lists global geographic examples of these systems and discusses their identification and interpretation in terms of diagnostic features as they appear in 2D and 3D seismic datasets and at sedimentary facies scale. It also considers the role that bottom currents play in shaping the seafloor and controlling the sedimentary stacking patterns of deepwater sedimentary successions. The growing interest in, and implications of, contourite and mixed depositional systems demonstrates that these systems represent significant deep-marine sedimentary environments. Combined efforts of researchers, industry partners and policy-makers can help advance understanding and responsible stewardship of deepwater depositional systems.

Discriminatory diagnostic criteria for contourites with respect to other deepwater sedimentary facies

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Bottom currents and a series of secondary oceanographic processes interact frequently at different scales to form distinct sedimentary deposits referred to as contourite and mixed (turbidite-contourite) depositional systems. These systems represent major depositional systems along the continental margins and abyssal plains of the world's oceans. A recent proliferation of both academic and industry research on deep-water sedimentation has revealed significant advances in the understanding of these systems, but non-specialists remain unaware of their sedimentary features and how they were formed. A paucity of examples in the ancient record and a lack of consensus regarding the diagnostic criteria used to characterise and differentiate them from other deep-water deposits limits our understanding of how they may record past processes, such as global oceanic circulation, tectonic events, gateway evolution, among others. In this work, examples of deep-marine deposits from onshore (Cyprus, Morocco, Spain, Italy and Angola) and offshore (Gulf of Cadiz, West Portugal, Mozambique, Antarctica, etc.) areas have been studied through a multidisciplinary approach to discriminate the main deep-water facies as contourites, pelagites/hemipelagites, turbidites, reworked turbidites and mass-transport deposits and determine why, when and how these deposits were formed in response to long-term tectonic history. The results described here highlight the importance of using primary sedimentary structures, microfacies and ichnological features as the best diagnostic criteria to distinguish reworked turbidites from contourites at the sedimentary facies scale. Diagnostic criteria for discriminating bottom current deposits include sedimentary condensation, reworking, reactivation surfaces, smaller grain-size variations, small-scale hiatuses, and omission surfaces. All of these vary according to the paleoenvironmental conditions, especially current velocities and sedimentation rates. Petrophysical properties of such deposits can furthermore make them extremely relevant as potential reservoirs in the context of energy geosciences.

Keywords: bottom currents; deepwater sedimentary systems; reworked turbidites, contourites

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Late Miocene to Quaternary Contourites and Mixed Depositional Systems in the Gulf of Cadiz and West Portugal related to the Mediterranean - Atlantic exchange evolution: decoding bottom currents behaviour and oceanographic processes associated with gateways

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Contourite depositional systems (CDS) represent the sedimentary records of paleoceanographic circulation and paleoclimatic changes established throughout the geological timescale. These records offer expanded but contingent information relative to their adjacent marine gateways, documenting changes in the intensity and the direction of modern-day and paleo-currents pathways on multi-centennial, millennial and million-year timescales. This study investigates the late Miocene to Quaternary CDSs from the Gulf of Cadiz towards the West Iberian margin, which developed after the exit of the past Betic and Rifian corridors and most recent Strait of Gibraltar, the key gateways for the Mediterranean – Atlantic exchange trough time. A summary of the relevant results is presented as a representative study case for decoding the long- and short-term behaviour of oceanographic processes related to gateways and their associated overflows.

It is well known that the Mediterranean Outflow Water (MOW) has generated a complex CDS in the study area since the full opening of the Strait of Gibraltar in the early Pliocene (5.3 Ma). Recently, an ancient CDS has also been discovered in the late Miocene, which is separated from the Pliocene-Quaternary CDS by a period of quiescence representing the restriction of bottom water circulation across the Mediterranean-Atlantic exchange during the late Messinian (~6.4 - 5.3 Ma). The late Miocene CDS was established after the final closure of the Indian Gateway (IG) and the Neo-Tethys Ocean in the Middle Miocene, which was followed by the inception of the Mediterranean Sea (~13.8 - 11 Ma). The final closure of the IG conditioned a wide gateway configuration for the connection between the Mediterranean Sea and the Atlantic Ocean, with the full establishment of an anti-estuarine circulation similar to the present day as opposed to its previous situation.

Interestingly, both the late Miocene and the Pliocene-Quaternary CDSs have a long-term common evolution that could be simplified into two stages: an initial- and growth-drift stages. The late Miocene CDS is then buried under dominantly hemipelagic late Messinian (~6.4 - 5.3 Ma) deposits, whereas the buried-drift stage is absent for the Pliocene-Quaternary system due to the ongoing nature of the CDS's evolution. The long-term development of these CDSs can be correlated with a coeval shallowing of sills, which caused a change from an outflow to an overflow setting across the gateways through time. These long-term variations (>5-10 My) in paleo-circulation are thus driven by the tectonic control associated with the evolution of oceanic gateways. The internal sedimentary architecture of the late Miocene and Pliocene-Quaternary CDSs suggests a complex stratigraphic stacking pattern of deposits (bounded by internal discontinuities and hiatuses) in response to the intermittent behaviour of the MOW at different temporal scales. This intermittent behaviour has been attributed to tectonic pulses, climatic and eustatic changes and oceanographic processes that have caused deepening/shoaling or weakening/strengthening of bottom currents through time, exerting a major effect on deepwater sedimentation and the benthic habitat.

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IODP Expedition 401: Investigating Miocene Mediterranean-Atlantic Gateway Exchange (IMMAGE)

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Marine gateways play a critical role in the exchange of water, heat, salt and nutrients between oceans and seas. The advection of dense waters helps drive global thermohaline circulation and, since the ocean is the largest of the rapidly exchanging CO2 reservoirs, this advection also affects atmospheric carbon concentration. Changes in gateway geometry can therefore significantly alter both the pattern of global ocean circulation and associated heat transport and climate, as well as having a profound local impact. Today, the volume of dense water supplied by Atlantic-Mediterranean exchange through the Gibraltar Strait is amongst the largest in the global ocean. For the past 5 My, this overflow (the Mediterranean Overflow eater, MOW) has generated a saline plume at intermediate depths in the Atlantic that deposits distinctive contouritic sediments in the Gulf of Cadiz and contributes to the formation of North Atlantic Deep Water. This single gateway configuration only developed in the early Pliocene, however. During the Miocene, a wide, open seaway linking the Mediterranean and Atlantic evolved into two narrow corridors: one in northern Morocco; the other in southern Spain. Formation of these corridors permitted Mediterranean salinity to rise and a new, distinct, dense water mass to form and overspill into the Atlantic for the first time. Further restriction and closure of these connections resulted in extreme salinity fluctuations in the Mediterranean, leading to the formation of the Messinian Salinity Crisis salt giant.

IMMAGE is an Land-2-Sea drilling proposal designed to recover a complete record of Atlantic-Mediterranean exchange from its Late Miocene inception to its current configuration. This will be achieved by targeting Miocene offshore sediments on either side of the Gibraltar Strait with IODP Expedition 401 and recovering Miocene core from the two precursor connections now exposed on land with ICDP. The scientific aims of IMMAGE are to constrain quantitatively the consequences for ocean circulation and global climate of the inception of Atlantic-Mediterranean exchange; to explore the mechanisms for high amplitude environmental change in marginal marine systems and to test physical oceanographic hypotheses for extreme high-density overflow dynamics that do not exist in the world today on this scale.

Here we summarise the Late Miocene contourite depositional systems being targeted in the Gulf of Cadiz and West of Portugal, the drilling locations and the main objectives of IMMAGE and IODP Expedition 401.

Further information about the IODP Expedition 401 at:
https://iodp.tamu.edu/scienceops/expeditions/mediterranean_atlantic_gateway_exchange.html

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Facies variability and depositional architecture of bioclastic bottom-current deposits formed on a Devonian contourite terrace (Tafilalt Platform, Morocco)

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Bioclastic carbonate contourites are analysed that arise from the broad spectrum of bottom-current related sedimentary processes ranging from deposition to erosion. The contourite deposits result from an intermittent accumulation of sediment, causing thin and condensed sequences with abundant hiatuses. Such bottom-current deposits are poorly known, since the broadly accepted contourite-facies model, the bi-gradational sequence, characterizes environments of contourite depositional systems as a continuous accretion of fine-grained siliciclastic sediments.

To increase current understanding of hiatal contourite records, the Eifelian–Frasnian of the Tafilalt Platform in Morocco was investigated. The carbonate succession is divided into five facies associations that are interpreted to reflect pelagic sedimentation and deposition from bottom currents on a contourite terrace, i.e. a gently inclined section of the upper slope of Gondwana shaped by a water-mass interface. Contourite deposition was mainly controlled by oxic clear-water currents, at times also by an anoxic water mass. Oxic clear-water currents are documented by moderately to completely bioturbated limestones with abundant hydrogenetic ferromanganese nodules and low organic-carbon contents. Anoxic bottom currents are featured by organic-rich coquinas with absent to sparse bioturbation and predominantly syngenetic framboidal pyrites. Biostratigraphic data and the overall depositional architecture display palaeoceanographic hydrodynamic processes associated with a shifting water-mass interface. The inner terrace was characterized by an alongslope contourite channel and a small mounded drift at its downslope margin. Energetic bottom currents furthermore caused abraded surfaces, i.e. plain areas of non-deposition and localized erosion, and sandy condensation layers.

The microfacies reflects repeated alternation between suspension deposition, winnowing of fines, bedload traction, dynamic sediment bypassing and reworking, together with concomitant seafloor cementation. Coquinas of mainly planktonic and nektonic organisms are identified as integral parts of bi-gradational contourite sequences showing inverse and normal grading. Hiatal lag concentrations of carbonate intraclasts, ferromanganese nodules and conodonts often drape hardgrounds and erosional surfaces at the midpoint of these frequently incomplete sequences.

This Devonian case provides the opportunity to investigate the spatial and temporal variability of the bed-scale contourite sequence, also with regard to the drift-scale depositional architecture. In addition, the identified high-resolution record is a starting point for unravelling the pattern of oceanic circulation in the Devonian greenhouse world.

Hüneke, H., Gibb, M.A., Mayer, O., Kniest, J.F., Mehlhorn, P., Gibb, L.M., Aboussalam, Z.S., Becker, R.T., El Hassani, A., Baidder, L. (2023) Bioclastic bottom-current deposits of a Devonian contourite terrace: Facies variability and depositional architecture (Tafilalt Platform, Morocco) – Sedimentology, online-first, https://doi.org/10.1111/sed.13089.

Seismic stratigraphy of an Eocene-Pliocene mixed depositional system on the SE New Zealand continental margin, Great South Basin

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Deeply buried mixed depositional systems have been identified in the Eocene-Oligocene succession of the Great South Basin in southeast New Zealand. This margin is currently affected by energetic flows of baroclinic western boundary currents which are associated with the formation of a contourite depositional system. Extensive analysis of 2D and 3D datasets acquired offshore SE New Zealand have revealed at least eleven drifts of three distinct mixed depositional systems that were formed in the mid-Eocene - late Eocene (onset of drift formation) and to early- late Oligocene (vertical growth stage). These mixed systems have been classified on the basis of their orientation, asymmetry, lateral migration, spatial distribution, and vertical variability of their depositional and erosional features.

Drift A-E and J occur in a synchronous mixed system formed due to coeval interaction between the gravity-driven and bottom current processes. This mixed system is characterized by downslope elongated mounded drifts and channels along the middle continental slope. Drifts F, G, H and I were identified in a contourite-dominated mixed system, characterized by along-slope elongated mounded drifts, moats, and downslope-oriented channels that contour around the drifts. Drift K occurs in a contourite depositional system consisting of an along-slope elongated mounded drift, landward moat and subsidiary drifts.
The depositional evolution of these mixed systems changed in the Oligocene. The mixed system is characterized by a drastic shift in its architecture and gross geometry. The synchronous mixed systems (composed of drifts A-E and J) evolved into a turbidite-dominated mixed system, characterized by small channel levees, channel drifts and small mounded drift or asymmetric levee. Therefore, the change in geometry reflects a weakening of the bottom current system, and a shift of their location during the vertical drift growth stage.

The drifts built within these distinct mixed systems can be distinguished from each other based on their acoustic response, internal stacking patterns and direction of lateral migration. Furthermore, the changes observed within these drifts and their mixed systems have been linked to variations in continental slope topography, different current systems with conjugate flow directions, and an active tectonic margin (particularly during the Paleogene interval) which led to local fluctuations of the ACC flow and other currents linked to intermediate water masses (SAMW and AAIW). It has been deduced that the Paleogene mixed systems were generated in the New Zealand Basin by intermediate water mass flows, from the Eocene-Oligocene boundary (which are coeval with the opening of the Tasmanian gateway and the inception of east-west flowing ACC) until the late Oligocene.

Keywords: Mixed systems, Turbidite dominated, Contourite-dominated, ACC, lateral migration

Contourites developed along the Japan and Kuril Trenches

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Contourites are sediments that are deposited and/or reworked by the persistent action of bottom currents (Stow et al., 2002). They are important for paleoceanographic and paleoclimatological analysis, especially around active margins where they are associated with the formation of bottom water (Rebesco et al., 2014). A recent study by Nicholson et al. (2020) suggested that the instability of contourite drift, with its well-selected fine-grained sediments and slope-parallel sedimentary structures, is involved in the mechanism of tsunamigenic submarine landslides. In other words, their study highlights the importance of studying contourites in convergent margins, which have not been well studied in the past. The Discovery of new contourite drift and clarification of depositional processes in convergent margins, which have different component particles and topographic characteristics from active margins, has been one of the challenges in recent contourite studies.

