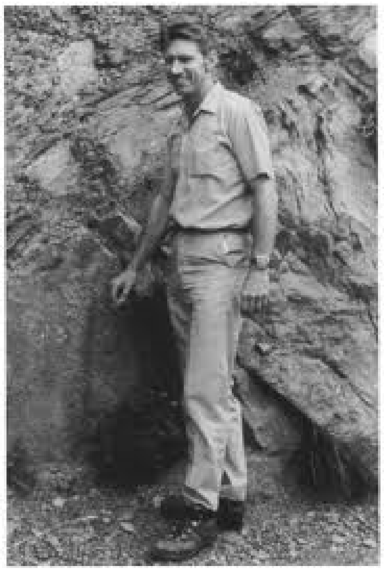 

2022 Virtual Bouma Conference
Abstract Booklet

SEPM
20-22 April 2022
Virtual Sampler
Bouma Conference

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Table of Contents

Day 1 (April 20th)

FLOW PROCESSES
Introduction & Remembering Arnold Bouma
Peter Talling - Flood and tides trigger longest measured sediment flow that accelerates for thousand kilometers into deep-sea (**keynote**)
Meg Baker - Passive seismic sensors record the longest runout sediment flows ever measured on Earth
Sean Rufell - First time-lapse surveys reveal patterns and processes of erosion by exceptionally large turbidity currents that flush submarine canyons
Daniel Bell - Linking knickpoint morphodynamic processes to the stratigraphic products of modern and ancient submarine channels
Lenaig Brun - Reworking and deeper sea transfert of cohesive turbiditic deposits in the Cassidaigne submarine canyon by internal and regional currents
BREAK
Fabiano Gamberi - Plunge pools and beyond: the influence of slope breaks in deep-sea sedimentary processes (Tyrrhenian Sea, Italy)
Rebecca Englert - Critical role of density in the initiation of cyclic steps in sandy submarine channels
Patricia Buffon - Turbidity currents triggered by water jets as a sediment management technique in water reservoirs
Marianne Coholich - Mechanisms of sand deposition within the Lucia Chica submarine channel system, offshore California, USA: Geohazard assessment for potential offshore windfarms and modern petroleum reservoir analog
Tian Yang - Quasi-armored mud clasts as indicators of transport processes of subaqueous sediment gravity-flow
Frederick Nwasike - Influence of submarine channel sinuosity on grain-size sorting of channel and levee deposits
DISCUSSION

FLOOD AND TIDES TRIGGER LONGEST MEASURED SEDIMENT FLOW THAT ACCELERATES FOR THOUSAND KILOMETERS INTO DEEP-SEA

Peter J. Talling[1*], Megan L. Baker[2], Ed L. Pope[2], Ricardo Silva Jacinto[3], Maarten S. Heijnen[4,5], Sophie Hage[5,3], Stephen M. Simmons[7], Martin Hasenhündl[8], Catharina J. Heerema[9], Sean Ruffell[9], Claire McGee[10], Ronan Apprioual[3], Anthony Ferrant[3], Matthieu J. B. Cartigny[2], Daniel R. Parsons[7], Michael A. Clare[4], Raphael Tshimanga[11], Mark A. Trigg[12], Costa A. Cula[13], Rui Faria[13], Arnaud Gaillot[3], Gode Bola[13], Dec Wallance[14], Allan Griffiths[15], Robert Nunny[16], Morelia Urlaub[17], Christine Peirce[9], Richard Burnett[18], Jeffrey Neasham[18], and Robert J Hilton[19]

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ABSTRACT

Keywords: turbidity current, direct measurements, ignition, triggers

The study document for the first time how major rivers connect directly to the deep-sea, by analysing the longest runout sediment flows (of any type) yet measured in action on Earth. These seafloor turbidity currents originated from the Congo River-mouth, with one flow travelling >1,130 km whilst accelerating from 5.2 to 8.0 m/s. In one year, these turbidity currents eroded 1-2 km^3 of sediment from just one submarine canyon, equivalent to ~10-28% of the annual global-flux from rivers. It was known earthquakes trigger canyon-flushing flows. We show major river-floods also generate canyon-flushing flows, primed by rapid sediment-accumulation at the river-mouth, but triggered by spring tides weeks to months after the flood. This is also the first field-confirmation that turbidity currents which erode can self-accelerate (ignite), or reach a state of near-equilibrium (autosuspend) thereby travelling much further. These observations explain how highly-efficient organic carbon transfer can occur, and have important implications for hazards to seabed cables, or how terrestrial climate change impacts the deep-sea. More generally, the study shows how it is possible to directly measure turbidity currents in action, including unusually powerful and less frequent canyon flushing events, which carry globally significant sediment volumes to the deep-sea.

PASSIVE SEISMIC SENSORS RECORD THE LONGEST RUNOUT SEDIMENT FLOWS EVER MEASURED ON EARTH

Megan L. Baker[1*], Peter J. Talling[1], Richard Burnett[2], Morelia Urlaub[3], Jeffrey Neasham[2], Steve M. Simmons[4], Ed L. Pope[1], Ricardo Silva Jacinto[5], Sean C. Ruffell[1], Matthieu J. B. Cartigny[1], Dan R. Parsons[4], Michael A. Clare[6], Christine Peirce[1] & Shipboard Science Party on JC187

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ABSTRACT

Keywords: turbidity currents, seismic signals, direct monitoring

Turbidity currents form some of the largest sediment accumulations on Earth, carry globally significant volumes of organic carbon, and can damage critical seafloor infrastructure. These fast and destructive events are notoriously challenging to measure in action, as they often damage any instruments anchored within the flow, making it difficult to record the frequency and flow behaviour of turbidity currents. Here we show for the first time that turbidity currents emit distinctive seismic signals that can be remotely sensed by instruments located outside the flow path, and thus out of harm's way. Passive Ocean Bottom Seismograph (OBS) sensors, located on terraces of the Congo Canyon, offshore West Africa, recorded thirteen turbidity currents over an 8-month period. The occurrence and timing of these turbidity currents was confirmed by nearby moorings with acoustic Doppler current profilers. Results show that turbidity currents travelling over ~1.5 m/s produce a seismic signal concentrated below 10 Hz with a sudden onset and more gentle decay. Comparison of the seismic signals with information on flow velocities from the acoustic Doppler current profilers demonstrates that the seismic signal is generated at the flow front. This suggests that the flow front may contain a powerful and dense near-bed layer compared to the rest of the flow. The Ocean Bottom Seismographs measured two exceptionally powerful turbidity currents in January and March 2020. These flows broke seabed telecommunication cables and travelled >1,100 km offshore with transit speeds of up to 8 m/s, making these the longest runout sediment flows ever measured in action on Earth. The seismic signals show that these huge turbidity currents comprise a series of distinct pulses, and provides new insights into the internal structure and behaviour of large turbidity current events.

FIRST TIME-LAPSE SURVEYS REVEAL PATTERNS AND PROCESSES OF EROSION BY EXCEPTIONALLY LARGE TURBIDITY CURRENTS THAT FLUSH SUBMARINE CANYONS

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ABSTRACT

Keywords: repeat bathymetry, turbidity currents, erosion

Turbidity currents transport huge quantities of sediment to the deep-ocean via submarine canyons and channels, and are volumetrically one of the most important sediment transport processes on Earth. Multibeam echosounder bathymetric surveys covering ~50% of the Congo Canyon and Channel were collected in both September 2019 and October 2020. Between these surveys, two large canyon flushing turbidity currents flowed down the Congo Canyon and Channel, travelling >1,100km and accelerating from 5 to 8 m/s as they traversed the system, which destroyed two critically-important submarine telecommunication cables that cross the canyon. These are the longest runout sediment-driven flows (of any type) yet measured in action. Comparison of the survey datasets showed discernible geomorphic change relating to the turbidity current activity. The total amount of erosion quantified between the surveyed areas was ~1 km^3 of sediment, representing an estimated 1/7th of the annual flux of sediment from all the world's rivers to the ocean. Erosion is not evenly distributed, and was categorized (with the percentage of the total erosion quantified) as follows: 'canyon or channel flank-collapses' (6%), 'knickpoint migration' (24%), 'outer bend erosion' (6%), and 'channel floor erosion that is unrelated to knickpoints or outer bends' (64%). This work presents the first detailed analysis of patterns of erosion and deposition within a submarine canyon system following a large canyon-flushing event. It shows the amount of sediment eroded enroute far exceeds the annual sediment supply from the Congo River (~0.2 km^3). The results also show how and where this exceptionally large amount of material was eroded. Some reaches show no obvious geomorphic fingerprint from the events, while others have vertical erosion in the 10's of meters. This has important implications for the burial efficiency of organic carbon, pollutants, and a geohazards, including work to mitigate the impacts of turbidity currents to telecommunication cables.

LINKING KNICKPOINT MORPHODYNAMIC PROCESSES TO THE STRATIGRAPHIC PRODUCTS OF MODERN AND ANCIENT SUBMARINE CHANNELS

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ABSTRACT

Keywords: knickpoints, submarine channels, repeat bathymetry, morphodynamics

Near-continuous monitoring of rivers through field-observations and remote sensing reveals the lateral migration of barforms is a primary control on their evolution. This produces high aspect ratio channel belts containing laterally accreting sedimentary bodies and couples sedimentary processes to stratigraphic products. Conversely, submarine channels are notoriously challenging to monitor; hence the link between their sedimentary processes and stratigraphic products are comparatively poorly understood. Their planform similarity to rivers means the point-bar model is often applied to submarine channels. However, submarine channel belts exhibit lower aspect ratios, and stratigraphic architectures are dominated by cut-and-fill patterns rather than laterally accreting bodies.

