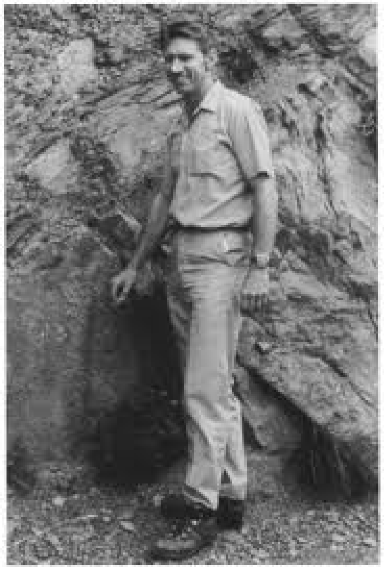

2023 1st In-Person Bouma Deep Water Geoscience Conference

Conference Booklet

SEPM

17 - 21 APRIL 2023

Utrecht, Netherlands

Bouma Conference

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Conference Activities

Tuesday, April 18

Core Workshop **9.00–16.30**
Utrecht University, Victor J. Koningsberger Building, Budapestlaan 4a-b, 3584 CD Utrecht

Flume Workshop **9.00–16.30**
Utrecht University, Victor J. Koningsberger Building, Budapestlaan 4a-b, 3584 CD Utrecht

Icebreaker **17.00**
Utrecht University, Vening Meinesz A Building, Princentonlaan 8a, 3584 CB Utrecht

Wednesday, April 19

Oral Presentations **9.00–17.15**
Utrecht University, Room: Cosmos, Budapestlaan 4a-b, 3584 CD Utrecht

Poster Presentations **9.00–17.15**
Utrecht University, Minnaert Building, Leuvenlaan 4, 3584 CE Utrecht

Dinner (optional) **18.30**
Utrecht University, University Hall, Room 1636, Domplein 29, 3512 JE Utrecht

Thursday, April 20

Oral Presentations **8.55–17.00**
Utrecht University, Room: Cosmos, Budapestlaan 4a-b, 3584 CD Utrecht

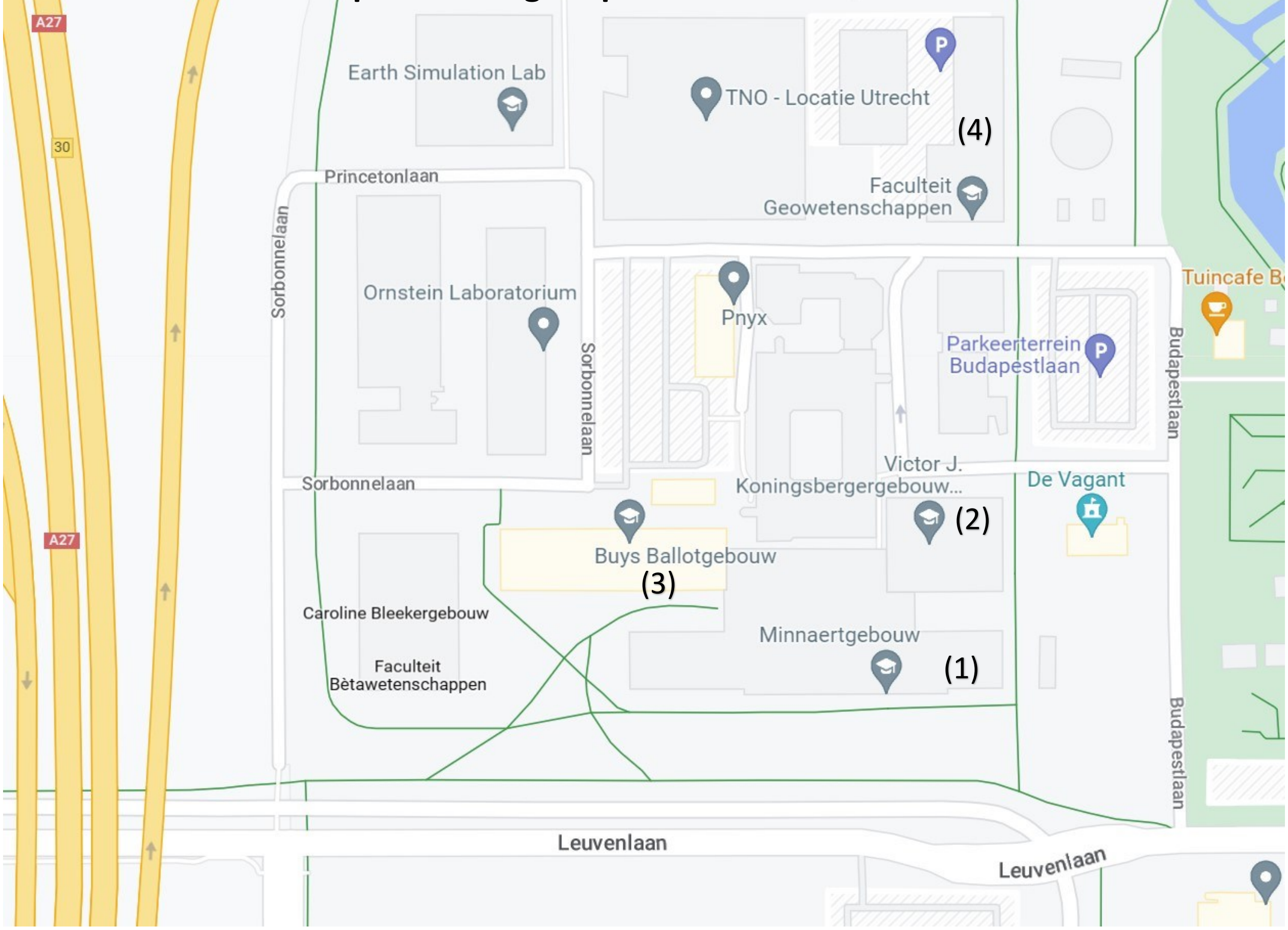
Poster Presentations **8.55–17.00**
Utrecht University, Minnaert Building, Leuvenlaan 4, 3584 CE Utrecht