The Japan Trench and Kuril Trench are convergent margins where northward bottom currents originating from the Lower Circumpolar Deep Water (LCDW) flow along the outer slope (Ando et al., 2013). However, contourites deposited by bottom currents have been not found in this area. In this study, we analysed piston core samples by means of a analysed method of the Sortable Silt range (McCave, 1995) and interpreted seismic profiles to discover contourite drift on the oceanic plate of this area.

Furthermore, we preliminary report a result of IODP expedition 397. We set a final goal of this study to make a standard model of contourites in NW Pacific and/or active margins to comparison with examples in Atlantic.

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Geomorphology of deep marine sediments, Northwest Borneo

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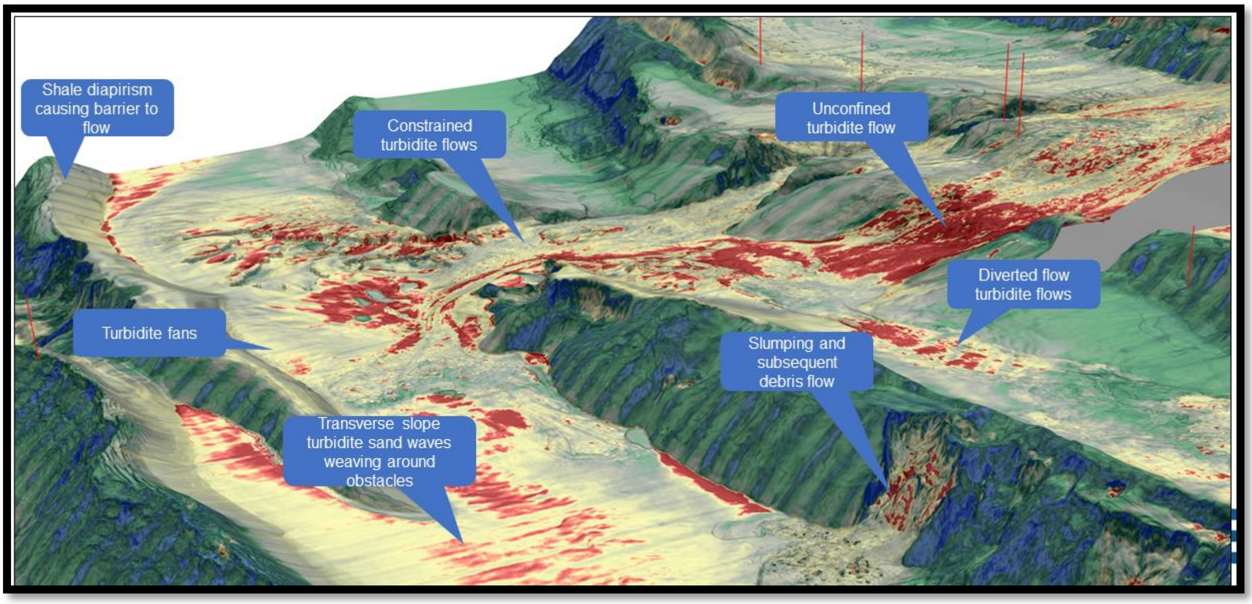
A well-known series of sedimentary basins of Cenozoic age form a prolific hydrocarbon region situated on the NW Borneo margin. Recently acquired high-resolution seismic imaging profiles around Sabah and the Dangerous Grounds by PGS and its JV partners, reveal a wealth of distinctive depositional, erosional morphological features, which allow for a detailed analysis of the architectural elements that comprise these deepwater depositional systems. Some turbidite fans and associated submarine processes such as slumps and slides and overall sand distribution patterns are readily interpretable.

In this presentation we will discuss a number of profiles from this Sabah MultiClient 3D Data set, describe certain reservoir elements that may provide challenges to companies that try to develop these, and finally we will attempt to place our observations in a sequence stratigraphical framework.

Comparisons of the modern-day shelf Northwest Borneo indicate many similarities to the geomorphological architecture of the Tertiary subsurface. The turbidites of Northwest Borneo are deposited in a structurally controlled tectonic basin, with multiple linear shale diapers transverse to slope. The subsequent frontally confined turbidites produce fill-and-spill sediments, where the topographical highs cause rapid deposition and diverted flows transverse to the slope as it weaves around the structural obstacles.

These fans interact with megabeds that form from either small slope failure fans to vast tectonic mega slope failure blanketing the basin. In turn, these mega beds are highly erosive and remove the previous turbidite fans and redeposit the sand mixed in with the chaotic muds forming only partial seals. The modification of these slope fans by subsequent contour currents is unclear and potential identification of contourites is difficult as their characteristics are masked by the slope parallel geomorphology of the contour driven turbidites. However, based on the strength of modern-day oceanographic currents it seems likely that the turbidites deposits should and could be reworked into contourite sand waves.



Example of high-resolution imaging profiles from Sabah fold a thrust belt forming the basin margin, illustrating the deep-water sediments geomorphology (**Scale 1cm=10km**) (courtesy of PGS and JV Partners)

Bottom current dynamics and its impact in sedimentation in the Drake Passage

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The Southern Ocean is a major component of the coupled ocean-atmosphere climate system. It connects all the other major oceans and influences the properties of water masses of the deep oce an over a large portion of the world. The Antarctic Circumpolar Current (ACC) is the only deep link between the three ocean basins of the Southern Ocean. The Drake Passage (DP) is the most convenient location for monitoring the ACC and its variability, since it is the narrowest constriction through which the ACC passes through. The main aim of this study is to better understand how the ACC affects modern sedimentation in the Drake Passage, in order to improve palaeoceanographic reconstructions based on the sedimentary record.

In this study, we present data from CTD, high resolution multibeam bathymetry, sub-bottom profiler data and grain size analyses from surface sediments collected in the DP from February to April 2016 during cruise PS97 on board the R/V "Polarstern". To have a regional view of bottom currents and complement the in-situ data over larger spatial and temporal scales, we processed 27 years (1993-2020) of daily data from the global reanalysis model GLORYS12 Mercator Ocean. The vertical grid has 50 levels with 22 levels in the upper 100 m, leading to a vertical resolution of 1 m in the upper levels and 450 m resolution for the deepest levels up to a maximum depth of 5727 m. The horizontal resolution is 1/12°.

Results from empirical orthogonal functions (EOF) present patterns (first modes) of bottom currents that are related to the local topography. Time series of bottom currents reveal multiple high-speed current events. The hydrographic section in the west DP shows that bottom waters are dominated by Lower Circumpolar Deep Water (LCDW) and at the surface, the ACC fronts are clear boundaries for water masses. In the Drake Passage the formation of contourite drifts and moats is related to bottom-current distribution and variability. Weak bottom currents and low eddy kinetic energy are related associated with the presence of contourite drifts. However, lower intense bottom currents are shown by the model, particularly when compared at the locations of the sediment cores. This discrepancy may be related to the complex topography in the area that results in patchy sediment accumulation and complex bottom-current patterns that cannot be accurately resolved by the relatively coarse grid of the model near the seafloor.

Keywords: Antarctic Circumpolar Current; Drake Passage; Bottom Currents; Topography; Sediments

Contourite depositional systems on the South Shetland margin in Antarctica

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Island-arc systems are sites of intense tectonic activities, such as vocalism, earthquakes, and fault movements. Tectono-sedimentary interactions occur over geological time and determine the modern morphology of the continental margin (Bailey et al., 2020). However, such interactions have been poorly documented in high-latitude regions. This study focuses on deep-water sedimentary systems in forearc and back-arc basins of the South Shetland margin (an island-arc system) in Antarctica. Contourite features are identified and interpreted based on gravity cores, bathymetry, oceanography, and reflection seismic data. The results show significant tectonic influences on sedimentary system evolution in such basins.

The forearc basin is characterized by numerous gullies and canyons, and different types of contourite drifts. Mineral contents and grain size derived from the gravity core, located at a downslope elongated mounded drift, indicate the asynchronous interplay of turbidity and bottom currents at the transition zone from passive margin to island arc during the last climate cycle. Small-scale mounded and plastered drifts are restricted on slide-induced terrace. Turbidity currents dominate the rest of the margin.

The back-arc basin (the Bransfield Strait) is an enclosed deep basin. Numerous of contourite drifts are developed along the gentle flank of the back-arc basin. The results show that deep and bottom waters were weak or the oceanic circulation was completely different from its modern counterpart at the beginning of the back-arc basin opening. Active volcanism at ca. 0.7–1.0 Ma generated a series of large obstacles (Fisk, 1990) that deflected and changed the path of bottom currents and fully determined the modern circulation of the Bransfield deep and bottom waters.

Late Miocene to present-day sandy deposits in the Gulf of Cadiz associated to the Mediterranean Outflow Water

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This work contributes to improve the knowledge of deep marine deposits, specifically those generated by the interaction of gravitational sedimentary processes and bottom currents (mixed processes). The study of these deposits is of great relevance both in the academic world, and in the industry, due to their potential as energy resources and for carbon dioxide (CO2) storage. However, there is still a great lack of knowledge about their diagnostic criteria, how they are generated, how they evolve, and their socio-economic implications.

Offshore seismic reflection and logging data analyses from the continental slope of the Gulf of Cadiz reveal Late Miocene and Pliocene-Quaternary contourite and mixed deposits that host sandy bodies of special interest as potential geological storages. In general, it has been observed that the sandier deposits, exhibiting high-amplitude reflections (HARs), are located mainly on the erosional elements of these depositional systems or in the transition between the erosional and the depositional features: a) contourite channels (or moats and furrows); b) in the proximal setting of contourite terraces; and c) at the exits of the Gibraltar Strait. The sandier deposits in these systems are brought into the channels/moats and terraces by gravitational processes; and once inside they are reworked by the bottom currents, being laterally transported and deposited by a higher velocity core of the current along it. The contourite and mixed deposits generated before the full opening of the Gibraltar Strait, during the Late Miocene (~8.2-5.33 Ma), display different geometries and correspond to depositional features such as sheeted, plastered, confined, mounded and mixed drifts, as well as levees, and erosional features such as furrows, contourite and turbidite channels. These features are related to the paleo-Mediterranean Outflow Water (MOW) circulating through the Betic and Rifian corridors prior to the restriction of the Mediterranean-Atlantic gateway.

Natural gamma-ray logs from exploration wells in this area show sand deposits up to 50 m thick, except in wells close to the Miocene paleo-shore where alternating deposits of sand and clay are identified. After the opening of the Gibraltar Strait, the Mediterranean Outflow Water (MOW) has generated a complex Pliocene-Quaternary (5.33 Ma-present) contourite depositional system. Sampling of sandy contourites associated with seismic features also suggests the extensive distribution of mature, well-sorted Pliocene–Quaternary sand about 600 m thick, and showing the following characteristics: a) Early Pliocene deposits (~5.3-3.2 Ma), correspond to sheeted drifts developed mixed with gravitational sedimentary processes and low acoustic response; b) Late Pliocene-early Quaternary deposits (~3.2-2 Ma) displaying sheeted contourite drifts and enhanced acoustic response towards the top, especially in areas adjacent to highs and banks. Borehole logs for these deposits show cyclic swings in amplitude that are generally lower than those observed for the overlying Quaternary deposits; c) Natural gamma-ray logs along the Quaternary sequence show medium-amplitude cyclic swings, varying on decimetre to sub-meter scale, with no major steps in base levels. Detail studies on Pleistocene mixed deposits show a possible correlation between serrated gamma-ray trend and interbedded sandy deposits within a contourite drift due to sediment supply from an adjacent channel-levee system. On the other hand, a coarsening-upward, funnel-shaped gamma-ray trend is associated to an increased sandy input into the drift during a period of enhanced MOW, when an adjacent contouritic channel became more active. The differences of LM sandy deposits respect to the recent succession, consist of higher thicknesses, better-sorted and higher grain size of the sands, and increasing medium-high amplitude on seismic reflections. The Miocene and Pliocene deposits also exhibit cyclic swings in gamma ray logs, but with lower amplitude and at lower frequencies than those observed for the Quaternary ones.

The research is related to the project PID2021-123825OB-I00 (ALGEMAR) and was conducted in the framework of "The Drifters" Research Group. This research also used data collected through the Integrated Ocean Drilling Program (IODP).