To investigate this disparity, we analyse the depositional geometries of an active submarine channel using repeat bathymetric surveys (Bute Inlet, Canada); and an outcropping example using field mapping and a digital outcrop model (Tres Pasos Fm., Chile). Over decadal timescales, the evolution of the submarine channel in Bute Inlet is dominated by upstream migrating (100s of m/year) knickpoints, with minor lateral migration. Vertical incision is focused in the thalweg at the knickpoint head, whilst deposition occurs downstream of a knickpoint; consequently, successive knickpoints rework the deposits of previous knickpoints. This process produces a repeated cut-and-fill pattern in strike-view, with dip perspectives characterised by discontinuous lenticular-, flute-, and wedge-shaped deposits. These architectures are comparable to those developed in the Tres Pasos Formation over geological timescales, and we suggest that these geometries and lack of obvious lateral accretion in the Tres Pasos Formation channel-fills can be explained by repeated knickpoint migration. We hypothesise that upstream migrating knickpoints are primary morphodynamic agents in submarine channels, comparable in function to point and braid bars in rivers. Accordingly, the role of knickpoints has been previously unappreciated, and may provide an improved channel-fill model prompting re-appraisal of previously studied deep-water depositional systems.

REWORKING AND DEEPER SEA TRANSFER OF COHESIVE TURBIDITIC DEPOSITS IN THE CASSIDAIGNE SUBMARINE CANYON BY INTERNAL AND REGIONAL CURRENTS

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ABSTRACT

Keywords: source to sink, canyons, turbidity currents, upwelling

Submarine canyons are common morphological features incising continental slopes. They may start from shallow waters (*i.e.* submitted to wave action), littoral settings (*i.e.* submitted to rivers plumes) or even estuaries (*i.e.* exposed to turbidity maximum). They link continental platforms to the deep sea and are the major pathway for turbidity currents and hence sediment transport. These sediment-laden gravity flows are able to sculpt the continental margins, submarine canyons and eventually produce the large sediment accumulations in the deep-sea together with associated elements as organic carbon, oxygen, nutrients and pollutants.

The study of turbidity flows, much based on their deposits and sediment archives, have been neglecting the interaction with the highly dynamic ocean they are flowing through. The physical investigation of the way gravity-driven flows and oceanic circulation interact is an opening research field. Beside regional contour currents, canyons may locally trap energy and momentum: internal tides, quasi-inertial waves, denser water cascading and upwellings are canyon-specific flows that may modulate the sediment transfer to the deep sea.

Here, we are presenting monitoring data from the Cassidaigne submarine canyon (Gulf of Lions, French Mediterranean) in order to identify how ocean flows may remobilise sediment previously brought by gravity-driven turbidity currents. The Cassidaigne canyon is used as a field-scale laboratory. From 1967 to 2015, exogenous residual red mud from the industrial treatment of bauxite ore was rejected in the canyon at 320 m of water depth. The estimated 35 mega-tonnes of red mud outflow generated an extended turbiditic system with characteristic deposits.

These red muds are now used as a proxy of how hydrodynamics in a submarine canyon, induced by regional ocean circulation, may eventually affect turbiditic systems and their deposits. Among others, results show that canyon internal energy is able to regenerate turbidity currents from previous deposits and preserve sediment transfer to the deep-sea.

PLUNGE POOLS AND BEYOND: THE INFLUENCE OF SLOPE BREAKS IN DEEP-SEA SEDIMENTARY PROCESSES (TYRRHENIAN SEA, ITALY)

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ABSTRACT

Keywords: turbidity current, hydraulic jump, mouth bar, submarine canyon, deep-sea fan

In the submarine environment, plunge pool depressions form through perturbations in submarine gravity-flows in correspondence of abrupt gradient reductions. In this paper, through bathymetric data, we examine plunge pools in the Tyrrhenian Sea, a basin with large, topographically complex slopes. Canyon-mouth plunge pools are relatively large and deep, perpendicular to the slope, and often surrounded by levee-like features. Canyon-mouth plunge pools are flanked downslope, either by the flat top of a mouth bar or by a large radial bulge, suggesting deposition from rapid flow deceleration, to form fan bodies. In both cases, turbidity currents, modified in the plunge pool area also through hydraulic jumps, continue downslope forming either a single, low-relief flaring channel or gather zones with converging, tributary channels. Gully-mouth and slope-embayment plunge pools are mainly sub-circular and often enclosed by a sediment rampart. Open-slope-plunge pools form at the base of featureless slopes and are likely due to unconfined currents flowing in seamount flanks. Fault-step plunge pools occur in grabens, where unconfined flows cross escarpments formed by transverse structures. They consist of narrow, continuous depressions parallel to the structure, or of laterally discontinuous, circular features at the mouths of small channels, concurring to the degradation of the seafloor steps. Landslide-plunge pools result from the interaction of turbidity currents and mass-transport processes and are associated to base-of-slope aprons. Our analysis details the wide range of physiographic settings and sediment-gravity flow dynamics that are conducive to plunge pool formation. It shows that, in small basins in active margins, plunge pool formation has pervasive effects, which guide the sedimentary evolution of large parts of the adjacent seafloor areas. Hence, it reveals important details for understanding canyon and channel inception and infill, and deep-sea fan evolution, furnishes analogues for modelling experiments and hydrocarbon reservoir evaluation, and contributes to submarine geo-hazard studies.

CRITICAL ROLE OF DENSITY IN THE INITIATION OF CYCLIC STEPS IN SANDY SUBMARINE CHANNELS

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ABSTRACT

Keywords: submarine channels, cyclic steps, turbidity currents, numerical modeling, density stratification

Decameter-scale upstream-migrating bedforms formed by turbidity currents are common in sandy submarine channels worldwide. Such bedforms play an important role in sediment transport through submarine channels, which are major conduits for delivering material to the deep ocean. Although many are interpreted to be cyclic steps, the flow processes associated with these bedforms and the flow conditions required to initiate and maintain them remain debated. This is due to the inaccessibility of turbidity currents and bedforms on the seafloor, as well as the difficulty in measuring key flow parameters such as density in natural flows. In this study we use a depth-resolved, field-scale numerical model to constrain flow processes over upstream-migrating bedforms and examine the role of density stratification in their formation. Fifteen trials were conducted where turbidity currents with different inlet conditions were simulated over an inclined, erodible bed. In 6 trials, upstream-migrating bedforms developed with 20 – 60 m wavelengths and 0.5 – 2.5 m wave heights. Trains of hydraulic jumps occurred in the troughs of the bedforms resembling the flow configuration of cyclic steps. Comparison of flow properties between bedform-forming flows and flows that did not form or interact with bedforms suggest that density plays a fundamental role in establishing bedforms of this type. Bedforms only developed and migrated when basal sediment concentrations exceeded 5% vol. Rather counterintuitively, we find that dense flows are needed to reach the Froude subcritical flow conditions required in cyclic step flow instabilities, despite being relatively fast. Our numerical modeling results support that sandy, decameter-scale upstream-migrating bedforms in submarine channels are initiated by cyclic step instabilities in the denser basal layers of turbidity currents, consistent with previous conceptual models and field observations.

TURBIDITY CURRENTS TRIGGERED BY WATER JETS AS A SEDIMENT MANAGEMENT TECHNIQUE IN WATER RESERVOIRS

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ABSTRACT

Keywords: impinging plane free turbulent jet, physical modeling, water injection, reservoir sedimentation

In the discipline of sedimentology, turbidity currents are the main mechanism transporting sediment from the continental platform to the deep sea, and their study has historically been of interest to the fossil fuel industry. While these flows are triggered in nature by various phenomena, they can also be intentionally triggered and used as a tool for sedimentation management in diverse environments such as water reservoirs. These are key infrastructure for securing water supply for human consumption, food and energy production, among others. However, in many places, their sustainability is strongly dependent on the efficient application of sediment management techniques. The goal of this research is to quantify and describe key hydrodynamic processes driving sediment fluxes induced by an impinging jet. To achieve this goal a tailor-made 2D physical model has been developed at the Hydraulic Engineering Laboratory at the Delft University of Technology to approach the problem from a fluid mechanics perspective. In this presentation, initial and boundary conditions, techniques for measuring velocity and concentration profiles, and results from preliminary experiments will be discussed, as well as current and future research. It is expected that the quantification and description of the processes involved in the use of this technique will outline optimum scenarios for generating turbidity currents in water reservoirs and improve the predictability of real applications, contributing to a more sustainable engineering practice.

Acknowledgments: CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, Brazil).