Friday, April 21

Oral Presentations **8.55–15.30**
Utrecht University, Room: Cosmos, Budapestlaan 4a-b, 3584 CD Utrecht

Poster Presentations **8.55–15.30**
Utrecht University, Minnaert Building, Leuvenlaan 4, 3584 CE Utrecht

Campus Building Map—Bouma Conference



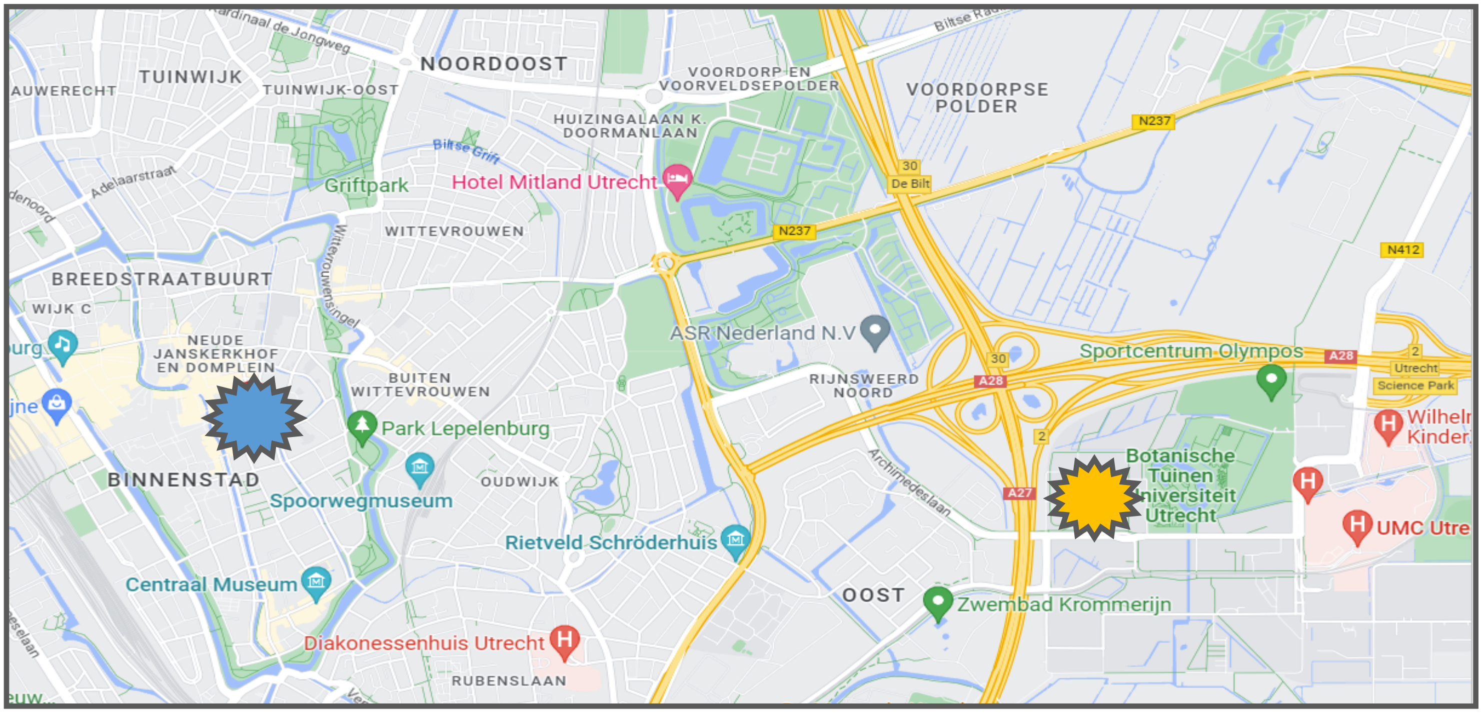
Registration, lunch and poster sessions (1):
Minnaert building, Leuvenlaan 4,3584 CE Utrecht https://www.uu.nl/en/minnaert-building