Evolution of contourite (paleo)channels after the full opening of the Gibraltar Strait

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The present-day Strait of Gibraltar is one of the important oceanic gateways worldwide, opened at the end of the Miocene. Offshore seismic reflection data analyses from the southern continental slope of the Gulf of Cadiz at the exit of the Strait of Gibraltar reveals a succession of deeply incised valleys/channels, channel fills, and mounded structures. This opens up new evidences of the onset and intermittent behaviour and evolution of the Mediterranean Outflow Water (MOW) circulation during the Pliocene and Quaternary after the opening of the Strait of Gibraltar. Nine different paleochannels (PC) were identified that developed simultaneously to regional unconformities related to nine major Seismic Units (SU) (Fig. 1). Their correlation to IODP Exp. 339 Sites and regional chronostratigraphy have enabled us to comprehend the sedimentary evolution of these channels. As a result, three tectono-sedimentary stages have been differentiated. Within the first tectono-sedimentary stage, (latest Miocene to Early Quaternary), five channels are recognized (PC-1 to 5 and SU 1 to 4) about 4 km eastward from the Present-day channel. All these channels are developed in a central depression between two structural highs. The second stage (Early Quaternary to Late Pleistocene) is characterised by the displacement of three channels (PC-5 to 9 and SU-5 to 8) as well as the formation of adjacent smooth mounded drifts on their distal side located at similar place than the Present-day channel location. The latest stage comprises the Late Pleistocene to Present (PC-9 to seafloor and SU-9). During this period the southern channel maintained its present-day location and morphosedimentary characteristics. High-amplitude reflections are observed in channel facies, whereas the intercalation of low-amplitude and high-amplitude reflections are seen laterally in contourite drifts. After PC-5, there is also an increasing reflectivity of contourite drift facies proximal to contourite channels.

The variable locations and depths of the channel incisions and channel infill suggest local variations in the erosive capacity of the MOW, conditioned mainly by the inherited regional basin topography and the presence of local topographic highs. De Weger et al. (2020) reported the intermittent behaviour of the paleo-MOW during the Late Miocene and the present work confirms that behaviour during the Pliocene and the Quaternary, highlighting the complex interplay of tectonic changes and climatic variability in controlling that variability at different scale on gateways. These variations show a long-term intermittent behaviour of the MOW, which correlate with main tectonics events, of about 0.8–0.9 Ma duration with a pronounced overprint of ~2–2.5 Ma cycles, and shorter-term climatic (orbital) cycles of ≤0.4 Ma.

Contourite channels, filled by coarse (sandy) facies, have been recognized to contain large amounts of well-sorted sands associated with adjacent mud-prone contourite drifts, which can constitute effective storage/seal formations for antropogenic CO_2 and sustainable energies. The studied modern and buried channels are great analogues for ancient contourite channels that could potentially represent valuable reservoirs for underground geological storage exploration.

The research is related to the projects CGL2016-80445 (SCORE) and PID2021-123825OB-I00 (ALGEMAR) and was conducted in the framework of "The Drifters" Research Group. This research also used data collected through the Integrated Ocean Drilling Program (IODP).

IODP Exp-403: The high-resolution paleoclimatic record of the western margin of Svalbard (Proposal IODP 985-Full2)

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High-resolution depositional archives were identified in the contourite drifts developed on the mid-upper slope of the western continental margin of Svalbard (Bellsund and Isfjorden drifts, Vestnesa and Svyatogor ridges) under the persistent effect of the West Spitsbergen Current (WSC). The sediment drifts contain very similar stratigraphic sequences characterised by depositional marker beds (Heinrich-like and meltwater related deposits) outlining a synchronous, almost simultaneous response of the Svalbard-Barents Sea paleo-ice sheet to changing climatic conditions. These observations strengthened the idea that the WSC, transporting warm Atlantic Waters to the Arctic ,was one of the major drivers of the Arctic climate variability and cryosphere evolution in the area.

The above considerations inspired the writing of Proposal IODP 985-Full2 that was motivated by the necessity of retrieving continuous, high-resolution, and datable depositional sequences containing the record of the palaeoceanographic characteristics and cryosphere evolution during the past climatic transitions that followed the opening of the Fram Strait in the Arctic. Such data are greatly needed to better constrain global climate connections, forcing mechanisms and climate models.
The general objective of 985-Full2 is the reconstruction of the variability of the WSC and its influence on climate changes particularly during key climate transitions (i.e. the late Miocene–Pliocene transition, late Pliocene–Pleistocene Transition, Mid-Pleistocene Transition, Mid-Brunhes Transition, and sub-orbital Heinrich-like events), its impact on the Arctic glaciations, ice shelves development and stability, and sea ice distribution over last 5.3 Ma.

The proposal submitted in April 2020 was approved in May 2022 and scheduled as IODP Exp. 403 (June 4th to August 2nd, 2024).

One million years of Mediterranean Outflow strength

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An orbitally tuned age model is based principally on sortable silt mean grainsize ($\overline{SS}$ proxy for flow speed) changes for sediments deposited under the influence of the Mediterranean Outflow (MO) at IODP Site U1389 in the Gulf of Cadiz. The possibility of tuning sortable silt grainsize to insolation was indicated by close agreement between these two parameters with grainsize on an earlier isotopically-based age model for the upper 130 m of the core. Successful tuning of this section led to tuning of the whole 390 m-long record with addition of a magnetic susceptibility control at Termination VI, and the LO *R. asanoi* datum at around 900 ka (now dated at 910 ka in this core).

There is strong precessional variability in $\overline{SS}$ with speed maxima at insolation minima, especially in glacials, superimposed on an increase in flow speed from 620 ka to the present. From 990 to 620 ka the average amplitude of speed changes is 3.7 cm/s, but this increases to 7.7 cm/s from 620 to present. Most of the glacial-interglacial cycles after 500 ka display increasing magnetic susceptibility related to sand content, and several also show increases in $\overline{SS}$, both indicating increase in flow speed.

Deep ocean flow speeds are mainly density driven. Previous work has demonstrated that the major drivers of this system's density are the precipitation - evaporation - inflow balance in the eastern Mediterranean plus cooling in the Gulf of Lions. One or both of these must have increased the density contrast between overflow and overlying waters over the past 620 ka. Published benthic $\delta^{18}O$ for 125-235 ka, corrected for ice volume changes, which tracks the combination of seawater temperature and salinity that controls density, demonstrates that flow speed and density maxima are coincident. A further possible control of outflow speed is the water depth over the Gibraltar sill. Although longer flow maxima are seen during major glacial sea level lowerings, the amplitude of these SL changes on precession time scales does not match flow speed amplitudes, indicating that this is a subsidiary effect. However, the Gibraltar sill is undergoing long-term shallowing – 50 to 65 m over the last Ma – which may play the key role in MO acceleration of the last 630 ka by control of surface inflow and residence time indicated by ε_{Nd} in the eastern Mediterranean.

Deep-sea neoichnology: new in-situ observations on bottom current affected settings

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The number of detailed deep-sea neoichnological studies has increased during the last decades, mainly through advances in the visual instrumentation used to observe this complex and underexplored environment. The appearance of new technology has enabled the acquisition of highly detailed images (e.g., 4K resolution) over large-scale areas of the deep-sea floor, and the subsequent characterization of biogenic traces (lebensspuren) and modern trace makers. In this research, we provide some examples of new deep-sea neoichnological studies, in bottom current affected settings, which have helped us to assess environmental conditions affecting past producers, trace fossils, and then ancient deep-sea settings: 1) At an abyssal site in the NE Pacific ('Station M'), high-energy periods associated with benthic storms have been related to the impoverishment of lebensspuren abundance and ichnoassemblage diversity. The local-scale erosion and re-suspension of unconsolidated surface sediment inhibits the formation of previous softground traces and led to the redistribution of organic matter resources. Also, these brief energetic events (<3 days) involved the appearance of exhumed surface patches; however, no firm/hardground traces developed. These findings may offer a new perspective on the temporal gap needed for the development of traces in consistent substrates at deep-sea settings. 2) We report the distribution of small *Paleodictyon* at six abyssal sites near the Aleutian Trench. This study reveals for the first time the presence of *Paleodictyon* at Subartic latitudes (51º-53ºN) at depths over 4500m, although the traces were not observed at stations deeper than 5000 m. The six abyssal sites are affected by different bottom current velocities ranging from 2.1 to 3.6 cm/s, however no correlation has been observed with *Paleodictyon* morphology. 3) At an abyssal site with a dune field in the Bering Sea, lebensspuren abundance and diversity varies in a transect from out to inside dune field. Changes in the abundance of specific lebensspuren seem to be related to the high energetic conditions typical of deep-sea dunes.

Preliminary obtained results support the importance of the rapid increase in capture seafloor images from deep-sea environments for significant advances in neoichnological research. However, there are still many steps to be taken to establish a standard procedure for the description, identification, and classification of these deep-sea lebensspuren. Particularly, characterization of endobenthic lebensspuren remains a significant challenge in deep-sea environments.

Keywords: Deep-sea, neoichnology, lebensspuren, environmental features, trace fossils, sedimentary basin research

Ichnofabric analysis as a tool for characterization and differentiation between calcareous contourites and calciturbitites

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Ichnofabric approach has been shown as a valuable proxy in sedimentary basin research and particularly in the characterization of shelf-sea or deep-sea calcareous environments, leading to the interpretation of paleoecological parameters affecting macrobenthic trace maker community (e.g., Ekdale and Bromley, 1984, 1991). However deep-sea environment is a complex setting in which interaction between numerous depositional processes occurs. This is the case of the Eocene Lefkara Formation at the Petra Tou Romiou beach section (Cyprus) which shows the incidence of deep marine bottom current and distal turbiditic episodes. Here we present a trace fossil analysis, including ichnofabric approach, of this section to precise the palaeoenvironmental conditions featuring this complex setting. Ichnofabric analysis has allowed us the characterization and differentiation of sporadic turbiditic events affecting contourite deposition. Calciturbidite episodes show ichnofabrics consisting of post-depositional U-shaped traces (i.e., *Arenicolites* isp., ?*Diplocraterion* isp.,) and vertical borings typical of consolidate substrates. High energy sandy contourite deposits are dominated by horizontal deposit-feeders traces and the development of ichnofabrics with *Planolites* isp., and *Thalassinoides* isp. The record of ichnofabrics with slightly deformed *Planolites* in the interbedding of sandy contourites or in the transition between the facies reveals variations, even pauses, in sedimentation inside the bi-gradational succession. Pelagic / hemipelagic background sedimentation is associated with chalky calcilutites deposits consisting of *Chondrites* isp., *Planolites* isp., *Taenidium* isp., *Thalassinoides* isp., and *Zoophycos* isp., assemblages, typical of the *Zoophycos* ichnofacies (Miguez-Salas and Rodríguez-Tovar, 2019), that may represent calcareous muddy contourites (Hüneke et al., 2020).

Can internal waves control the formation of channels, contourite drifts and cold-water coral mounds in upper continental slopes?

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The formation and evolution of outer shelves and upper continental slopes are controlled by several factors, such as changes in sediment supply related to sea-level and climatic fluctuations, activity of gravity flows and slope instability, as well as ocean currents. In addition to alongslope ocean currents related to the general circulation, internal waves are also known to often affect continental margins. It is however still not well understood in which areas internal waves may play a major role in shaping the seafloor and in favouring the development of cold-water coral mounds. In this study, we show two examples in which internal waves are suggested to strongly affect the seafloor morphology and sediment distribution, one case in the upper slope of the Mozambican margin and another one in the outer shelf of the Namibian margin. The interpretation is based on a broad data set that integrates multibeam bathymetry, seismic and seismo-acoustic data of the sub-seafloor and the water column, measurements of water masses properties (temperature, salinity and turbidity), sediment cores and current measurements.

Off Namibia and Mozambique, a straight channel extends parallel to the slope contours over several 10s of km at water depths ranging between 150 and 190 m. The channel is not related to a particular tectonic feature or a slope break. In Mozambique, the channel is relatively shallow and has a depth of 2-13 m, while in Namibia, the channel is associated with a 40-50 m high escarpment. Erosional truncations and abraded surfaces are also found in several areas of the upper slope in both cases. The lower and upper parts of the escarpment offshore Namibia are strongly eroded and are characterized by the presence of dormant cold-water coral mounds. Offshore Mozambique a field of upslope migrating sand dunes is also found in an area where the channel is absent. We observed internal waves interacting with the slope and evidence of breaking internal waves in both study areas. Moreover, in the Namibian margin, we observed solitons breaking on the slope. Hydraulic jumps were observed at the top of the escarpment, which may also favour seafloor erosion and sediment resuspension. A nepheloid layer could be identified in the turbidity measurements and the echosounder images of the water column associated with the abraded area located at the bottom of the escarpment. Previous lander measurements have shown that in this area fluctuations in turbidity are related to internal tides. Dormant cold-water coral mounds have been found also in this area and their growth probably benefited from the supply of particles by internal waves.

Although internal waves are intermittent processes, they may result in the formation of sedimentary features that are preserved in the geological record. In the Mozambique margin, a buried channel formed during the previous sea-level highstand is still preserved in the sedimentary record. During sea-level lowstands, no channel was formed because the Zambezi delta provided high amounts of sediments directly to the slope, which could not be reworked fast enough by bottom currents. Although no time constrains are available at present for the Namibian margin, the channel and the escarpments seem to have formed over a very long period of time. In conclusion, internal waves in upper continental slopes can induce intense localized seafloor erosion and sediment resuspension, especially in areas of relatively low sedimentation rates.

Ocean currents as conveyor belts for potentially tsunamigenic 'submarine landslide factories': case studies from the Antarctic Circumpolar Current and Indonesian Throughflow

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Ocean currents with sufficiently high near-bottom velocities are capable of eroding and subsequently transporting marine sediment across large (~101-3 km) distances. These sediments are redeposited when current velocities decrease sufficiently, or where along slope "accumulation space" traps sediment in contourite drifts or similar features. The depositional geometry and often-rapid accumulation of sediment in these areas can lead to overpressure development and precondition the slope for repetitive submarine mass failure events. Thus ocean currents can act as 'submarine conveyor belts' for potentially hazardous landslide events. In this presentation, we highlight two case studies that emphasis the role of ocean currents on slope stability and landslides hazards.