MECHANISMS OF SAND DEPOSITION WITHIN THE LUCIA CHICA SUBMARINE CHANNEL SYSTEM, OFFSHORE CALIFORNIA, U.S.A.: GEOHAZARD ASSESSMENT FOR POTENTIAL OFFSHORE WINDFARMS AND MODERN PETROLEUM RESERVOIR ANALOG

Marianne Coholich[1*], Charles Paull[2], Maureen Walton[3], David Caress[2], Mary McGann[4], Eve Lundsten[2], Roberto Gwiazda[2], Tim McHargue[2], Matthew Malkowski[5], and Stephan Graham[1]

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ABSTRACT

Keywords: Submarine channels, loosely confined channels, turbidites levee deposits

Newly acquired piston cores and high-resolution autonomous underwater vehicle (AUV) seafloor images of the Lucia Chica deep-water channel system offshore central California reveal the extent of turbidite deposits that occur within its channels and levees. This study aims to determine the frequency of sediment flows in the channel system and to assess the geohazard risks that these flows might pose to the potential development of offshore windfarms in this area. The high-resolution data also provide a modern analogue of petroleum reservoir characteristics in low-relief submarine channels.

Ten jumbo piston cores up to 7.5-m long and eight vibracores up to 1.5-m long were acquired in 2019 by the U.S. Geological Survey and the Monterey Bay Aquarium Research Institute (MBARI) from the Lucia Chica channel system in transects within the axis of the channel and in adjacent pockmark depressions. The most recent flow event, recovered in a jumbo piston core (30JPC) taken on a bench within the main channel at 996 m water depth, left a 15-cm thick fine sand bed buried ~188 cm below the sea floor. A ^{14}C measurement of the underlying sediment reveals this event deposit is <~6,100 years old, suggesting Holocene flow activity. Sandy turbidites and even boulders extend more than 1 km away from the channel's thalweg. Additional ^{14}C measurements will be used to determine the timing and frequency of the flows outside the channel.

MBARI AUV bathymetry surveys provide 1-meter lateral resolution and as little as 10 cm vertical resolution, while AUV Chirp surveys have a constant line spacing of ~40 m. Together, these data will be used to analyze how turbidite deposits identified and dated in the cores correlate throughout the channel system, thus showing the spatial extent of flow events and avenues of sand movement throughout the Lucia Chica system.

QUASI-ARMORED MUD CLASTS AS INDICATORS OF TRANSPORT PROCESSES OF SUBAQUEOUS SEDIMENT GRAVITY-FLOW

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ABSTRACT

Keywords: quasi-armored mud clasts, hybrid event bed, glow transformation, subaqueous sediment gravity-flow

To build the relationship between transport processes of subaqueous sediment gravity-flows and the character of their deposits is the expectation of various research works. A special type of quasi-armored mud clasts, which are coated with occasional sand, granules, or pebbles, but with various irregular shapes are present in core of subaqueous sediment gravity-flow (SSGF) deposits worldwide. One type of quasi-armored mud clasts is characterized by grains around the clasts, while another is characterized by grains within them. Quasi-armored mud clasts are caused by the erosion by high-density turbidity currents and distributed in H1a, H1b, H2, and H3 division of the hybrid event beds. The formation and distribution of quasi-armored mud clasts demonstrates the process of downflow transformation from high-density turbidity current to low strength debris flow through the erosion of muddy substrate. At the same time, the presence of quasi-armored mud clasts in massive sandstone also clearly demonstrates a high-density turbidite origin. Recognition of quasi-armored mud clasts and their distribution in deep-water deposits can have important implications for reconstruction of SSGF transport processes.

INFLUENCE OF SUBMARINE CHANNEL SINUOSITY ON GRAIN-SIZE SORTING OF CHANNEL AND LEVEE DEPOSITS

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ABSTRACT

Keywords: submarine channel, sinuosity, experiment, turbidity current

Spatial trends in grain-size distribution within submarine fan deposits are controlled by turbidity current properties. Previous studies focused on the relationship between fan deposits and sediment grain-size and suspension cloud concentration of parent flows. However, the effects of channel elements, such as channel sinuosity, on turbidity current flow properties and on characteristics of fan deposits remains understudied. This work uses experimental approach to understand the influence of varying submarine channel sinuosity on grain-size distribution of levees and submarine channel fills. Here we present results from flume experiments conducted at Queen's University Coastal Laboratory. Four submarine channels with varying sinuosity were built in a 4 m x 4 m x 1 m deep basin. Flow discharge, sediment concentration and basin gradient were held constant. Turbidity currents consisted of plastic melamine as sand proxy and ground walnut-shell as clay proxy. Samples were collected from channel fill and levee deposits for grain-size analysis.

Preliminary results show that remixing of suspended sediments as currents move through channel bends favor transportation of fine sediments down the channel. Coarse sediments are relatively less affected by remixing at channel bends, hence deposited. As sinuosity increases, this trend becomes more pronounced. At high channel sinuosity, grain-size analysis shows fine-grained sediment almost entirely dominate deposits at the distal part of the channel as coarse grains are trapped at channel bends, the ratio of fine to coarse sediment at distal channel areas also increases. Laterally across channel bends, inner levees are relatively sediment starved, coarse sediment dominates channel fill and the proportion of coarse-grained sediment within the channel increase from inner to outer banks. Turbidity currents overtop channel banks and deposits sediment as overbank primarily in outer levees, which fine distally and become more pronounced with increasing sinuosity. These show that increasing sinuosity favors fine-grained sediment bypass at channel bends.

Day 2 (April 21st)

FAN BUILDING PROCESES

Introduction & Remembering	Arnold Bouma & Chris Edwards
Gwladys Gaillot - Gradient control on submarine fan growth, combining results from best sampled modern systems, experiments and numberical models (**keynote**)	
Michael Sweet - How fast do submarine fans grow? Insights from the Quaternary Golo Fans, offshore Corsica	
Anthony Shorrock - Stratigraphic evolution of a northern Hikurangi Margin trench-fill sequence during the late Quaternary	
Donald Christie - Forward modelling for stratigraphic and structural analysis, offshore Sureste Basin, Mexico	
Elena Scacchia - Short-distance facies changes related to a lateral bounding slope (Marnoso-arenacea Formation, Italy)	
BREAK	
Arijit Chattopadhyay - Morphodynamics of deepwater Moki Fan systems from mid Miocene section of offshore Taranaki Basin, New Zealand	
Vanni Pizzatti - The influence of confining morphology on lateral and vertical turbidite facies distribution (Firenzuola turbidite system, Marnoso-arenacea Formation, Italy)	
Ashley Ayckbourne - Controls of foreland tectonics on epicontinental slope formation	
Jungang Pang - Depositional model of channel and lobe turbidite deposits in lacustrine deep-water fans, Ordos Basin, China	
Leonela Aguada - Quantification of the lateral lithofacies and chemofacies heterogeneity of distal submarine-lobe deposits, Wolfcamp Formation, Delaware Basin, Texas	
Filip Anđelković - Lacustrine deep-water turbidites of the southern part of Lake Pannon	
Kun Chen - High-inclination coring of Chang-6_3 of the Yanchang Formation in Huaqing Oilfield, Ordos Basin: Implications for paleocurrent direction and fracture orientation	

GRADIENT CONTROL ON SUBMARINE FAN GROWTH, COMBINING RESULTS FROM BEST SAMPLED MODERN SYSTEMS, EXPERIMENTS AND NUMERICAL MODELS

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ABSTRACT

Keywords: submarine fan, depositional model, modern system, gradient control

Submarine fan depositional models are commonly split in endmembers of dominant grain-sizes, tectonic settings, or sea-level stands, stressing the influence of global factors (through sediment type and supply) on their final sizes, general morphology and facies distribution. The nature of submarine fan growth, however, is not well understood, its evolutionary part often missing, as it involves investigations at much lower scales of the deposits resulting from the interactions between gravity currents and evolving basin topography.

This study relies on high resolution seismic and core penetrations to depict the internal architecture and facies distribution within lobate bodies of three Quaternary Fans deposited on various gradients. The observed stacking patterns and hierarchy, compared to outcrop studies, laboratory experiments and flow simulation results, indicate the influence of supercritical vs subcritical hydraulic regimes largely controlled by depositional gradients.

The Golo submarine fan on the eastern margin of Corsica, Mediterranean Sea is a Plio-Quaternary example of a small, sandy, steep deep-water fan deposited on average gradients between 3° for the proximal part and less than 1° for the distal part. Erosive, stacked sandy-leveed channels, are found in the proximal part of lobe elements. They transition rapidly to subtle aggrading channel geometries to end in relatively short unconfined sandy mouth bar deposits. Lobe elements stack in a clear retreating pattern forming 8km long, 2-3km wide lobes with 25m maximum thickness.

On the opposite end of the spectrum the Zaire Fan is a large mud-rich submarine fan deposited on average slopes between 0.5° for the proximal part and less than 0.1° for the distal part. Lobes are large bodies (20km long, 10km wide for 25m thick) but only sandy in the proximal part where distributary channels are stacked. The remaining of the accumulation appears to be composed of muddier facies attributable to slurries deposited in an array of thin and elongated channels.

Between these two endmembers lies Basin IV of the Brazos-Trinity series of mini-basins, Gulf of Mexico, which possesses both high and low gradient slopes from the steep basin inlet to the flat and reverse slopes at the end of the bowl-shaped basin. The 3D imaging reveals the transition from poorly developed channel-mouth bar pairs on the initially steeper basin slopes to increasingly elongated and sinuous channels splitting into ever smaller sandy distributary channels on the lower slopes built during fan deposition. These “feathery looking” lobes are similar in shape to other lobes from low gradient fans (i.e. Mississippi terminal fan) and are thought to be the locus of transition from sandy channels to slurry deposits as turbulent flows transition to laminar.