Wednesday—Friday Bouma Conference (Oral Sessions) (2):
Victor J. Koningsberger building, Room: Cosmos,
Budapestlaan 4a-b, 3584 CD Utrecht, https://www.uu.nl/en/victor-j-koningsberger-building

Tuesday Flume and Core Workshops (3):
Buys Ballot building, Rooms BB061 and BB165, Princetonplein 5, 3584 CC Utrecht
https://www.uu.nl/en/buys-ballot-building

Tuesday Ice breaker (4):
Vening Meinesz A building, Princentonlaan 8a, 3584 CB Utrecht
https://www.uu.nl/en/vening-meineszgebouw-a

Wednesday Dinner (in Central Campus –not on this map)
University Hall, Room 1636, Domplein 29, 3512 JE Utrecht
https://www.uu.nl/en/university-hall



Main Bouma Conference Area

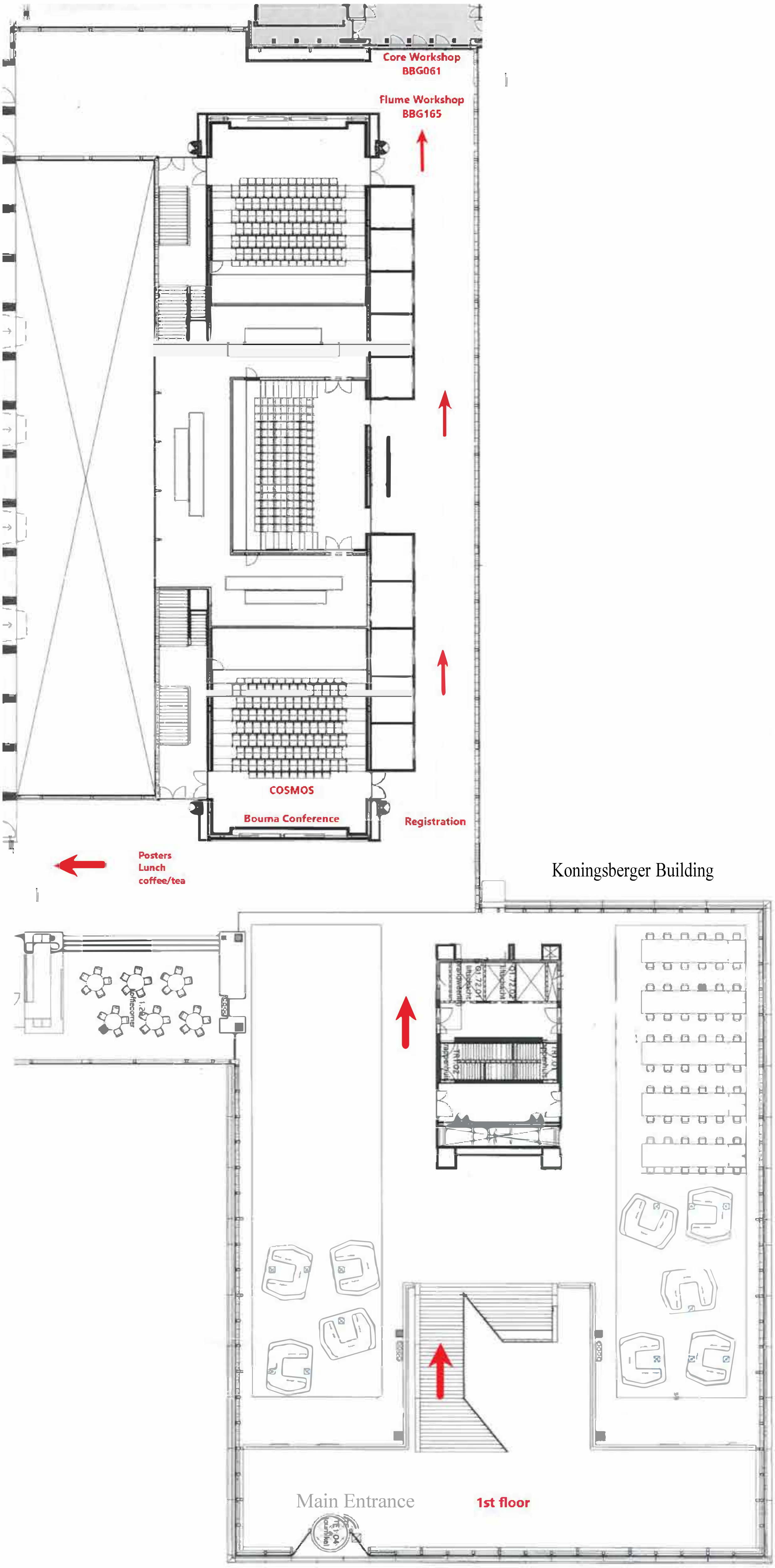
Registration, Workshops, Presentations, Lunch

Wednesday Conference Dinner:

University Hall

Room 1636, Domplein 29, 3512 JE Utrecht

https://www.uu.nl/en/university-hall


Core Workshop
BBG061
Flume Workshop
BBG165
COSMOS
Bouma Conference
Registration
Posters
Lunch
coffee/tea
Koningsberger Building
Main Entrance
1st floor

Day 1	Wednesday, April 19
Theme: Mud Matters; the influence of clay and silt on depositional processes, deposits, and architecture	
	Chairs—Matthieu Cartigny and David Hoyal
9.00–9.15	Welcome by the Organizers