The Sub-Antarctic Front (SAF) corresponds to one of the three main jets of the Antarctic Circumpolar Current (ACC), the Earth's largest current system. The SAF flows round the eastern margin of the Burdwood Bank, part of the North Scotia Ridge (NSR). This jet, with measured velocities locally exceeding 50 cm/s[1], deeply erodes the slope of the Burdwood Bank as it exits a narrow gateway in the NSR and transports the sediment westwards across the slope. A significant part of the sediment load of the current is deposited in a broad embayment at the north of the ridge, in a plastered contourite drift that we call the Burdwood Drift[1]. 3D seismic reflection data shows that a series of large (~100 km^3) Mass Transport Deposits (MTDs) are derived from this drift. This provides evidence that the drift undergoes successive failure events, separated by periods of re-accumulation of sediment from the current. This system is an entirely self-contained 'source-to-sink' system, with no other viable source of sediment, with the conveyor belt ending in the submarine landslide complex at the base of the Burdwood Drift. Numerical models suggest that these landslides are likely to represent a significant and overlooked tsunami hazard for this region.

The Indonesian Throughflow is the main current transporting warm water from the Pacific to the Indian Ocean. The main branch of the current, representing around 10-15 Sverdrups, flows through the Makassar Strait, between Sulawesi and Borneo. The current is deflected to the west of the Makassar Strait, where it entrains sediment from the Mahakam Delta, and transports it south-westwards to the Makassar Contourite Depositional System[2]. This drift system is the source of the largest (up to ~700 km^3) MTDs in the region, with evidence for submarine mass failure occurring at least once every 250 ka. New 3D seismic data shows that the drift has several different segments, at various stages of failure and re-deposition. Incipient failure features, and recent slide scars, show that failure is likely strongly controlled by the presence of shallow gas and hydrates, combined with the depositional geometry of the drift. Free gas accumulates at the base of the gas hydrate stability zone (GHSZ) and then migrates laterally to the intersection of the GSHZ and the seabed. Most failure events appear to nucleate at this point, with small initial failure events progressing to large-volume transgressive failures incorporating the upper drift sequence. This has important implications for landslide and tsunami modelling to understand the possible hazards associated with this system.

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Ryukyu Sand Sheet: a new contourite field in the Ryukyu Island Arc, northwestern Pacific Ocean

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Contourites are well-known from many continental margins under the influence of bottom currents. Studies in the last two decades have greatly advanced our understanding of contourites, including their facies characteristics, the depositional and erosional processes beneath bottom currents, and the principal controls that affect their nature and occurrence. However, despite these growing number of contourite studie s, and despite major wind-blown currents and thermohaline-driven circulation being well established in the Pacific, there is a relative paucity of data on Pacific Ocean contourites. This study investigates previously collected sediment samples, geophysical and oceanographic datasets from an area around the central Ryukyu Islands, southwest Japan, in the north-western Pacific Ocean, mainly influenced by the Kuroshio currents, which is one of the strongest oceanic currents in the world.

As the result, we here document a new area of contourite-controlled sedimentation in the NW Pacific Ocean associated with a very varied topography, which we call the Ryukyu Sand Sheet. This contourite sand sheet has an area of around >35,000 km^2 and extends from the narrow island shelves to over 1500 m water depth. This is one of the most distinctive sand sheets worldwide, not because of the extensive area, but also the complex oceanographic processes associated with the Kuroshio Current. The sand sheet comprises mainly moderate to well-sorted, fine-grained sands, with current ripples. The mean ripple wavelength is 12.5 cm (n = 66 sites), with a range from 7.0–24.1 cm. Some linguoid ripples are also evident at several stations, and these more clearly indicate current direction. The current direction and ripple sense are highly variable across the region, including downslope, upslope and alongslope. Some areas show a distinctly alongslope orientation. Several videos were taken from a Remotely Operated Vehicle at selected stations. These all show active bottom current flows above the sandy substrate at depths up to 700 m. Giant sediment waves (up to 10 m in amplitude, 100–400 m in wavelength) and small drifts develop in distinct locations.

It is formed under the influence of three principal current systems – the Kuroshio Current, the Kuroshio Countercurrent and the Ryukyu Current. The interaction of these currents with each other and with a complex seafloor topography, spawns a series of meso-scale gyres, eddies and vortices that shape the seafloor and lead to deposition of an extensive sandy substrate, locally with gravels and exposed seafloo r. Strong surface currents, as well as deep-water thermohaline circulation, both influence the depositional and erosional processes of deep-sea sediments. The role of the modern Kuroshio Current in this context supports earlier work that proposed an ancestral Kuroshio Current for the deposition of Miocene contourites onshore Japan. Sediment supply to the Ryukyu Sand Sheet is by a mixed process of seafloor polishing and sand spillover that involves combined oceanographic and gravitational processes.

Geostatistical analysis of cyclicity in deep marine facies

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Cyclic depositional features are commonly developed in deepwater sedimentary facies. Stacked sequences in varied forms is the most obvious characteristic, which is related to complex variation in depositional conditions. This study introduced several geostatistical approaches to analyse the cyclical bi-gradational sequences of contourite deposits from IODP Expedition 339 in the Contourite Depositional System (CDS) in the Gulf of Cadiz. It analysed both the vertical sequences and their cyclicity and their lateral correlation, both qualitatively and quantitatively. Additionally, similar geostatistical approaches were applied to colour sequences in turbidite and hemipelagite deposits from the Benguela Current Upwelling System, SW African continental margin. This allowed comparison of sequences and cyclicity between the different deepwater facies types. It also demonstrated the general applicability of this method to deepwater sedimentary facies.

This study systematically examined contourite bi-gradational sequences deposited at IODP Sites U1386 and U1387 between mid-Pleistocene to Recent. Transition probability analysis based on the lithological logs confirmed the statistical validity of typical bi-gradational sequences composed of coarsening-upward to fining-upward contourite divisions. The cyclic patterns of contourite bi-gradational sequences varied to some extent between each studied hole. The 3-layer-sequence dominates in this study area, and a few sequences with more than 4 divisions include sandy division. Autocorrelation of sequence duration in all studied holes indicates the existence of long-term cyclicity of around 350 ky. Cross-correlation of this long-term sequence frequency as well as of individual sequences shows moderately good but not perfect correlation between holes and sites. This study suggests contourite deposition at the study sites is controlled by both bottom current strength and sediment supply, both of which can most probably be related to a complex variation in paleoclimate evolution and orbital cycles.

In hemipelagite and turbidite-hemipelagite hybrid deposits beneath the Benguela Upwelling System off SW Africa, two colour sequence models (Hemipelagite Dominant Sequence and Turbidite Hemipelagite Hybrid Sequence) were developed based on light-dark variation related to organic matter content. Autocorrelation of sequence duration pointed out long-term cyclicity through the past 4 My, which can be correlated to stages in the long-term evolution of the Benguela Current Upwelling System. Lateral correlation between studied sites indicated differences of sequence frequency in time and space, which further contributed to reconstruction of the upwelling system.

The geostatistical study of cyclicity in contourite bi-gradational sequences and its comparison cyclic characteristics of other deepwater facies (turbidites and hemipelagites), demonstrates that such geostatistical approaches can be an important technique to evaluate the basic sedimentary character of different systems and their numerical expression. It allows for comparison between facies types and for better correlation with other time series records, such as orbital climate patterns. Cyclic signatures can be correlated between different sites and help better understand the sedimentary processes involved in their deposition.

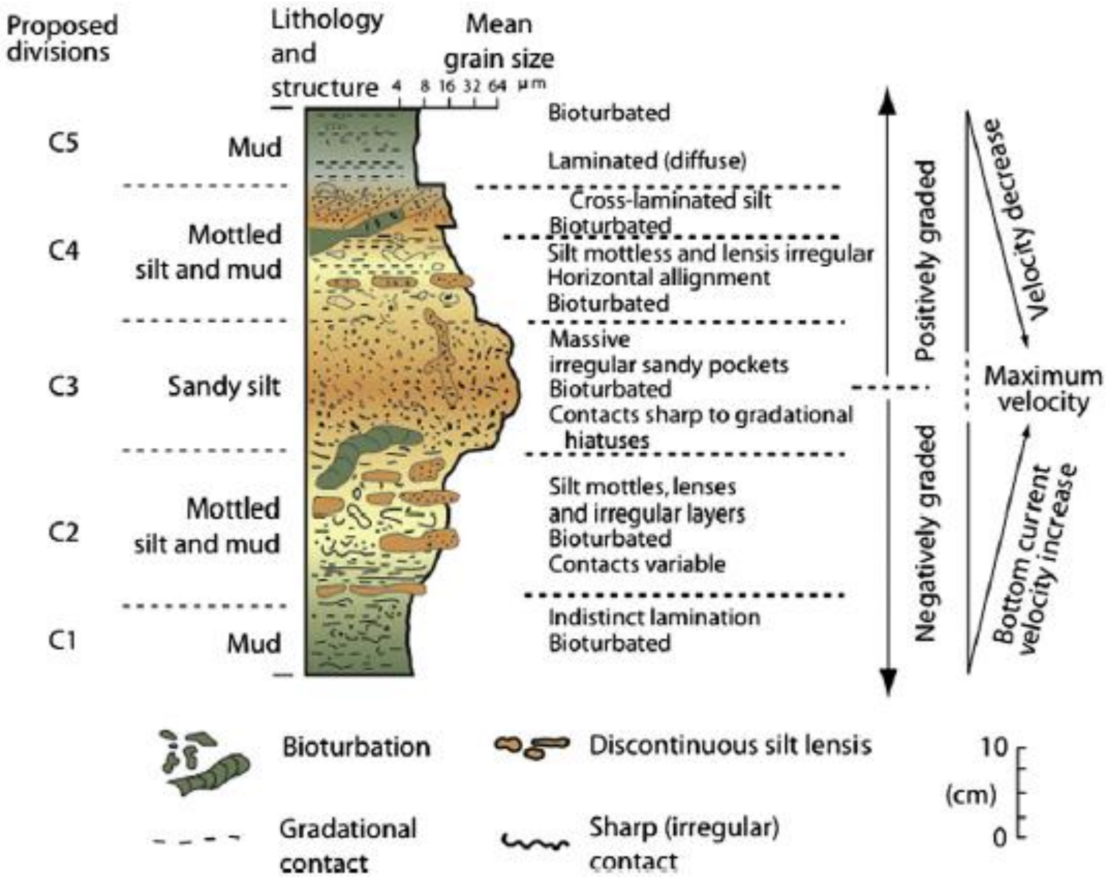
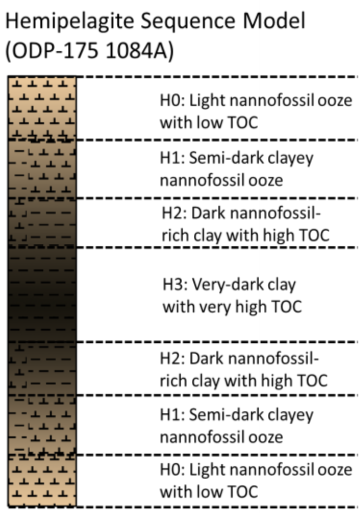


Figure 1. Contourite bi-gradational sequence model



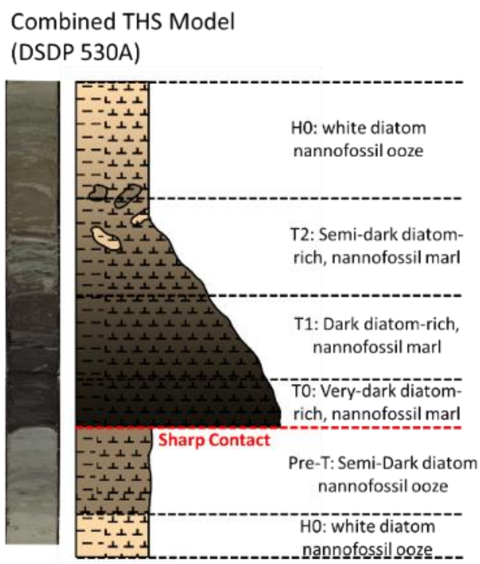


Figure 2 (left). Hemipelagite dominant colour sequence model
Figure 3 (right). Turbidite - hemipelagite hybrid colour sequence model

The influence of deep marine circulation on gas-related seafloor morphologies over a salt tectonic domain: Case studies on the continental slope of Santos Basin, southern Brazilian margin.

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The Santos Basin slope is a physiographic feature whose seafloor morphology is influenced by both geological and oceanographic processes. Regarding geological processes, halokinesis has been one of the main forces driving the geological evolution of this margin and influencing the present-day seafloor morphology. Salt dynamics is considered to be responsible for the development of faults and fractures, which behave as fluid conduits toward the seafloor surface. The supply of fluids added to the nature of the sediments provide favourable conditions for the formation of gas-escape seafloor morphologies, such as pockmarks, carbonate mounds and ridges. Additionally, the observation of exhumed salt diapirs in the south-western part of the Santos Basin seafloor is suggestive of active halokinesis. Besides, oceanographic processes leave a conspicuous fingerprint in the formation of an extensive array of morphological and sedimentary seafloor features. The interaction of bottom currents with pockmarks, carbonate structures and exhumed salt diapirs erodes the seafloor relief and contributes to the formation of moats, comet marks and scours. Associated with the prevailing erosive features, bottom currents-related deposits are formed along the slope structures constituting contourite systems.