Depositional gradient help explaining the different kind of lobe elements resulting from either retreating sandy mouth bars or dispersive slurry strings. As lobes arrange into larger lobe complexes and channels elongate, distinctive fan growth models can be proposed with a tendency to evolve from high gradient sandy lobe dominated systems to low gradient channel-levee-slurry lobes systems.

HOW FAST DO SUBMARINE FANS GROW? INSIGHTS FROM THE QUATERNARY GOLO FANS, OFFSHORE CORSICA

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ABSTRACT

Keywords: geochronology, fans, Quaternary

Deposition rates in terrestrial and shallow-marine environments are well-constrained in Quaternary systems with the timescales for the formation of fluvial channel belts or delta lobes known to range from 10^3 to 10^4 yrs. By contrast, timescales required to form environments within submarine fans are for the most part poorly constrained. Our work on the Golo Fans, Corsica adds important new data and insights into the rates and timing of deep-water deposition. High-resolution seismic, sedimentological, and geochronological data were used to determine rates and volumes of deposition for submarine fan elements of Quaternary Golo submarine fan system. Data from the Golo submarine fans indicate rates of deposition from 0.1 to 10 m/ka depending on the time scale and the location of the observation. Over 100 kyr glacial-interglacial timescales, vertical and volumetric deposition rates are buffered by changes in global sea level that result in fluvial systems extending across the shelf to connect with submarine canyons and deliver sand to the deep-water basin, or restrict deep-water sediment delivery because the river mouth is located on the inner shelf and far from the canyon head. Over millennial timescales, autogenic river avulsions on the shelf can favor sand transfer through one submarine canyon to its associated lobe complex while, at the same time, mud-rich deposits drape the rest of the fan system. On active fans, autogenic avulsion of submarine channels results in lateral shifting of the locus of deposition and construction of a succession of compensationally stacked lobes and lobe elements. Short-term deposition rates on the fan range from 8.6 m/kyr at proximal portions of submarine fans to 0.4 m/kyr along the distal fringe. Individual submarine fan lobes 5-10 m thick were deposited in as little as 1-13 kyrs.

STRATIGRAPHIC EVOLUTION OF A NORTHERN HIKURANGI MARGIN TRENCH-FILL SEQUENCE DURING THE LATE QUATERNARY

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ABSTRACT

Keywords: Hikurangi Margin, gravity flows, IODP, seismic stratigraphy

An integrated investigation on the stratigraphic characteristics of a northern Hikurangi Subduction Margin (HSM) trench-fill sequence has been undertaken to assess how this deep marine depocenter has evolved in the late Quaternary. This study has incorporated bathymetric, seismic, and lithologic datasets acquired from the region to define the spatiotemporal distribution of key stratigraphic and geomorphic features that can be related to the nature and timing of depositional processes These analyses integrate with core data acquired from International Ocean Discovery Program (IODP) Site U1520 during Expedition 372B/375 to provide a chronology and a three-dimensional regional context for the sedimentary facies present in the core.

The results of this study show that the northern Hikurangi Trough has undergone significant changes in the past three Marine Isotope Stages (MIS). Gravity flows are interpreted as the primary conduits of sediment delivery to the trough floor and were dominantly sourced from both the Māhia Canyon system and from overspill of flows from the Hikurangi Channel. Such flow processes may have infilled a depression that was blocked by a Mass Transport Deposit (MTD) in MIS3 (57-27 ka). In MIS2 (27-14 ka), there was a substantial increase in sediment supply during the glacial lowstand that facilitated the development of large-scale sediment waves downslope of the mouth of the Māhia Canyon and a weakly-confined channel-belt system above Site U1520. This channel system was subsequently infilled in MIS1 (14 ka – present) as sediment supply decreased, forming the gently-sloping, modern plain.

These findings provide new insights into what sedimentary processes have been active along the northern HSM during the late Quaternary and how they have varied over time in response to changing environmental conditions.

FORWARD MODELLING FOR STRATIGRAPHIC AND STRUCTURAL ANALYSIS, OFFSHORE SURESTE BASIN, MEXICO

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ABSTRACT

Keywords: forward stratigraphic modelling, tectonostratigraphic evolution, deep-water minibasins, sediment gravity deposits, minibasin stratal architecture

Structurally active minibasins, in which the sediment fill is built mostly by sediment gravity flows, plus pelagic and hemipelagic deposition, characterize continental margins such as deep-water Angola, Brazil, North Borneo, and the Gulf of Mexico. The stratal architecture of these minibasins is controlled by the interplay of structure growth and sediment supply. We use a reduced-complexity, fast computational method (Onlapse-2D) to simulate and reproduce the observed stratal geometry, using a process of iteration to match the model output to available subsurface control (well logs, 3D seismic data). This illuminates the tectonostratigraphic evolution of two intersecting sections in a complex minibasin in the offshore Sureste Basin, Mexico. A good first-pass match between model output and geological observations was obtained, allowing us to identify and separate the effects of two distinct phases of compressional folding and a longer-lasting episode of salt withdrawal/diapirism, and to determine the timing of these events. This modelling provides an indication of the relative contribution of background sedimentation (pelagic and hemipelagic) vs. sediment-gravity-flow deposition (e.g. turbidites) within each layer of the model. Integrating this with well data interpretations allows Onlapse-2D to be used to make predictive statements about the deep-water stratigraphy away from direct well control. The inferred timing of the compressional events derived from the model is consistent with other geological observations within the basin. The process of iteration towards a best-fit model leaves significant but local residual mismatches at several levels in the stratigraphy; these correspond to surfaces with anomalous negative (erosional) or positive (constructive depositional) palaeotopography. At these levels, the magnitude of mismatch allows us to estimate the geometry and magnitude of the local erosional or constructional seafloor topography produced by unmodelled processes. Reduced-complexity simulation is a useful and effective approach to understand the tectonostratigraphic evolution of complex deep-water minibasins.

SHORT-DISTANCE FACIES CHANGES RELATED TO A LATERAL BOUNDING SLOPE (MARNOSO-ARENACEA FORMATION, ITALY)

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ABSTRACT

Keywords: facies analysis, foredeep turbidites, lateral confinement, hydraulic jump

Seafloor topography has a strong influence on turbidity current behaviour and related deposits. In particular, large scale tectonic structures are pervasive elements and the relationships between their orientation and the path of turbidity currents affects flow's evolution. Specifically, this study focuses on the effects of a lateral slope, parallel to the paleocurrent direction, on the facies distribution at different scales (from lobe element to single bed). Field data derive from a high-resolution physical stratigraphy, with bed-by-bed correlations, of two depositional lobes, and related interlobes, of the Paretaio Turbidite System (PTS) in the Marnoso-arenacea Formation (northern Apennines, Italy). The PTS is laterally confined by an important regional structure, namely the NW-SE-oriented M. Castellaccio thrust-related fold (CTRF). Tripartite slurry beds tend to occur at the base of each lobe and can be related to mud-rich flows strongly decelerated by lateral confinement. Above the slurry beds, massive to crudely laminated coarse-grained beds, rich in water escape structures and lacking any upper-fine grained divisions, prevail. These beds are interpreted as produced by bipartite turbidity currents featuring drastic deceleration (with the possibility of forming a hydraulic jump) of the basal dense flow and the bypass of the overlying turbulent flow. The occurrence of hydraulic jumps is recorded by massive to crudely laminated beds characterized by mud-draped scours and backset-type laminae. Subtle small-scale morphologies, related to the CTRF, can also influence the flow behavior producing a lateral facies change characterized by an increase in amalgamations above the topographic highs and well-developed traction structures indicative of deceleration in the depocentres. Our work shows that, according to the degree of stratification of the flow, turbidity currents respond in a different way to lateral confinements and that important facies changes can occur over short-distances due to small-scale morphologies.

MORPHODYNAMICS OF DEEPWATER MOKI FAN SYSTEMS FROM MID MIOCENE SECTION OF OFFSHORE TARANAKI BASIN, NEW ZEALAND

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ABSTRACT

Keywords: morphology, avulsion, stacking, lobe

Confinement, basin slope, local topography, and sediment supply are major factors controlling the dimensions of individual turbidites and submarine lobe geometry. The same factors that control individual turbidites and lobes also influence the larger-scale submarine fan morphology, however these dimensions can vary even within a single submarine fan. This study investigates whether basin topography and sedimentary dispersal patterns have any bearing on the spatial distribution of individual lobes within deepwater fan systems, or whether individual lobes' migration is independent of external forcing on the system. Here, we will present results from an analysis of 3D seismic data addressing the linkages between individual lobe morphology and large-scale fan morphology.