Keywords: deep marine circulation; gas-related seafloor morphology; comet marks, contourite systems.

Contourite features: observations and process implications

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Are observations enough for the inference of the oceanographic processes that generate contourite features? After many years of observation-based research, a precise match between contourite features and oceanographic processes forming them is still to be established. The inherent gap in spatial and time scales between disciplines (geology and physical oceanography) is among the reasons of difficulty.
We present a new contouritic case study on the west Sardinian margin where both appropriate regional oceanographic information and suitable geophysical data are available.

The oceanographic dataset (including gliders, floaters, CTD etc…) document the presence of a barotropic-type boundary current along the continental slope and of very energetic anticylonic submesoscale coherent vortices (small eddies) detaching from its flow due to the influence of bathymetry. The geophysical observations detail the effects of bottom currents on the development of small sedimentary drifts, moats around obstacles and wide (U-shaped) long-lasting (millions of years) erosional/non depositional depressions distinguishable from a network of narrow (V-shaped) more recent turbidity channels. For the interpretation of the genesis of these wide erosional/non depositional depressions various mechanisms are considered, including structural control, slope instability, spillover of turbidity currents, bottom current acceleration associated to seafloor obstacles (morphology of prominent volcanoes), effects of energetic eddies.

Though undeniably sensible considerations can be made on the basis of the integration of regional oceanographic information with geophysical data, it is difficult to draw a definitive interpretation about the sedimentary processes without numerical modelling (possibly supported by dedicated long-term current measurements).

Deep-water depositional processes in an Upper Cretaceous Neotethyan intra-continental fore-arc basin (Kannaviou Formation, W Cyprus)

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In active margin settings (i.e., trench, fore arc, arc, back arc), local to regional tectonic settings are critical to understanding deep-water basin formation and related depositional processes. This includes both intra-oceanic and intra-continental fore-arc basins. A good example is the Upper Cretaceous (Campanian-middle Maastrichtian) intra-continental fore-arc basin in W Cyprus known as the Kannaviou Formation. This basin was constructed on supra-subduction zone oceanic lithosphere, represented by the Troodos ophiolite, after its formation in the S. Neotethys (c. 90-91 Ma). The basement of the overlying fore-arc basin is deep-water ophiolitic extrusive rocks, local scree-type volcanic breccias and rare ponded metalliferous sediments (umbers). The ophiolite formed near a ridge-transform intersection and as a result the oceanic lithosphere rifted in places exposing mantle (mainly harzburgite) on the ocean floor, where it was directly covered by fore-arc sediments. The overlying fore-arc basin succession (up to c. 750 m thick) is mainly volcaniclastic sediments, with subordinate terrigenous sediments, rich in radiolarians, together with planktic foraminifera suggesting accumulation above the carbonate compensation depth. Background muds contain abundant mixed-layer clays (volcanogenic), while discrete reddish interbeds are rich in kaolinite (continentally derived). The background sediments are interspersed with channelised volcaniclastic sandstones, exposed as discontinuous lenses (up to c. 10 m thick x 300 m long). The sandstones contain abundant relatively unaltered tephra of mafic/intermediate and felsic compositions, derived from a contemporaneous volcanic arc (U-Pb zircon age=80.1 ± 1.1 Ma). Intermixed terrigenous silt and sand were derived from a tectonically active continental margin (e.g., metamorphic quartz, limestone, chert), represented by the adjacent Mamonia Complex. Trace-element analyses of the volcanic glass are consistent with a primitive arc source; i.e., an arc constructed on oceanic crust or on thin continental crust. Several processes contributed to the infill of the fore-arc basin: 1. Background pelagic deposition; 2. Fall-out of fine-grained to sand-sized tephra from a volcanic arc (coarse detritus is absent); 3. Gravity reworking of silt and sand down tectonically active slopes, mainly by mass-flow processes (regular-bedded turbidites are rare). Taking account of the well-documented c. 90° anti-clockwise rotation of the Troodos ophiolite and its sedimentary cover, together with other regional evidence, the related continental margin arc was located generally to the north, near the Kyrenia Range of N Cyprus. Subduction ceased or slowed by late Maastrichtian time when the basin was locally covered by emplacement-related mass-flows (Kathikas Formation) and then, more regionally, by pelagic chalks marking the base of the transgressive Lefkara Formation.

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Key sedimentary facies and facies associations of mixed depositional systems on the Antarctic Peninsula Pacific margin: Implications for bottom-current and gravity-driven flow interactions

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Interactions between deep-water sedimentary processes are responsible for building a large variety of features and deposits across mixed turbidite-contourite depositional systems, from <5 cm thick beds to >200 km long sedimentary drifts. Investigations of the spatial and temporal variability of their sedimentary facies and facies associations are therefore crucial to reveal the dynamics between along-slope bottom currents and gravity-driven flows, as well as their impact on drift construction and channel erosion.

This study focuses on a large modern mixed (turbidite-contourite) system developed across the continental rise of the Antarctic Peninsula Pacific margin. Nine sediment cores were sampled and analysed, through granulometric and geochemical methods, to study the sedimentary facies at a high-resolution scale (ca. 1 to 20 cm). Three main sedimentary facies associations have been identified across distinct morphological features (i.e., mounded drifts and trunk channels), comprising intercalations of hemipelagites, bottom current reworked sands (which include reworked sand-rich turbidites and fine- to coarse-grained contourites) and gravitational facies (such as turbidites and mass-transport deposits). These sedimentary facies associations appear to reflect fluctuations in the background sedimentation and oscillations of both the bottom-current velocity and the frequency of gravity-driven transport processes. The sedimentary record features cyclic alternations during the Late Quaternary (>99 kyr), suggesting that variations between along-slope bottom currents and down-slope gravity-driven flows are strongly linked to glacial–interglacial cycles, such as those of Marine Isotope Stages 1 to 6.

Sedimentary records affected by bottom currents on polar margins are essential to decipher the facies and facies sequences of bottom-current deposits, as the low degree of bioturbation throughout most of the sediments, especially those deposited during glacial periods, allows us to observe the original sedimentary structures, which are usually poorly preserved in highly bioturbated deposits from other continental margins.

Keywords: Mixed systems; Sediment cores; Late Quaternary; Antarctic Peninsula.

Cretaceous South Atlantic contourite and mixed depositional systems

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The South Atlantic Ocean is considered an extensive ocean basin with a complex oceanic circulation, characterized by dynamic interactions, diverse marine ecosystems, miscellaneous topographic plateaus and large continental margins. Bounded by South America to the west and Africa to the east, its evolution was intrinsically linked to the separation of these two continents since the Early Cretaceous. During this event, the formation of early connections between the Southern, South Atlantic and Central Atlantic Oceans (i.e., the Equatorial Atlantic Gateway and the Malvinas/Falkland-Agulhas Seaway) led to the establishment of a new regional and global oceanic circulation. This circulation was vastly different from its modern counterpart as it occurred during a time of warmer global temperatures, high relative sea levels and ice-free poles. Deciphering its evolution has been a subject of debate for many years. Several studies have shown that a wide range of transport and depositional sedimentary processes, from along-slope bottom currents to gravity-driven flows and hemipelagic settling, have affected its evolution. Along-slope bottom currents built large contourite depositional systems across most South Atlantic continental margins and abyssal plains (from Argentina to Namibia and South Africa), whereas their interactions with gravity-driven flows have led to the development of mixed depositional (turbidite-contourite) systems across other continental margins (i.e., off Argentina, Uruguay, Brazil, Walvis Ridge, Namibia and South Africa). In other settings, gravity-driven processes dominated over the margin's depositional and morphosedimentary evolution, creating turbiditic systems (such as those observed offshore Brazil and Angola).

This work attempts to compile and summarize the main contourite and mixed systems that were formed across the South Atlantic Ocean during the Mesozoic era, taking into consideration the various sedimentary transport and depositional processes that have influenced its continental margins, and the global paleogeographic changes that occurred at that time. Several examples of contourite and mixed depositional systems are presented, from Uruguay, Argentina and Brazil in the west to Angola, Walvis Ridge, Namibia and South Africa in the east. Furthermore, knowledge of how these depositional systems were shaped and evolved through time will provide a better understanding of their importance for paleoceanography and paleoclimate, as well as their relevance in hydrocarbon exploration and CO_2 sequestration.

Keywords: South Atlantic; Cretaceous; contourites; mixed systems; bottom currents.

Ancient Jurassic to Eocene mixed depositional systems built offshore Nova Scotia: Implications for paleoceanography and sediment distribution

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Several Jurassic to Eocene mixed turbidite-contourite systems were identified along the upper to middle continental slope of Nova Scotia (Canada), providing a unique opportunity to investigate the impact of along- and down-slope process interaction on sediment deposition, transport and redistribution. The mixed systems were studied using 3D seismic reflection data and well-established chronostratigraphy from five exploration wells.

Seismic interpretations and correlations suggest four main evolutionary stages for the Late Jurassic to Eocene sedimentary record, characterized by distinctive features at a large (>1–10 km) to small (<100 m) spatial scale: 1) various turbidite systems, initially developed between ~160 and 125 Ma with extensive tributary channel networks along the upper continental slope that fed submarine channels and channel-levees further down-slope; 2) mixed systems that developed between ~125 and 78 Ma, characterized by a seaward progradation and NE migration of down-slope elongated mounded drifts and wide, U-shaped channels, formed under potentially synchronous interactions between a SW-flowing bottom current and SE-directed turbidity flows; 3) switch in system migration from NE to SW at ~78-50 Ma, associated with a potential change in bottom current direction or intensity at ~78 Ma; and 4) burial of the mixed systems, which occurred around >50 Ma due to several phases of hemipelagic deposition followed by gully erosion at approximately ~50, 40 and 35 Ma.

The gradual transition from turbidite systems to fully developed mixed systems is associated with the tectonic and sedimentary background of the Nova Scotian margin, as well as the establishment of a Cretaceous to Eocene paleoceanographic circulation during the Mesozoic and Cenozoic. Comparisons with other ancient and modern mixed systems reveal similar morphological features (e.g., mounded drifts and submarine channels) formed under synchronous and asynchronous interactions between along- and down-slope processes. Their lateral distribution and vertical variability therefore reflect a gradual change between the most influential process, from down-slope turbidity currents to along-slope bottom currents. Secondary depositional features along the mounded drifts, such as N-S oriented sediment waves, also suggest along-slope sediment redistribution and remobilization near the seafloor.

Keywords: Mixed systems; Jurassic-Eocene; Nova Scotia; 3D seismic.

Application of mercury intrusion porosimeter analysis on contourite facies: the role of bioturbation

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Over the last years, the effect of bioturbation on rock petrophysical properties modification (e.g., porosity and permeability) and its impact on reservoir quality has been clearly demonstrated. However, the incidence of burrow features on rock properties of contourite deposits, a facies of economic interest, has been underestimated.

In this contribution, a mercury intrusion porosimeter technique was used to evaluate the effects of bioturbation on different types of contourite facies, such as dominant-calcareous and sandy clastic contourites, from the Eocene-Early Miocene of Cyprus and Late Miocene Rifian Corridor of Morocco, respectively. The studied samples were selected according to the ichnological features, as abundance of bioturbation or infilling material (passive vs active) of trace fossils. Thus, for Moroccan sandy clastic contourite facies, samples with *Macaronichnus*, *Parahaentzschelinia* and *Scolicia* from El Adergha and Kirtma sections were selected. In the calcareous contourite facies from Cyprus, samples with *Chondrites* and *Thalassinoides* from Kalavassos (muddy contourite facies), and *Planolites* from Agios Konstantinos and *Thalassinoides* from Petra Tou Romiou (calcarenitic contourite facies) outcrops were studied.

Preliminary results reveal the variable impact of bioturbation on porosity, depending on the type of contourite facies and the involved ichnotaxa. Thus, *Parahaentzschelinia* from sandy clastic contourite facies show the highest impact, increasing porosity values. *Scolicia* also has a positive effect on porosity. *Macaronichnus* presents a variable effect; positive in the case of El Adergha and negative in the case of Kirtma. *Chondrites* and *Thalassinoides* from muddy chalk contourite facies produce a minor effect on porosity, as occurs with *Thalassinoides* and *Planolites* from calcarenitic contourite facies. The obtained results underline the impact of bioturbation on porosity of contourite facies, being a main factor to be considered in reservoir quality characterization.

Complex cut-and-fill structures within the Ewing Terrace reveal a highly dynamic bottom current regime at the Argentine Margin since the Early Miocene

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The Ewing Terrace, located at the Argentine Continental Margin, reveals an extensive Contourite Depositional System (CDS) that is build up under the influence of a highly dynamic oceanographic setting including the Brazil-Malvinas Confluence zone. The terrace is located in water depths of ~ 1000 – 1200 m and deeply incised by the Mar del Plata Canyon. The complex internal architecture of the terrace results from large-scale oceanography and mesoscale ocean circulation and its variations over (geological) time. Consequently, this region offers a unique environment to reconstruct paleoceanography by identifying morphosedimentary features that were eroded, transported and deposited by along- and down-slope processes.
The area was targeted during cruises SO260 (2018), M78/3 (2009) and M49/2 (2001) by acquiring numerous high-resolution multichannel seismic profiles and hydroacoustic data. Detailed analysis of the seismic data reveals a complex sequence of erosive and depositional features accompanied by channels and moats, refining and extending the seismo-stratigraphy by Preu et al (2012) and Grützner et al (2016). The identified depositional and erosional stages suggesting vertical rearrangements as well as waxing and waning of bottom currents in the region, probably accompanied by relocations of the Brazil-Malvinas Confluence zone.
Most striking features within the Ewing Terrace are complex cut-and-fill structures. One of these structures is a buried moat dated to be active in the Early Miocene. Additionally, two surficial depressions were localized north and south of the Mar del Plata Canyon (Warnke et al., 2023). The onset of the northern depression was dated to the middle Miocene and subsequently filled in the Middle and Late Miocene, whereas the southern depression started developing at the Miocene/Pliocene boundary and was mainly filled during the Pliocene. All three fillings reveal several erosional and depositional events during their lifetime. These new findings demonstrates that the local bottom current activity was much more variable in the past as already interpreted from regional unconformities and that the oceanographic setting in the region is even more dynamic as already suggested.

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The role of micro-aggregates in organic carbon preservation in deep-marine sediments

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Mudclasts (shale clasts) are found in sediments from many environments, and typically range from 0.01m to 1m in length. Much smaller microscopic mudclasts, or micro-aggregates, are also present in many sediments, ranging from 20-200 µm in diameter. Here we study fine-grained deepwater facies – turbidites, pelagites, hemipelagites and a hybrid hemipelagite-contourite facies (hemicontourites) – from the Namibian slope, South Atlantic Ocean (ODP 175). The study area is influenced by the Benguela Upwelling System, North Atlantic Deep Water and Antarctic Intermediate Water. The Orange River provides terrigenous input in the south, while the Walvis Ridge acts as a topographic barrier in the north. We have also studied organic-rich biogenic-mud turbidites re-distributed from the Walvis Ridge into the SE Angola Basin (DSDP 75). The nature and distribution of the micro-aggregates in all facies are particularly interesting for understanding sediment transport and deposition, including the transfer of organic matter in deepwater environments.

Common to all facies is the presence of micro-aggregates. We use this as a generic term for silt to sand-sized (i.e. micro-scale, < 1 mm) sedimentary particles that contain various proportions of clay/silt minerals, biogenic material and organic matter. We recognise principal types as follows:

1) Micro-aggregate #1 (micro-mudclasts): well-defined, semi-lithified, angular to subrounded, 30-60 µm, clay-rich, organic-poor clasts eroded and transported either within or from outside the basin (extraformational). They show high Si/Al and low C.
2) Micro-aggregate #2 (fecal pellets): soft ill-defined, non-lithified, well-rounded oval shape, 15-25 µm, clay-rich and commonly organic-rich, both from the water column zooplankton and from meiofaunal burrowers.
3) Micro-aggregate #3 (organo-aggregates): well-defined, rounded to sub-angular, few microns to a few tens of microns, organic-rich, occurring individually and as inclusions in fecal pellets.

In addition, we recognise dispersed organic matter within the sediment matrix of clay minerals, silt and biogenic material with very fine-grained, amorphous organic material. This we interpret as most likely having been transported and deposited, in part, as organo-clay flocs and marine snow that have disaggregated on deposition and burial and by intense bioturbation. The presence of organic matter facilitates formation of micro-aggregates, flocs and marine snow.

The principal transport mechanisms for organic matter include: (a) Slow lateral advection across-slope (off-shelf) by normal hemipelagic processes of settling, drift and suspension cascading (Sites 1084, 1082 and the Walvis Ridge), depositing hemipelagites. The transport distance for organic-rich pellets and flocs is up to at least 100 km. (b) Alongslope transport as suspended load within surface and bottom currents, linked to the Benguela Current system, as a hybrid contourite-hemipelagite process, depositing hemicontourites (Site 1082). The transport distance for organic-rich pellets, flocs and mudclasts may be up to 700 km (estimated). (c) Downslope transport as suspended load in turbidity currents fed from organic-rich sediments on the Walvis Ridge to the Angola Abyssal Plain. This process deposits organic-rich turbidites at Site 530. Transport distance for organic-rich pellets, flocs and mudclasts is up to at least 100 km.

Holocene Contourites in the Arkona and Bornholm Basins, Baltic Sea

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The Baltic Sea is a marginal sea characterized by a significant freshwater surplus and a connection to saline water inflow at the sea bottom from the North Sea over several sills into Arkona, Bornholm and Gotland Basins. Accordingly, deep water formation, ventilation, stratification and estuarine circulation are observed. Brackish surface water is outflowing today through the Kattegat, while at depth various amounts of saline water enter the Baltic Sea, accumulating in depressions.

From modern oceanography, episodic saline inflows are known controlled by North Sea temperatures and prevailing wind pattern, pushing eventually during summer or in autumn high salinity waters through the Kattegat into the brackish Baltic Sea. Here the flow converts into a mid water or bottom water flow, driven by density and topography. Along this path, Arkona Basin and Bornholm Basin have been investigated.
The Arkona Basin is showing mud and silt deposition in its deepest part of >45 m, and subtle patterns of thickness variations are observed around its southern rim. In the Bornholm Basin, more than 100 m deep, even more pronounced current-related depositional patterns are observed. The basin has undergone major geological and hydrodynamic changes during its late Quaternary geological history thus making it a particularly interesting target to reconstruct environmental conditions.

After the Fennoscandian Ice Sheet started to retreat at 15 cal ka BP the oceanographic setting of the region was greatly influenced by opening and closing of the connection between North and Baltic Sea. It caused variations of the bottom water current path and salinity of the Baltic water. During the early Yoldia Sea Stage, starting at 11.56 cal ka BP to 11.1 cal ka BP, the currents passed the Bornholm Basin within a wider range than today. Deposition occurred in spatially continuous areas with local areas controlled by erosion and subsequent infill processes.

The bottom water of higher density and salinity remains within the sub-basins of the Baltic Sea and only gets exchanged during Major Baltic Inflows (MBI), and it is assumed that sediment drifts develop along the bottom water flow paths. The evolution of current related drift bodies in the Bornholm Basin, which were mapped by a dense grid of sediment echosounder data, is presented and put into the framework of late Glacial and Holocene stratigraphy.

Drift bodies of different types are found at the inflow area of the Bornholm Channel crossing the Christiansø Halfgraben from West to East and at the southernmost outflow zone. Those sediment deposits and erosional features are linked to event-based bottom water currents which may be as fast as up to 20 cm s^{-1} during MBIs. From their size, structure and hydrodynamic environment they can be referred to as shallow-water contourites.

Overview of current-controlled depositional patterns at the Southwest African continental margin

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Since the 1990's, marine geophysical surveys including sediment echosounder, multichannel seismic and multibeam swath mapping measurements had been carried out by the University of Bremen at the Southwest African continental margin.

In contrast to the western Atlantic, currents are less important for depositional patterns, but nonetheless major water masses like the northward oriented Benguela Surface Current, Antarctic Intermediate Water, North Atlantic Deep Water or the Antarctic Bottom Water are present in the two main basins, Cape Basin and Angola Basin. The Walvis Ridge acts as the main barrier for deep water circulation between Cape and Angola Basin and thus limits capabilities for sediment transport and erosion in greater water depths.

Among the prominent current-related features we could document intermediate water small scale sediment waves, strong winnowing in intermediate water depths, cold water coral mounds, mid-slope moats, through-flow channels on Walvis Ridge, climate-controlled variations in sediment transport and deposition and many more. Offshore Namibia, a reconstruction for changes in the current regime could be tracked back to Neogene times.

A margin-wide study of current-sediment interaction has not yet been carried out, but in this presentation we intend to compile evidences and examples from the data sets available in Bremen, which may lead to a more focused investigation of current interaction on this margin.

Anatomy of the bi-gradational contourite sequence: implications for the depositional process

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The bi-gradational sequence (C1-C5) is the standard facies model for fine-grained, mixed mud-sand contourites. Drilling in the Gulf of Cadiz during IODP 339 recovered over 4.5 km of contourites with over 1600 distinct contourite sequences, having an average thickness of 3 m (range 0.5-7.5 m). This study documents the past 1.1 My of contourite succession at IODP Site U1389, in which there are a total of 299 full and partial sequences, with a variable thickness of 0.13-10.6 m (mean 2.65 m) and estimated duration of 0.4-32 ky (mean 8 ky) (Stow et al., 2023). It also presents results from our geostatistical analysis of bi-gradational sequences at the two neighbouring sites (U1386 and U1387) on the Faro-Albufeira Drift (Pan et al., in press).

Two complete bi-gradational sequences have been analysed in detail. Primary sedimentary structures are absent, apart from some bedding-parallel sharp contacts and abrupt omission surfaces. Bioturbation is pervasive throughout, and a distinctive pattern of ichnofacies change is observed through each sequence. Textural trends show reverse to normal bi-gradation through the sequence: mean size ranges from 7 µm to 55 µm, sorting from 1.8-2.9 phi, skewness from -0.3 to +0.6, and kurtosis from mesokurtic to very platykurtic. Compositional trends based on mineralogy, inorganic and organic geochemistry vary systematically with mean size. Of the biogenic fraction, the proportion of foraminifera increases with mean size and dominates the coarsest fraction (>150 µm). There is no discernable trend in planktonic/benthic ratio, and the benthic foraminifera are all characteristic of the upper bathyal zone. Between 30-60% of the tests are broken. Both terrestrial and marine sources of organic matter are present, with the former more abundant after 1 Ma and the latter dominant from 2-1 Ma.

Collectively, these facets of the contourite sequence validate the dual controls exerted by long-term variation in bottom-current velocity and episodic changes in sediment supply (both clastic and biogenic). Of these, bottom current velocity is the more important. Estimates of bottom current speeds, based on the standard sortable silt (SS) proxy, for the two sequences range from approximately 12-24 cm s^{-1} (with fluctuations of 1-5 cm s^{-1}). However, we would support the case for a refined method that takes into account the very fine sand fraction moved by bottom currents. Where current speed is relatively high then non-deposition/erosion occurred and an omission surface results. Such omission surfaces probably account for between 20% and 35% of missing section in the two studied sequences. Where current speed was relatively low, thick featureless mud is deposited with a dominant hemipelagic sediment supply and slow alongslope drift. Such hybrid contourite-hemipelagite muds are believed to be widespread in the ocean. We suggest the term *hemicontourites* for these deposits

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Paleoceanography and tectonics of the DITCH: the last 7 million years

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Antipodeans colloquially refer to the Tasman Sea as "The Ditch". The aim of this micro-discussion is to socialise interest in joining a development team for an IODP pre-proposal focused on understanding the paleoceanographic, volcanic, and tectonic evolution across the Tasman Sea from ~ 7 Ma to today. Potential sites include the Great Barrier Reef, West Tasman, Mid Tasman, Lord Howe Rise, Reinga, Northland, and Taranaki basins. There are a wide range of legacy data sets at these sites, including comprehensive industry reflection seismic lines and boreholes, IODP sites, high resolution bathymetry, to areas with relatively scant data. The key geological features that tie these sites together are the occurrence of extensive contourite drift systems and submarine volcanoes. Few of these have been cored, dredged, and dated, but through regional scale seismic interpretations there appear to be several key time periods where major Tasman-wide paleoceanographic and tectonic reorganisation occurred.

Sedimentary process in a submarine canyon from Cape Darnley, East Antarctica under Antarctic Bottom Water inflow

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Antarctic Bottom Water (AABW) stores vast amounts of CO_2, and variations in the formation of AABW can significantly alter global climate. To reconstruct the interaction between AABW and global climate change, extracting information about the past AABW formation from the sedimentary record is crucial. In general, the submarine canyons around Antarctica, formed by highly energetic down-slope processes associated with developing grounded ice sheets, are considered preferential channels for AABW transport. Wild Canyon is one of them, the main pathway of AABW from Cape Darnley, East Antarctica. Therefore, the sedimentological record of Wild Canyon can serve as an archive for AABW transportation. The purpose of this study is to determine the sedimentary processes of the submarine channel-levee systems in Wild Canyon affected by modern AABW inflow in order to restore the past AABW.

For this study, 19 sediment cores were recovered from the continental shelf and deep seafloor around Wild Canyon during KH-20-1 cruise of R/V Hakuho-maru, the 61st Japanese Antarctic Research Expedition by icebreaker SHIRASE, and research cruises by the Japan National Oil Corporation. The grain size parameter, X-ray CT images, and deep-sea camera imagery were used. End-member modelling analysis was used to identify and quantify sedimentary processes in sediment with multimodal grain size distributions.

In Wild Canyon, ripples formed by AABW advection were identified. Furthermore, combining grain size parameters and sedimentary facies, which indicated that AABW advection affected the channel floor transport as a tractional bedload, whereas settling of suspended sediment prevailed on the canyon levee. In contrast, it was suggested that glacial sediment was formed by the transportation of debris flow-like process rather than the low-density flows typical of modern AABW. Given that earthquakes and submarine volcanoes that trigger turbidity currents are rare in the Antarctic region, debris flows likely resulted from slope failures caused by the seaward expansion of grounded ice sheet. These results indicate that the sedimentological characteristics of the deep-sea core from Wild Canyon have a great potential to reconstruct past AABW and expansion/retreat of the East Antarctic Ice Sheet.