The Taranaki Basin of New Zealand provides one of the best subsurface examples of a deepwater fan system. Within this basin, the Miocene stratigraphic section exhibits sinuous, leveed deepwater channel systems entrenched in the Mid-Miocene Moki fan system. Mapping of 3D seismic data reveals patterns of supra-fan distributary channel systems, avulsion of channels and compensational stacking of lobe systems. The deepwater Moki fan system exhibits an overall basin-ward progradation pattern as successive lobes are stacked vertically and subsequently entrenched by younger feeder channel systems. Gamma-ray log patterns from drilled wells also reveal a stacked coarsening- and thickening-up pattern of the Moki fan system.

The degree of progradation to aggradation of deepwater lobes in a submarine fan system is another parameter of interest. The detailed 3D mapping of subsurface seismic and well data from Moki Fan systems will provide a window into the sedimentological processes involved in generation of stacked deepwater fan-lobe systems. The documentation of spatial evolution and stacking of lobes to build the bigger fan system will in turn provide a scaled measure of lateral vs. longitudinal spreading of turbidity currents.

THE INFLUENCE OF CONFINING MORPHOLOGY ON LATERAL AND VERTICAL TURBIDITE FACIES DISTRIBUTION (FIRENZUOLA TURBIDITE SYSTEM, MARNOSO-ARENACEA FORMATION, ITALY)

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ABSTRACT

Keywords: foredeep turbidite, Marnoso-arenacea Formation, facies analysis, basin confinement

The Marnoso-arenacea Formation (MAF), as the other Northern Apennine foredeep turbidite deposits, records a progressive closure of the basin due to the north-east propagation of thrust fronts. This work focuses on the MAF Serravallian deposits (known in literature as the Firenzuola system or Unit V), which record the closure of the inner basin and consequent depocentre shift toward the outer basin due to the coeval growth of two tectonic structures parallel and perpendicular to the paleocurrents (i.e., M. Castellaccio thrust and Verghereto high).

The main goal is a high-resolution stratigraphy with bed-by-bed correlation and detailed facies analysis of these deposits in their more proximal part, whose deposition is strongly controlled by another important transversal structure associated with the complex emplacement of the Casaglia mass transport complex (MTC), which, in this area, can reach a thickness of about 500m.

As also shown by previous works, Unit V can be subdivided into two subunits, Va and Vb, separated by the Bedetta MTC. Said MTC records a further phase of basin narrowing and an increase in basin confinement, which favour flow decelerations and hydraulic jumps. This is testified, in Unit Vb, by the drastic increase in the sandstone-mudstone ratio, mud-draped scours and massive to crudely laminated coarse-grained sandstones characterized by widespread occurrence of mudstone clasts, flame structures and tractive bypass facies. Essentially, while Unit Va is dominated by contained-reflected beds, which tend to compensate the frontal barrier represented by the Casaglia MTC, Unit Vb is dominated by facies recording the deceleration of basal high-density supercritical flows and the bypass of low-density turbulent flows. These processes influence the lateral and vertical facies variations of the deposition al lobes.

This work has allowed a paleogeographic reconstruction of this portion of the basin, which can be particularly suitable for stratigraphic modeling and analogs for laboratory experiments.

CONTROLS OF FORELAND TECTONICS ON EPICONTINENTAL SLOPE FORMATION

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ABSTRACT

Keywords: slope, tectonics, MTD, turbidites

The processes by which shelves and ramps on continental crust are converted into deep water basins are relatively understudied. This study describes the evolution from a subaqueous mixed carbonate-siliciclastic ramp to a prograding shelf-slope prism by foreland tectonics using meticulously collected outcrop data from the earliest slope turbidite succession of the Aínsa basin (Spanish, Pyrenees).

The initiation and evolution of the slope can be summarised into two phases. In the first phase, the initial propagation of a basin bounding thrust fault (Foradada Thrust) began to segment the ramp by uplifting the hangingwall, and oversteepening the ramp on the footwall, initiating a slope. On the hangingwall, shelf conditions prevailed, with deposition of relatively shallow water calcareous sediments. The new slope was dominated by deposition of mudstones, turbidites and mass transport deposits (MTDs). At the locus of uplift, mass-wasting processes resulted in backstepping of the shelf-slope rollover, synchronously with aggradation of shelf and slope deposits.

In the second phase, in-sequence thrusting resulted in propagation of new fault (Atiart Thrust) further down the slope. This new locus of uplift terminated backstepping of the shelf-slope rollover, and drove basinward propagation of the shelf-slope prism and eventual deposition of up to 900 m of slope deposits. These two phases represent tectonically driven transgression followed by regression.

The transgressive mud-dominated slope deposits are dominated by thick (up to 50 m) MTDs and mass transport complexes (MTCs) on which depositional topography funnelled and captured coarser-grained turbidites derived from slope and lip-failure. The regressive phase is characterised by less catastrophic MTDs, instead composed of evacuation scars filled by up-to-20 m thick mudstone debrites and turbidite deposits predominantly composed of surging and waning flows derived from the prograding shelf and delta ("hyperpycnites").

This work presents a unique view of the temporal and spactial distribution slope processes and facies in tectonically active foreland basins.

DEPOSITIONAL MODEL OF CHANNEL AND LOBE TURBIDITE DEPOSITS IN LACUSTRINE DEEP-WATER FANS, ORDOS BASIN, CHINA

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ABSTRACT

Keywords: channel and lobe turbidite, deep-water fans, Ordos Basin, China

Turbidity current flows are a key process for the delivery of sediment to deep marine and lacustrine environments. Turbidite sandstones form favorable petroleum reservoirs worldwide, commonly in marine successions, but in some cases also in lacustrine successions. Compared to marine environments, the process regime of lacustrine systems differs significantly. The rate, frequency and magnitude of oscillations in lake level may be higher, and water salinity can be considerably lower than in marine settings. As such, the characteristics of lacustrine turbidites may differ from those of their marine counterparts. The recognition of turbidites in different subenvironments of the lacustrine deep-water fan of the Yanchang Formation of the Ordos Basin (China) can guide the establishment of effective criteria with which to aid palaeogeographic restorations and can guide subsurface resource exploration and exploitation.

The Ordos Basin was occupied by a major lake during the late Triassic. The baisn developed in response to the rapid uplift of the Qinling Mountain, driving rapid subsidence in the southern Ordos Basin. The Yanchang Formation, which is composed mainly of fluvial-deltaic-lacustrine strata, is subdivided into 10 Members. Deep-lake turbidites are primarily found in members Ch-7, Ch-6 and Ch-1.

Based on a database of well cores, outcrop observations and well logs, this work examines the sedimentology of the turbidite fan succession of the Yanchang Fm:

(1)A classification scheme of lithofacies and lithofacies associations for lacustrine turbidite fan strata of the Yanchang Formation has been proposed.

(2)Different deep-lake channel and lobe subenvironments have been identified; these are juxtapoised vertically and laterally.

(3)A depositional model of the architecture and evolution of lacustrine turbidite fans of the late Triassic Ordos Basin has been proposed.

QUANTIFICATION OF THE LATERAL LITHOFACIES AND CHEMOFACIES HETEROGENEITY OF DISTAL SUBMARINE-LOBE DEPOSITS, WOLFCAMP FORMATION, DELAWARE BASIN, TEXAS

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ABSTRACT

Keywords: turbidite, chemofacies, lateral heterogeneity, submarine fan

Submarine-lobe deposits host important archives of paleo-environmental change and are major targets for the exploration and production of hydrocarbons. Conceptual models of submarine lobe deposit architecture typically exhibit a systematic decrease in bed thickness, grain size, sand content, and amalgamation in proximal-to-distal and axis-to-fringe transects. The details of downstream and lateral facies changes are often overlooked or grossly simplified, even though many early studies recognized complexity in distal lobe environments. This study is specifically focused on linking vertical and horizontal core datasets from the Wolfcamp A interval of the Delaware Basin, Texas to document complex lateral facies heterogeneity. Two core datasets from vertical and slant wells that are approximately 200 m apart form the basis for event-bed correlations. We combine these datasets to provide a correlation framework between the wells that is based on lithostratigraphic, chemostratigraphic, and depositional-process interpretations of the core data. These robust correlations are then mapped, where possible, into nearby wells to characterize the lateral heterogeneity of individual event-beds and event-bed packages (i.e., lobe elements). Preliminary analysis of the vertical well reveals highly heterogeneous facies that is discernable not only in the photographs but also in XRF, XRD, and CT-scan data. Several event-bed packages are recognized in the slant core spectral gamma ray, and ongoing work is focused on depositional-process and chemostratigraphic correlation of the two cores. This data provides a valuable predictive framework for improved geosteering operations and reservoir-model parameterization. This study will also generate important subsurface data for interpreting depositional processes and the resultant architecture in distal lobe deposits, particularly those in mixed-lithology systems.

LACUSTRINE DEEP-WATER TURBIDITES OF THE SOUTHERN PART OF LAKE PANNON

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ABSTRACT

Keywords: lacustrine turbidites, Lake Pannon, upper Miocene, reservoir rocks

Lake Pannon was a Caspian-type brackish megalake existing during the late Miocene-early Pliocene times in the Pannonian Basin System. The depositional systems present in the lake include deep-water basinal plain and turbidites, delta front, delta plain and alluvial. Recently, preliminary formations have been described in various parts of the basin. In the souther part, Upper Miocene deep-water turbiditic sediments are defined as Majdan Formation (Northern Banat), Velika Greda Formation (Southern Banat), Szolnok Formation (Great Hungarian Plain) and Andraševec Formation (North Croatian Basin).