Characterization of muddy contourites around the Ryukyu Islands under the Kuroshio Current

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The Kuroshio Current is one of the strongest oceanic currents in the world ocean. Numerous studies have investigated structures of water mass and seafloor sediments under the current (e.g., Nakamura et al., 2008; Itaki, 2015). Recently, a vast area of contourite sand named "Ryukyu Sand Sheet" around the Ryukyu Island Arc in south Japan has been revealed, suggesting that bottom currents influenced by the Kuroshio Current have developed widely in the area and reworked deep-sea sediments as contourites. However, little is known about muddy sediments in terms of the contourite sedimentation in the area. The aim of this study is that characterization of muddy sediments around the Ryukyu Islands with grain size and clay minerals to clarify the relationship between the formative processes on the muddy sediments and the bottom current influenced by the Kuroshio Current.

This study focuses on the area around the Ryukyu Islands including Ishigaki, Iriomote, Yonaguni, Miyako, Amami, Tokunoshima, Okinoerabu, and Okinawa islands. The northwest part of the area is characterized by the Okinawa Trough (1000 km long, 200 km wide, and 2200 m water depth in maximum). In contrast, the southeast part of the area is characterized by a slope, and the Ryukyu Trench with 7500 m water depth in maximum. This study investigated muddy sediments collected from 214 sites in the area by the Geological Survey of Japan, AIST in 2009–2019, and conducted grain size and clay mineral analyses. The grain size analysis was conducted with pretreatment by using H_2O_2 and sodium hydroxide solutions to remove organic matter and $CaCO_3$, respectively. Then, a laser diffraction particle size analyzer (HORIBA LA-960) was used for measurements. The obtained data are re-analyzed according to the sortable silt concept (McCave et al., 2017), providing an index ($\overline{SS}$) for the current speed of the bottom currents. The clay mineral analysis was conducted by using an XRD with oriented thin sections.

As the results of the grain-size analysis, the values of the $\overline{SS}$ correspond to water depths. In addition, the value of the $\overline{SS}$ for the Okinawa Trough area (35 sites) around Miyako, Ishigaki, Iriomote, and Yonaguni islands is 16.06 µm, which is finer than that in the northern part of the Okinawa Trough around Okinawa Island (23.59 µm). The results of the clay-mineral analysis show that the overall area is characterized mainly by muscovite and chlorite. Minor montmorillonite accumulates in the southern part of the area including around Miyako, Ishigaki, Iriomote, and Yonaguni islands, whereas that does not present in the northern part. In addition, kaolinite is found only around Okinawa Island.

The characteristics of the sortable silt suggest that the current speed of bottom currents in the studied area shows a spatial change; relatively faster in the north part and slower in the south part. The spatial change in distributions for the montmorillonite is interpreted to correspond to the current speed of the bottom currents. Consequently, the muddy sediments in the studied area are formed as contourites.

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Contourites and their ichnology in Lower Jurassic deposits from the Mochras drill core, Cardigan Bay Basin, UK

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The continuous uppermost Sinemurian – Toarcian section of the Mochras Borehole in the Cardigan Bay Basin, UK, comprises hemipelagic calcareous mudstones, wackestones/siltstones and subordinate packstones/ sandstones. Several beds show bi-gradational grading, and their sedimentary structures are typical of contourites. Most of them show a transition from massive, organic-rich calcareous mudstones to siltstones or very fine-grained sandstones/calcarenites with shallow-water bioclasts, and back to the massive mudstones. Many layers of siltstones/very fine-grained sandstones/calcarenites show pinstripe lamination and small current ripples, which are usually partly disturbed by bioturbation.

The contourites are heavily bioturbated. The siltstones/very fine-grained sandstones/calcarenites contain the most diverse and best visible trace fossils. Contrary to existing views that *Phycosiphon* is generally uncommon in contourites, the contourite deposits in Mochras are strongly dominated by *Phycosiphon incertum* (in four morphotypes Ph1–Ph4), which was produced by opportunistic colonizers in food (organic matter)-rich and oxygenated sediments. The dwelling and deposit-feeding structures, such as *Thalassinoides*, *Schaubcylindrichnus*, and *Teichichnus* are relatively common. They are accompanied by less common *Zoophycos* (fodinichnia), *Planolites* (pascichnia), *Palaeophycus* (pascichnia), *Trichichnus* (chemichnia), *Lockeia* (cubichnia), and rare dwelling structures, such as cf. *Polykladichnus*, *Siphonichnus, Monocraterion, Arenicolites,* and *Skolithos*. The trace fossil assemblage resembles the Zoophycos ichnofacies, but the eponymous ichnotaxon is uncommon. The intensive bioturbation is conditioned by a relatively stable supply of organic-rich sediment and oxygen.

The contourites were hypothesised to have been deposited by thermohaline-driven geostrophic contour currents flowing between the Boreal ocean and Peri-Tethys through the NE-SW trending, narrow and relatively deep Cardigan Bay Strait. Usually, contourites are important components of orbital cycles distinguished in the section studied on the basis of ichnological and sedimentological features (Pieńkowski et al., 2021, https://doi.org/10.1016/j.gloplacha.2021.103648). This implies that the contour currents were orbitally and climatically forced. The stability of contouritic deposition was disturbed at the Pliensbachian-Toarcian transition and at the beginning of the negative carbon-isotope excursion marking the Toarcian Oceanic Anoxic Event, where the bioturbation was less intensive, *Phycosiphon* is less abundant, and *Trichichnis* is more common. However, the anoxia marked by unbioturbated laminated mudstones is marginally developed, and the peak and recovery phase of the negative excursion of the anoxic event is characterised loss of *Trichichnis* and better oxygenated sea-floor conditions.

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Deep water incursions slow offshore West Antarctic Ice Sheet expansion during its early formation

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The stability of the West Antarctic Ice Sheet is threatened by the incursion of warm Circumpolar Deepwater which flows southwards via cross-shelf troughs towards the coast there melting ice shelves. However, the onset of this oceanic forcing on the development and evolution of the West Antarctic Ice Sheet remains poorly understood. Seismic reflection profiles image sediment bodies in troughs on the shelf of the Amundsen Sea Embayment, which possess the geometry and depositional pattern of plastered sediment drifts. Tentative dating of one drift via a seabed drill core suggests a formation age of this sediment body to be around the Eocene-Oligocene. We suggest this indicates a southward inflow of deep water which probably supplied heat and, thus, prevented West Antarctic Ice Sheet advance. We conclude that the West Antarctic Ice Sheet has likely experienced a strong oceanic influence on its dynamics since its initial formation.

Sediment drifts at the eastern Kerguelen Plateau: Achives of climate and circulation development

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The Kerguelen Plateau, southern Indian Ocean, which rises up 2000 m above the surrounding sea floor, forms an obstacle for the flow of the Antarctic Circumpolar Current (ACC) and Antarctic Bottomwater (AABW). The ACC is strongly deviated in its flow towards the north. A branch of the AABW flows northwards along the eastern flank of the plateau and in its path is steered by several basement highs and William's Ridge. Seismic data collected during RV *Sonne* cruise SO272 image sediment drifts shaped in the Labuan Basin, which document onset and variabilities in pathway and intensity of this AABW branch in relation to the development of the Antarctic ice sheet and tectonic processes, e.g., the opening of the Tasman gateway.

The eastern flank of the Kerguelen further shows strong erosion of the post-mid Eocene sequences. In places, the Paleocene/early Eocene sequences are also affected by thinning and erosion. A moat can be observed along the Kerguelen Plateau flank indicating the flow path of the north setting AAWB branch. Sediment drifts and sediment waves are formed east of the moat. Similar features are observed at the inner, western flank of William's Ridge thus outlining the recirculation of the AABW branch in the Labuan Basin. The chronological and spatial will be reconstructed via the analysis of those sedimentary structures to provide constraints on climate and ocean circulation variability.

Deep-Current Intra-seasonal Variability Interpreted as Topographic Rossby Waves and Deep Eddies in the Xisha Islands of the South China Sea

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Strong sub-inertial variability near a seamount at the Xisha Islands in the South China Sea was revealed by mooring observations from January 2017 to January 2018. The intra-seasonal deep flows presented two significant frequency bands, with periods of 9–20 days and 30–120 days, corresponding to topographic Rossby waves (TRWs) and deep eddies, respectively. The TRW and deep eddy signals explained approximately 60 % of the kinetic energy of the deep sub-inertial currents. The TRWs had 250-300 m vertical trapping lengths, and 40-55 km wavelengths. Deep eddies were independent from the upper layer, with the largest temperature anomaly being >0.4 °C. The generation of the TRWs was induced by mesoscale perturbations in the upper layer. The interaction between the cyclonic-anticyclonic eddy pair and the seamount topography contributed to the generation of deep eddies. Owing to the potential vorticity conservation, the westward-propagating tilted interface across the eddy pair squeezed the deep-water column, thereby giving rise to negative vorticity west of the seamount. The strong front between the eddy pair induced a northward deep flow, thereby generating a strong horizontal velocity shear because of lateral friction and enhanced negative vorticity. Approximately four years of observations further confirmed the high occurrence of TRWs and deep eddies. TRWs and deep eddies might be crucial for deep mixing near rough topographies by transferring mesoscale energy to small scales.

The role of bottom currents in shaping the continental slope off NW Ireland, Rockall Basin, NE Atlantic Ocean

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Bottom currents are capable of affecting seafloor morphology and sediment characteristics of continental margins. Their control of sedimentation and erosion in deep-marine environments results in the formation of contourite depositional systems. The Northeast Atlantic Ocean, particularly the Rockall Basin is characterized by various contouritic features, including sheet drifts, elongate drifts, moats and sediment waves. Hence, it is an excellent region to better understand how different oceanographic processes shape the sea floor and control sedimentation.

In this study, the distribution and quantification of both depositional and erosional features related to bottom currents in the northern Rockall Basin, offshore Ireland are mapped from multibeam bathymetric, seismic and sub-bottom profiler (Parasound) data as well as sediment samples from multicores. Moreover, vessel-mounted Acoustic Doppler Current Profiler data, Conductivity, Temperature and Depth data and results of numerical simulations are used to characterize the types, intensity and direction of bottom currents. The purpose of this research is to establish a link between the spatial distribution of various contourites and different oceanographic process through a multidisciplinary approach. This study can provide a new insight on the controlling factors and formation mechanism of large-scale contourites.

The study area is located in the confluence zone of the northward flowing Northern Atlantic Current, Labrador Current, Mediterranean Overflow and the southward flowing Wyville Thomson Ridge Overflow. The part of the continental slope offshore NW Ireland in which we focus our study is characterized by two contourite terraces and associated drifts at around 600 and 900 m water depth, respectively. The lower slope is dominated by landslide scars, and mass transport deposits are observed in the basin floor. The analysis of 7 multicores and 2 grabs in the study area shows that surface sediments on the open middle and upper slope are relatively coarse (mean grain size 120-165 µm) and contain low total organic carbon content (TOC, 0.3-0.4 %), while fine-grained sediments (mean grain size 16-25 µm) with slightly higher TOC content (0.45-0.57 %) dominate the canyon floor and the deep part of the basin. These results agree with the relatively strong bottom currents of up to 50 cm/s observed along the continental slope in the upper 1000 m. Below 1000 m, bottom currents are general weaker, typically below 15 cm/s.

Bottom current sediment waves control origins of submarine canyons

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Submarine canyons are one of the most common large-scale landscapes on continental margins. Their origins are generally attributed to gravity flows, although with various triggers. Along-slope migrating submarine canyons, with regular spacing, are present at the northern South China Sea, especially during the late Miocene. Their along-slope migration has been explained by interaction between bottom currents and turbidity currents, but their migration direction remains controversial and the origin of the regular spacing remains unclear. Based on high-resolution three-dimensional seismic data, our study, taking both the along-slope migration and regular spacing into consideration, revealed the origins of these canyons. The results showed that these canyons initially built upon the topography of bottom current sediment waves before 10.5 Ma. After then, with the increasing of wave amplitude and thus confinement, turbidity currents were captured and confined within wave troughs, forming well-developed submarine fans at the canyon mouth during ~10.5-5.5 Ma. Under the confinement of sediment waves, submarine canyons were forced to migrate eastward by the migration of sediment waves, with regular spacing. This study presents a new mechanism for the origins of such regularly spaced, along-slope migrating submarine canyons for the first time, highlighting the important role of bottom currents in the formation of submarine canyons.

Self-emerging contourite system in a flume tank demonstrates the conditions necessary to form moat-drift-systems

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Ocean currents control seafloor morphology and the transport of sediments, organic carbon, nutrients, and pollutants in deepwater sedimentary systems. A better connection between deposits formed by bottom currents (contourites) and hydrodynamics is necessary to improve reconstructions of paleocurrents and sediment transport pathways. We present the first three-dimensional flume tank experiments that show under which conditions a contourite depositional system, consisting of an elongated depression (moat) and an associated sediment accumulation (drift), can form. In the tank, current dynamics were measured with an Ultrasonic Doppler velocimeter and the bathymetry was scanned with a laser. The main current direction is along-slope and the speed is higher against the slope and decreases basinwards over the terrace. The moat-drift system forms on the flat surface parallel to a slope if there is a secondary flow near the seafloor that transports sediment from the slope toward the drift. The secondary basinward-directed flow increases with higher speeds and steeper slopes, leading to steeper adjacent drifts. Once the moat-drift system is developed, the vertical velocity is upwards along the drift side of the moat. Thus, the secondary circulation is confined by the drift into a helix structure within the moat. This enclosure of the helix within the moat coincides with an increase of the primary along-slope velocity component. The developed morphology depends on the current speed and the steepness of the slope at which the moat is located. Higher current speeds and steeper slopes increased the drift angle (measured at the terrace-side of the moat). If the current speed and slope angle is below a critical threshold, no secondary flow is measured, and uniform aggradation occurs on the terrace.