These turbiditic formations are composed of intercalating sands, silts, clays and marls, which were generated by an overspill from upstream basins. In seismic profiles, they are diagnosed as having high-amplitude continuous reflections. In well logs, these formations can be inferred by the first appearance of turbidite sandstone at the bottom and by the last appearance of turbidite sandstone at the top of formation. The thickness of the formation is from 100m to over 1000m, depending on the part of the basin.

Such lacustrine turbidites are an important reservoir rock in the petroleum system. Individual sand bodies of Majdan Formation are 2-40m thick and have a mean porosity of about 17%. Petroleum accumulation is also controlled by neotectonics, as the large Szeged fault represents a partial barrier to migration of the hydrocarbon fluids.

HIGH-INCLINATION CORING OF CHANG-6$_3$ OF THE YANCHANG FORMATION IN HUAQING OILFIELD, ORDOS BASIN: IMPLICATIONS FOR PALEOCURRENT DIRECTION AND FRACTURE ORIENTATION

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ABSTRACT

Keywords: sandy debris flow, massive sandstone

A promising method is to use coring of high-inclination well to find paleocurrent direction and orient tiny natural fractures in massive sandstone of sandy debris flow. Determination of paleocurrent direction can reduce the number of exploratory wells, and orientation of natural fractures has directive significance for deploying the flooding well network. In Block X of Huaqing Oilfield of Ordos Basin, the cores of Chang-6$_3$ in the Yanchang Formation with a total length of 105m were taken from Well Y by 16 coring operations. Cores were oriented through drilling parameters, core number, the angle between core edge and horizontal bedding, core section coincidence, and directional flame structure. As a result, the micro-fractures on the core were oriented. The paleocurrent directions of sandy debris flows were reconstructed by load cast, flute cast, groove cast, and imbricate structure. Our results show that the paleocurrent directions of sandy debris flows were southwest, southeast, northwest, and west from bottom to top. Wuqi delta front is the primary provenance of massive sandstone with the best oil-bearing property. The local turning of the sandy debris flows in the northeast affected by the lake bottom topography formed the sandy debris flows from this direction. The NEE-SWW-trending fractures formed in the Yanshanian period are most developed in the Huaqing area, which should be considered in deploying the flooding well network. The N-S-trending micro-fractures formed in the Himalayan period can improve the physical properties of tight sandstone and have important significance for tight sandstone reservoirs.

Day 3 (April 22nd)

BOTTOM CURRENT AND THEIR DEPOSITS

Introduction & Remembering	Arnold Bouma
Elda Miramontes - Along-slope and across-slope channels formed or affected by bottom currents **(keynote)**	
Michael Clare - Surprisingly frequent and powerful turbidity currents in a land-detached submarine canyon	
J. Clark Gilbert - Submarine channel evolution along a steep basin margin: Miocene Modelo Formation, Lake Piru, California, USA	
Daan Beelen - Predicting bottom current deposition and erosion	
Natalia Varela - Turbidity currents associated with dense bottom-water formation in Antarctica: Evidence from Pliocene-Pleistocene deposits in the Ross Sea (IODP Site U1524)	
BREAK	
David Ricardo Pedreros Bastidas - Seismic reflection data reveal Mesozoic-to-Recent bottom current activity in the Browse Basin, offshore NW Australia	
Fabien Laugier - The scales and impacts of heterogeneity in deepwater fans	
Celeste Cunningham - Controls on organic carbon deposition and preservation in ancient deep-marine levees	
C. Robertson Handford - Deep-water carbonate-sediment waves, dunes, and supercritical bedforms, Mississippian Fort Payne Formation, Tennessee	
Pilar Clemente - Shallow lacustrine debris flows and thin-bedded turbidites. The Lower Cretaceous Rupelo Formation, Cameros Basin, Spain	
Pintu Layek - Evidences of deep-water turbidites from the Arjuni Formation, Sonakhan Greenstone Belt, Chhattishgarh, Central India	
Javier Hernández-Molina - Turbidites, reworked turbidites and contourites in Cyprus: diagnostic criteria and implications	

ALONG-SLOPE AND ACROSS-SLOPE CHANNELS FORMED OR AFFECTED BY BOTTOM CURRENTS

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ABSTRACT

Ocean currents flowing near the seafloor (i.e. bottom currents) can profoundly reshape the seafloor and even modify the characteristics of turbidite systems. The interaction of bottom currents with the seafloor can generate erosion or avoid deposition resulting in the formation of channels, which can have different orientations and morphologies depending on their driving processes. Bottom currents flowing alongslope and related to the thermohaline circulation (i.e. contour currents) often form moats or contourite channels at the foot of slopes and are typically associated with a zone of sediment accumulation named contourite drift. Contour currents can also generate channels parallel to the bathymetric contours in open slopes, without an associated drift, when depressions such as pockmarks are present at the seafloor. The interaction of bottom currents with pockmarks induces a significant erosion at their streamwise edges. When pockmarks are distributed aligned in pockmark trains, they can be eroded and elongated in the streamwise direction, finally coalesce and form a channel. Other oceanographic processes can also contribute to the formation of rectilinear channels in open slopes oriented parallel to the contours. This type of channels has been so far mainly identified on upper continental slopes (e.g. in the Mozambican and Namibian margins) and seems to be related to internal waves.

The interaction of bottom-current related processes and downslope gravity driven processes and products forms mixed turbidite-contourite systems. The synchronous interaction of contour currents and turbidity currents generates asymmetric channel-levee systems that are oriented across-slope and commonly migrate in the opposite direction of contour currents. Bottom currents can also interact with deposits previously formed by turbidity currents and modify their morphology and sediment facies. For instance, bottom currents flowing along across-slope submarine channels can erode their flanks and induce the deposition of contouritic sand.

The role of bottom currents in the inception and modification of channels has widely been recognised based on geophysical and sedimentological observations. However, the oceanographic and sedimentary processes that control the development of such channels are still poorly understood due to the scarcity of in situ observations of the flows, as well as, physical and numerical simulations.

SURPRISINGLY FREQUENT AND POWERFUL TURBIDITY CURRENTS IN A LAND-DETACHED SUBMARINE CANYON

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ABSTRACT

Keywords: turbidity current, submarine canyon, land-detached, highstand

Sediment, nutrients, organic carbon and pollutants are funnelled down submarine canyons from continental shelves by sediment-laden flows called turbidity currents, which dominate particulate transfer to the deep-sea. Post-glacial sea-level rise disconnected more than three quarters of the >9000 submarine canyons worldwide from river or long-shore drift sediment inputs. Existing models therefore assume that land-detached submarine canyons are dormant in the present-day; however, as previous monitoring focused on land-attached canyons, this paradigm remains untested. Here we present the most detailed field measurements yet of turbidity currents within a land-detached submarine canyon, documenting a remarkably similar frequency (6/year) and speed (up to 5-8 m/s) to those in large land-attached submarine canyons. Our monitoring data from the deep-sea Whittard Canyon in the NE Atlantic reveal that major triggers such as storms or earthquakes are not required for turbidity current inception; instead, seasonal variations in cross-shelf transport explain temporal-clustering of flows, and why the storm season is surprisingly absent of turbidity currents. As >1000 other canyons have a similar configuration, we propose that contemporary deep-sea particulate transport via such land-detached canyons may have been dramatically under-estimated.

SUBMARINE CHANNEL EVOLUTION ALONG A STEEP BASIN MARGIN: MIOCENE MODELO FORMATION, LAKE PIRU, CALIFORNIA, USA

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ABSTRACT

Keywords: submarine-channel, process sedimentology, drone photogrammetry

Submarine-fan systems host important archives of paleo-environmental change and are major targets for the exploration and production of hydrocarbons. These systems contain multiple subenvironments (e.g. channels, lobes, levees), often with unique depositional architectures. However, similarities in grain-size trends and bed thickness between subenvironments often make identification difficult, particularly because some subenvironments are transitional or quite variable. While channel complexes can often be resolved on seismic data, only outcrop data yields high-resolution detail of their heterogeneity. This study integrates 11 measured sections with drone-based photography to document lateral and vertical changes in depositional architecture patterns in a well-exposed submarine channel outcrop of the Miocene Modelo Formation at Lake Piru, California.

The architecture of this channel element is well constrained by erosional surface mapping and facies changes. In addition to the macro-scale architectural parameters, grain-size and bed-thickness data from each measured section were digitized to quantify facies changes. At the base of the channel element, the facies changes are gradational, with alternating mudstones and sandstones becoming amalgamated sandstones over the span of tens of meters laterally. The channel element has a predictable vertical facies succession with thin sandstones and intercalated mudstones at the base, which are overlain by contorted beds of sandstone and mudstone that are interpreted as mass transport deposits. Thick, amalgamated sandstones overlie the contorted beds and both of these facies are not present in the channel-element margin. Near the top of the channel element, thick sandstone beds separated by thin mudstones are overlain by chertified siliceous mudstones which we interpret as evidence of a drastic change to hemipelagic sedimentation and abandonment of the channel. With the quantitative documentation of grain size, bed thickness, and lateral facies heterogeneity, this study provides important data for understanding channelized sediment gravity flow dynamics as well as to aid in reservoir model parameterization.