The migration of the moat-drift system and the formation of internal stratigraphic architecture is a function of current strength in combination with sediment availability. Low sediment availability leads to migration basinward onto the terrace and truncation of reflectors. High sediment availability leads to migration basinward onto the slope and the formation of sigmoidal deposits on the terrace-side of the moat. The different types of more erosive or more depositional moat-drift systems have also been observed in seismic data of the deep-sea and lakes. This study shows how bottom currents shape the morphology of moat-drift systems and highlights their potential to be used as a paleo-velocity proxy.

“Deepwater” processes and deposits in shelfal and upper slope settings: A reconsideration of paradigms

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Contourites; deposits that appear to have forms that conform to seafloor contours, are most often considered deepwater (>1000 m deep) features, and are described as those liberated, transported, deposited and shaped by geostrophic-driven currents – currents most often found in deep waters. However, “deepwater” processes; gravity-flow, grain-flow, debris-flow and continuous current-flow are often found in shelfal or upper slope water depths (Mallorca, Australia, Maldives). In these settings, such processes create a cornucopia of deposits that deserve examining, since the distal shelf and upper slope remain the source of sediments shed into the deep ocean.

This talk will discuss several examples of shelf-centric processes resulting in shelfal bedforms that look suspiciously like those documented in deep ocean systems. Examples discussed include:

- Continuous global, shelf-hosted currents that generate large sediment waves in carbonate ramps (Fort Payne Formation, Mississippian), and in both muddy and sandy siliciclastic shelves. Sediment waves in the Mississippian-age Fort Payne are composed of crinoidial carbonate clastics that aggrade and mold into sediment waveforms 10-15m high. Carbonate-ramp slumps surround these waveforms, and cyclic steps are thought to ornament their surfaces (Handford, pers. comm., 2023).
- Cross-shelf valleys such as the Berbice Canyon (Cretaceous) of the Guyanan shelf illustrate the linkages between the “deepwater” processes of the margin and the processes active in the shelf and even shoreline. In this subaerial-subaqueous valley, giant clinoforms over 300 m high, confined within a 1200 m deep incision facilitate critical-to-subcritical flow transitions. Llittoral currents erode subaqueous valley margins undermining the valley walls and resulting in deposition of interior-sourced mass failure deposits. These deposits contribute to a complex valley fill that forms a tortuous subaqueous pathway for systems feeding sediments into massive unconfined deepwater fans at the valley mouth.
- The use of physical models to illustrate the impact of combined gravity flow and wave processes on the basinward movement of sediments and the need to consider changing climate and its impact on processes active in the deep shelf. Modelling of basin physiography will also be used to illustrate the impact of continuous currents on bedforms and erosional features building on the upper and middle slope.

Formation and depositional records of Mindoro channel of Southern South China Sea

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Understanding the evolution of oceanic gateways can help to identify oceanographic and geological processes of intersection between two plates. The Luzon strait constitutes the main passage of the Kuroshio current in the western Pacific into the northeastern margin of the South China Sea, which has received high attention from most people, while the existence of an oceanic passage in the southeastern margin is still unclear. This study highlights the contourite depositional characteristics of the Mindoro channel based on the interpretation of seismic profiles. The Mindoro channel is located in the arc collision zone between the South China Sea and the Philippine Sea plates, where forms a series of contourite sediments between the sea mountains along Calamian and Mindoro islands. The seismic profile revealed that four types of contourite sediments along the collision zone, including superposition of multi-channel with clear scour surfaces, nearly parallel mound-like contourite fan, plastering drift on sidehill and sheet drift away from channel. The study revealed that the multi-stage superimposed channels were mainly distributed between Calamian and Mindoro islands, mainly developed in the Late Miocene, and formed a nearly parallel seismic reflection layer on top. To the north to Huangyan Island, mound-like drifts and near-parallel sheet drifts are developed. Depositional records can infer that the Mindoro channel formed near Mindoro Island at the end of the Middle Miocene when the Philippine Sea and the South China Sea plates begin to collision, and continued to result in the close of deepwater passage as the collision continued. Thus, depositional records of ocean gateway can be explained the collision history of plates in the marginal sea along the western Pacific.

Keywords: Oceanic gateway, Contourite, Plate collision, Mindoro channel, South China Sea

Frequent and prolonged Deep-sea Turbidity Currents triggered by typhoon and earthquake in the Gaoping Submarine Canyon

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Submarine turbidity currents are argued to deliver more sediment along their long-runout propagation than other dynamic processes from shelf to deep sea. The in situ temporal and spatial features of turbidity currents are urgently required for a better quantitative constraints on sediment transport and deposition in the deep sea. Here, we document yearlong direct monitoring of turbidity currents in the middle reach at a water depth of 1265 m and the lower reach at 2425 m on the margin of the Gaoping Submarine Canyon off Taiwan, which has the wettest typhoons and active earthquakes. Both the two moorings (~35 km apart) were equipped with sediment traps and various sensors to collect particles consecutively with 18 days interval and to record velocity, sediment concentration, temperature and salinity with 20 min interval. Seven turbidity currents are identified consistently at these two reaches with enhanced sediment flux, which was recorded by a time-series sediment trap at 30 m above the seafloor. By combining the atmospheric measurements and earthquake data, four turbidity currents are triggered by the four powerful typhoons crossed Taiwan during typhoon season in boreal summer 2015, and one event is attributed to the ML 6.5 Kaohsiung earthquake in southern Taiwan in February 2016. The two types of turbidity currents associated with individual typhoon and earthquake show a sustained duration ranging from 9 to 41 days, far more prolonged than the longest documented deep-sea turbidity currents (~10 days) in other locations. The flow velocity observed on the margin (~0.2 m/s) is much weaker than that in the thalweg of the canyon (> 5.8 m/s) inferred from the break of cables. For the first time, our observation provides the variability of the timing and hydrographic properties of the turbidity currents triggered by individual mechanisms for better constraints on flow capacity and sediment redistribution.

Plate convergence controls long-term full-depth circulation of the South China Sea

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How plate tectonics may affect full-depth ocean/sea circulation is not well understood. We used seismic data plus drilling/core and geomorphologic data to examine the influence of regional tectonics on South China Sea circulation. The features of four contourite depositional complexes across the sea, continental shelf to abyssal plain, indicate that plate convergence has controlled circulation within this marginal sea since the beginning of its closure, primarily via Luzon Strait changes. Initially (late Miocene), South China Sea circulation was open, as a part of North Pacific ocean circulation. Later (Pliocene to early Pleistocene) creation of the Luzon Strait reversed the direction of South China Sea surface circulation but not its deeper circulation. Subsequent (middle Pleistocene to present) narrowing and shallowing of the strait weakened surface, intermediate, and bottom flows within the sea but strengthened deepwater flow. This contourite-based approach to elucidating tectonic effects on surface-to-bottom paleo-circulation can be applied to other marine basins within an active tectonic setting.

The propagation of polydispersed particulate gravity currents into a stratified ambient in a channel of general cross-section

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Particle-driven gravity currents are suspensions of dense particles that spread into an ambient fluid due to the difference between the density of the suspension and that of the ambient fluid. There are many examples of particle-driven flows in natural and industrial settings. These include volcanic ash flows, turbidity currents in the ocean and the particle-laden plumes arising from water-injection dredging. From the one hand, in most of the analytical works, it has been assumed that the suspension of particles possess a single settling velocity. However in many situations this is a considerable simplification and in virtually all real situations there is a range of particle sizes, and hence settling velocities. On the other hand, it has been assumed that the ambient has a constant density. However in many situations, especially in the ocean, the ambient is stratified. In the present work we consider the propagation of a high-Reynolds-number gravity current generated by polydispersed suspension spreading along a channel into an linearly-stratified ambient fluid. The bottom and top of the channel are at z = 0;H, and the cross-section is given by the quite general ⍰f1(z) _ y _ f2(z) for 0 _ z _ H. The flow is modelled by the one-layer shallow-water equations. We solve the problem by the finite-difference numerical code to present typical height, velocity and volume fraction of particles (concentration) profiles. The methodology is illustrated for flow in typical geometries: power-law, trapezoidal and circle.

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Deepwater interaction between gravity flow and bottom current in Zhongjian canyon, NW South China Sea: depositional architecture, evolution processes and main controlling factors

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The gravity flow and bottom currents are two basic deepwater flowing mechanisms， and the study on interaction between them is the frontier and weakness of the present sedimentology. The Zhongjian canyon, extending in NW direction and including the north and south two segmentations, has developed in the tectonic depression between Xisha and Guangle carbonate platforms in the northwest of the South China Sea since the Middle Miocene. The integrated analysis of high-resolution 2D/3D seismic data and bathymetric data were used to study the geomorphology and depositional architecture of the Zhongjian canyon, and the main controlling factors of the sedimentation process of the Zhongjian canyon are summarized. The depositional system in the northern segmentation of the Zhongjian canyon consists of gravity flow deposits (channels, sheets and slumps) and bottom current deposits (drifters, moats and troughs), and the northern segmentation is dominated by gravity channels and submarine fans. Depositional system of the northern segmentation is controlled by the interaction between bottom currents and gravity flows, of which the bottom currents came out in Middle Miocene, reworking the gravity channels, leading to migration of the axes or asymmetry wings; gravity flows became weakened while bottom currents strengthened after Pliocene, and sediment waves and drift bodies are widely developed. The channel in the southern segmentation of the canyon shows a depositional cycle of erosion-deposition-abandonment, and no bottom flow deposition was observed. The relative sea level changes, leading to the change of carbonate productivity, affect the provenance supply, so the highstand shedding of carbonate platform promotes the development of channel at high sea level. The flow direction turning of the circulation system and the strong vortex effect of the western boundary current of the South China Sea should be the main reason for the significant interaction between gravity flow and bottom current in the northern segmentation of the Zhongjian canyon.

Keywords: Deepwater, interaction, Gravity flow; Bottom current, Depositional architecture; Zhongjian canyon, South China Sea

Frequent and prolonged deep-sea turbidity Currents triggered by typhoons and earthquakes in the Gaoping Submarine Canyon

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Submarine turbidity currents are argued to deliver more sediment along their long-runout propagation than other dynamic processes from shelf to deep sea. The in situ temporal and spatial features of turbidity currents are urgently required for a better quantitative constraints on sediment transport and deposition in the deep sea. Here, we document yearlong direct monitoring of turbidity currents in the middle reach at a water depth of 1265 m and the lower reach at 2425 m on the margin of the Gaoping Submarine Canyon off Taiwan, which has the wettest typhoons and active earthquakes. Both the two moorings (~35 km apart) were equipped with sediment traps and various sensors to collect particles consecutively with 18 days interval and to record velocity, sediment concentration, temperature and salinity with 20 min interval. Seven turbidity currents are identified consistently at these two reaches with enhanced sediment flux, which was recorded by a time-series sediment trap at 30 m above the seafloor. By combining the atmospheric measurements and earthquake data, four turbidity currents are triggered by the four powerful typhoons crossed Taiwan during typhoon season in boreal summer 2015, and one event is attributed to the ML 6.5 Kaohsiung earthquake in southern Taiwan in February 2016. The two types of turbidity currents associated with individual typhoon and earthquake show a sustained duration ranging from 9 to 41 days, far more prolonged than the longest documented deep-sea turbidity currents (~10 days) in other locations. The flow velocity observed on the margin (~0.2 m/s) is much weaker than that in the thalweg of the canyon (> 5.8 m/s) inferred from the break of cables. For the first time, our observation provides the variability of the timing and hydrographic properties of the turbidity currents triggered by individual mechanisms for better constraints on flow capacity and sediment redistribution.

The frequency and periodicity of preserved turbidites in IODP Site U1431 of the South China Sea Basin

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High resolution record of magnetostratigraphic data from deep sea basin can be used to improve our understanding of graded turbidite systems and provides an important aid in assigning a tectonic and depositional setting to ancient sedimentary sequences. This research focuses on the Pleistocene turbidite sequences in Site U1431 drilled by the International Ocean Discovery Program Expedition 349 and located on central part of the South China Sea. The turbidite sequences consist of thin, fining-upward, silty clay and clayey silt gravity flow deposits. We conducted an integrated magnetostratigraphy, biostratigraphy, and sedimentology study to recognize turbidite cycles and refine the ages of sedimentation events for Site U1431. The results of this work show that the average frequency of turbidite distribution during Pleistocene ranges from 9-24 cycles/ka. We also found that there is an excellent correspondence between the low-field magnetic susceptibility variations of the turbidite cores and the marine oxygen isotope record at glacial-interglacial cycles, indicating that these proxies are sensitive to the paleoclimatic changes since the last ~0.9 Ma. The formation and preservation of the turbidite sequences in Site U1431 appear to be coeval with climatic changes and tectonic activities within and beyond the South China Sea basin since last 2.6 Ma.

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