PREDICTING BOTTOM CURRENT DEPOSITION AND EROSION

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ABSTRACT

Keywords: contourite, thermohaline bottom current, machine learning, ocean sedimentology

Mapping deposition and erosion by thermohaline ocean bottom currents is important for understanding the sedimentology of contourites and abyssal dunefields, and for the development of ocean infrastructure and future geo resources. However, only a limited percentage (estimated 20%) of the ocean floor has been mapped directly through seismic or sonar imaging. To better define where zones of bottom current deposition and erosion exist, we develop a predictor from numerical model solutions and sedimentological measurements of the ocean floor. This is achieved by integrating three types of data. 1) Bottom current shear stress from a model run of the HYCOM numerical ocean model (Chassignet et al. 2019). 2) Sedimentation rates from ocean lithospheric age and sediment thickness from the GlobSed Model (Straume et al. 2009). 3) The measured extent of some bottom current deposits from sonar observations (the Contourite Atlas by Claus et al. 2019). To make the prediction, an area of training data is defined in the Northern Atlantic Ocean, which has been mapped accurately through many sonar surveys. Shear stresses and sedimentation rates inside and outside the mapped extents of bottom current deposits allow us to quantify the conditions that are conducive for bottom current deposition. These conditions are then highlighted on a 1/12° arcsecond resolution map of the world's oceans and is validated through comparison with accurately mapped systems. Based on our prediction, around 26% of the ocean has significant deposition by bottom currents while only 2% has erosion. Most bottom current activity occurs where thermohaline currents impinge upon the ocean floor, like on continental slopes or on some areas of the abyssal plain. Deposition and erosion also occur where constriction of ocean bottom currents takes place like in straits and seaways. Inland basins (i.e., seas) and continental shelves are mostly disconnected from thermohaline bottom current conveyers and therefore have limited bottom current deposition and erosion. Finally, mid ocean ridges have little deposition due to low sediment supply.

TURBIDITY CURRENTS ASSOCIATED WITH DENSE BOTTOM-WATER FORMATION IN ANTARCTICA: EVIDENCE FROM PLIOCENE–PLEISTOCENE DEPOSITS IN THE ROSS SEA (IODP SITE U1524)

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ABSTRACT

Keywords: dense water cascading, Ross Sea, IODP U1524

Turbidity currents in polar regions can be triggered by a variety of oceanographic processes, providing an opportunity to use turbidite deposits as a record of globally important environmental change, including ice sheet-ocean interactions. Hillary Canyon, located ~120 km north of the Ross Sea Ice Shelf, West Antarctica, is a 500 m deep and 40 km wide submarine canyon-channel system and one of the largest conduits for Antarctic Bottom Water (AABW) outflow. In this study, we propose that the dense shelf water flowing down the continental slope segment of the Hillary Canyon initiated turbidity currents, and its sedimentary record is archived on the adjacent levees. International Ocean Discovery Program (IODP) Site U1524, drilled on the crest of the southeastern levee of the Hillary Canyon, recovered a 280 m-long section that comprises the history of AABW formation from the Pliocene (~3.3 Ma) to the present. We identified >3,300 thin (1.5 mm average thickness) turbidite beds, characterized by a yellowish color and a sharp lower contact. To assess current strength, we ran grain-size analyses on one-hundred pairs of the turbidite beds and their overlying mud. The turbidite beds have a median grain size between very fine to medium silt (5-30 µm), while the overlying mud has an average silt:clay ratio of 2 to 3. These parameters, combined with the conduit dimensions based on seismic-reflection data, are used as inputs in a Rouse-type model to evaluate suspended sediment concentration, flow velocity, and flow height. Preliminary findings suggest that the turbidity currents were very low concentration (< 1%), consistent with the notion that these flows are driven largely by dense water cascading. The turbidite record on Site U1524 allows us to expand the understanding of deep-water sedimentary processes in the context of climate change over the past 3.3 Myr, and their value as paleoceanographic proxies.

SEISMIC REFLECTION DATA REVEAL MESOZOIC-TO-RECENT BOTTOM CURRENT ACTIVITY IN THE BROWSE BASIN, OFFSHORE NW AUSTRALIA

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ABSTRACT

Keywords: facies, contourites, seismic reflection, offshore Australia

Contourites are marine sediments deposited by thermohaline-induced, deepwater bottom currents. The presence, direction, and strength of such currents are sensitive to changes in basin geometry, thus the distribution, geometry, and size of their related deposits provide a potentially rich archive of basin evolution. To date, however, relatively few studies have assessed the utility of ancient contourites as ‘tape recorders’ of long-term basin evolution, especially on the NW Shelf of Australia, where several major thermohaline currents interact along a tectonically active margin. Here we use (75,000 km2) 2D and 3D seismic reflection datasets from the Browse Basin to study the interaction between marine currents and tectonics. These data reveal the basin contains five main Palaeocene-to-Miocene and Recent seismic-sequences. The lowest sequence (S1) contains continuous to semi-continuous, low-to-moderate amplitude reflections, whereas the overlying sequence (S2) is composed of two sub-units; (i) lower sub-unit composed of continuous reflection and, we infer, well-stratified deposits; and (ii) upper units characterised by discontinuous, low-amplitude reflections that perhaps suggest higher-energy conditions and more seabed reworking by bottom currents. S3 contains large (400 ms TWT high by 10 km long wide by 5 km long) clinoforms that are intensely gullied. These clinoforms may document progradation of the basin margin or giant bedforms formed by bottom currents. S4 also contains up to 300 ms TWT high, steeply-dipping clinoforms. The shallowest sequence (S5) extends up to the seabed and contains abundant evidence for locally deep (up to 200 - 300 ms TWT by hundred metres wide) erosion, and the formation of contourite bedforms and related scours. Our analysis indicates the Browse Basin is an ideal location to study the deposits related to ocean bottom currents. 2D seismic imaging has allowed us to map the regional distribution of the main mega-sequences, providing insights into the geometry and scale of some of the main depositional elements and related erosional features.

THE SCALES AND IMPACTS OF HETEROGENEITY IN DEEPWATER FANS

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ABSTRACT

Deepwater fans are amongst the largest sediment accumulations on Earth and are key reservoirs for conventional and unconventional development and more recently a critical focus for CO2 injection. Based on qualitative analyses of sparse outcrop and subsurface data, deepwater fans are commonly characterized as homogeneous and laterally extensive reservoirs. However, recent studies focused on bed-scale outcrop analysis, high-resolution seismic, and computational experiments are yielding different conclusions on the degree of heterogeneity and spatial variations in rock properties at multiple scales within deepwater fans. These opposing models have significant implications not only our understanding of the stratal evolution of deepwater fans but also on the ability to optimally develop these reservoirs for hydrocarbon extraction and CO2 sequestration.

Here, we present an integrated study linking key heterogeneities in outcrops and subsurface data with physics-based numerical models. We apply quantitative stratigraphic analyses to first decipher the degree, scales, and controls on heterogeneity at various hierarchical levels, and second to assess the impact on controlling fluid flow. Our results highlight the inherent complexity in stratigraphic heterogeneity in deepwater fans, particularly in relation to key characteristics such as reservoir volume, quality, and connectivity. Leveraging these numerical models as digital analogs, we developed a predictive framework on how these properties vary spatially and temporally, which when combined with subsurface data, provide better recognition of the channelized, transitional, and sheet-like zones, and a more robust linkage between stratigraphic architecture and patterns in 1D and spatial heterogeneity in 3D. We demonstrate that these distinct variations in key stratigraphic heterogeneities compound to impact connectivity and fluid flow. A key finding is that accurately predicting the 3D extent of heterogeneities from 1D data is fundamentally dependent on their associated hierarchy. We conclude that for development-strategy optimization and performance forecasting, deepwater fans should be characterized and modeled as complex but with predicable heterogeneities that vary across multiple levels of stratal hierarchy.

CONTROLS ON ORGANIC CARBON DEPOSITION AND PRESERVATION IN ANCIENT DEEP-MARINE LEVEES

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ABSTRACT

Keywords: deepwater organic carbon flux, deep-marine levees, chemostratigraphy, sequence stratigraphy

Modern deep-marine levees have been shown to sequester a large proportion of the world's total buried organic carbon; however, few studies have attempted to assess this in ancient deep-marine sedimentary rocks. Deep-marine levees are areally extensive features that experience high rates of sedimentation, making them ideal sites for significant carbon burial and preservation. Examining the distribution of organic material in ancient levee deposits could provide insight into paleoenvironmental conditions and the evolution of ancient ocean and climate systems.

In levee deposits of the Neoproterozoic Windermere Supergroup at the Castle Creek study area (B.C., Canada), total organic carbon content (TOC) is highly variable and ranges from < 0.1% to 4.04% (uncorrected for the effects of greenschist metamorphism). Organic-rich strata are mainly concentrated in one stratigraphic interval, ~50 meters thick, and rarely found elsewhere in the outcrop. The enhanced organic carbon burial in this interval could be due to various oceanographic, climatic, and tectonic factors, such as biological productivity and source, bottom water oxygenation, sediment accumulation rate, and mineral interaction. In this study, a 300-meter-thick succession of mudstone-dominated levee deposits was sampled at an interval of 4 – 10 meters and geochemical analyses performed to determine TOC, stable carbon isotopes, and elemental composition. This data was used to evaluate each of the above mechanisms and assess their role in the burial and preservation of organic carbon in these strata.

By studying the geochemical trends of both organic-rich and organic-poor rocks in this ancient outcrop, this study aims to provide insight into the evolution of basin-wide conditions and dynamics, including primary productivity and platform development on the shelf, and sediment provenance and delivery mechanisms. This will ultimately improve our understanding of the complex interplay of physical, chemical, and biologic processes that govern marine sedimentation, and their relationship with past global climate and oceanographic conditions.

DEEP-WATER CARBONATE-SEDIMENT WAVES, DUNES, AND SUPERCRITICAL BEDFORMS, MISSISSIPPIAN FORT PAYNE FORMATION, TENNESSEE

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ABSTRACT

Keywords: sediment waves, cascading density currents, supercritical flow, bottomset, Mississippian Fort Payne

Recent studies documenting sediment waves, cyclic steps, and drift deposits in modern carbonate and siliciclastic slopes are reshaping our understanding of depositional and erosional processes in those environments. Concepts from those studies are now being applied to interpreting ancient carbonate slope and basin-floor deposits of the Lower-Middle Mississippian Fort Payne Formation of Kentucky-Tennessee.

This study documents carbonate sediment waves, deposited in thick bottomsets ~30-100 km basinward of a mixed carbonate-siliciclastic mud clinoform belt and in water depths of ~150 m. Previous investigations reported Waulsortian-like mounds, but the present study shows that these are sediment waves, formed entirely by hydrodynamic processes, and inhabited by crinoid-dominant heterozoans. Cliff exposures along streams and lakes display mixed shale/carbonate to carbonate, transverse sediment waves (500-m wave-lengths and 50 m high). Strike alignment is generally NE-SW and large waves consist of SE-inclined offlapping wedges that prograded basinward.

Facies associations include (1) burrowed to rippled, shaley, dolomitic wackestone, (2) thick-bedded, burrowed to vaguely laminated/rippled, cherty, dolomitic mudstone-wackestone with thin grainstones at base, (3) heterolithic, wavy/hummocky, crinoid rudstones and packstones with thin shale breaks, (4) sharp-based, thin to thick-bedded and fining-upward rudstones to rippled wackestone. Lee slopes of waves have 2-4 m-high dunes that migrate downdip. Beds on one crest contain inversely to normally graded, crinoid gravel laminae that transition down the leeside into 1-m high, upslope-migrating antidune bedforms. These suggest that upper-flow regime currents accelerated down the sediment-wave slope and became supercritical. Numerous, long crinoid stems exposed on leeside bedding planes are oriented parallel to SE dip.

Possible processes include (1) cascading density currents flowing downslope from adjacent shelves behind the clinoform belt, (2) internal waves reworking the crests of large sediment waves, (3) sediment gravity flows generated along flanks of sediment waves, (4) coastal upwelling of nutrient-rich water, and (5) contour currents.

SHALLOW LACUSTRINE DEBRIS FLOWS AND THIN-BEDDED TURBIDITES. THE LOWER CRETACEOUS RUPELO FORMATION, CAMEROS BASIN, SPAIN

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ABSTRACT

Keywords: shallow lacustrine resedimented carbonates, ephemeral storm runoff, storm surges

The primary processes by which thick and thin-bedded lacustrine limestones are modified by sub-aerial exposure and trap or bind cyanobacteria are not well understood. Resedimented carbonates can be misinterpreted as the deposits of low-energy water bodies, of deep, storm-dominated or shallow wave-dominated lakes. It is known that lacustrine turbidites can be triggered by river floods and/or transformation of slumps. However their occurrence in shallow lakes, imply alternative triggering mechanisms. The upper Rupelo Formation is a thin depositional sequence, which includes two facies associations of lacustrine-coastal carbonates. It is a classic example of low-energy water bodies. New data indicate the carbonates are resedimented. Detailed sedimentological sections, polished hand specimens and thin sections have been used to decipher the primary facies and the sediment gravity flows. The first facies association (FA1) consists of thick (0.5-2 m) bedded limestones of massive, clast-and matrix supported calcirudites, calcarenites deposited by debris flows originated by the transformation of turbulent flows. The second (FA2) are marls and thin (0.1-0.2 m) bedded limestones containing thin (1-2 cm, Ta-Td-Te) Bouma sequences. Ta are massive –graded calcarenites of ostracods, peloids and miliolids. Td-Te are faintly laminated and massive peloidal calcisilts and micrites. They are indicative of surge type, turbulent, waning flows. The depositional sequence represents a mixed system of inland debris fans, dominated by ephemeral storm runoff and coastal lobe- systems of thin-turbidites originated by the transformation of storm surges. The findings show that debris flows and thin turbidites are not restricted to deepwater but also occur in shallow waters. Moreover, lacustrine debris flows can originated by the transformation of turbulent flows, and thin-bedded turbidites can originate by storm surges. The identification of shallow resedimented lacustrine carbonates provides a new light on the sedimentary processes governing basins with low gradient margins.

EVIDENCES OF DEEP-WATER TURBIDITES FROM THE ARJUNI FORMATION, SONAKHAN GREENSTONE BELT, CHHATTISHGARH, CENTRAL INDIA

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ABSTRACT

Keywords: Sonakhan Greenstone Belt, Bouma sequence, turbidites, submarine fan

The Neoarchean-Paleoproterozoic Sonakhan Greenstone Belt (SGB) of Chhattishgarh state, Central India, preserves a very thick (about 5km) sedimentary succession around Arjuni and Karmel area that represents a deep-water submarine fan system. Our study reveals four distinct facies assemblages, which consist of conglomerate –sandstone facies (FA), medium to coarse sandstone facies (FB), fine sandstone-siltstone facies (FC), and siltstone –shale-BIF facies (FD). FA consists of boulder-cobble conglomerate facies (F1), pebble-granule conglomerate facies (F2), and coarse grain interbedded sandstone facies containing floating clast of granule to cobble size (F3). Lensoid occurrence, massive ungraded to graded character of the conglomerate indicates (F1) are deposited at the proximal part of the submarine fan system by debris-flow event. The Bouma sequence is partially developed within the inter-bedded sandstone (F3), indicating the transition of the debris flow event to a turbidity flow event. FB consists of massive to normally graded medium grain sandstone (F7), granule conglomerate (F8), plane-parallel laminated medium grain sandstone (F9), and trough cross-bedded coarse sandstone (F10). These are interpreted as broad low relief channel deposits. FC consists of medium grain sandstone showing normal gradation from medium to fine sandstones which are 25cm to 300cm thick amalgamated beds (F4), steel gray, plane parallel laminated siltstone (F5), and graded to massive 50cm to 90 cm thick coarse-grain sandstone (F6). These repetitive sand-dominated beds are interpreted to be deposited by turbidity flow. FD is dominated by siltstone and shale heterolith. Td and Te divisions of the Bouma sequence are developed within these beds. These beds are interpreted as typical turbidites, deposited at the distal part of the fan.

TURBIDITES, REWORKED TURBIDITES AND CONTOURITES IN CYPRUS: DIAGNOSTIC CRITERIA AND IMPLICATIONS

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ABSTRACT

In this work an exceptional example of Eocene to Middle Miocene deep-marine deposits has been studied onshore and offshore Cyprus by a multidisciplinary approach that allows the discrimination of the facies associations for finer- and coarser-grained contourites, pelagites/hemipelagites, turbidites, reworked turbidites and mass-transports (MTDs) deposits. These deepwater deposits developed in a slope basin located in the upper plate of an active margin that evolved from an initial wide basin during a tectonically quiescent period to a shallowing up segmented sub-basin in a complex compressional setting.

A sedimentary model is proposed where two long term contourites depositional systems were developed, and older one in the Eocene (dominated by fine-grained contourites) and a younger one during the latest Oligocene to Middle Miocene (dominated by coarse-grained contourites). Both systems are buried by extensive marls deposits and would represent the “on” and “off” circulation of deep and intermediate water masses respectively. This is a result of the plate tectonic dynamics that conditioned the enhancement of subduction processes south of Cyprus and the evolution of the water-mass exchanges between the Neotethys Ocean and the Indian and Atlantic Oceans until the final closure of the Indian Gateway. Within these contourite depositional systems, the coarser-grained (sandy) contourites are structured into packages. Coevally, the turbidites and MTDs developed in combination with pelagic/hemipelagic sediments, which constitute the sediment supply for the contourites deposits subjected to their winnowing and reworking.

The diagnostic criteria for discriminating contourites, turbidites and reworked turbidites are presented here, highlighting the importance of primary sedimentary structures, microfacies and ichnofacies in their identification at sedimentary facies scale. The turbidites recognised represent incomplete sequences, including either only the lower or upper divisions of the Bouma sequence model, associated respectively to low- and high-density turbiditic flows that are subsequently partially or fully reworked by the action of bottom currents. The studied deep-water deposits indicate the important role of tectonic in driving the paleo-oceanic circulation which in turn control the sedimentary processes and shape the morphology of oceanic basins and continental margins. As such, they are a good analog for comparisons with similar deposits in the present-day marine basins or within the ancient sedimentary record.