9.15–9.45	Baas—Friction in the relationship between the Bouma sequence and mud: time for reconciliation? **(keynote)**
9.45–10.00	Reijmer—Settling experiments of carbonate sand–mud suspensions
10.00–10.15	Taylor—Unidirectional and combined transitional flow bedforms: processes and distribution in submarine slope settings
10.15–10.30	Peel—Hindered settling versus Guinness Waves in dense, silt-dominated far-travelled submarine gravity flows: comparing model predictions to observations in core
10.30–11.00	Coffee and posters
Theme: Process Stratigraphy; process controls on deposits and architecture of channels, lobes, and transition zones	
	Chairs—Ben Kneller, Timothy Demko, and Roberto Tinterri
11.00–11.30	Steel—Break-down of mud clasts as a trigger for flow transformation: linkages between mud clast character and downflow facies transitions in hybrid event beds, Cloridorme Formation, Quebec **(keynote)**
11.30–11.45	Puigdefàbregas—Syn-depositional growth of sea-floor reliefs: Boltaña anticline, Ainsa basin, Eocene Echo Group, Southern Pyrenees
11.45–12.00	Stanbrook—The Annot confined fill & spill turbidite system: from transgression to termination
12.00–12.15	Tinterri—Turbidite facies tracts as related to flow criticality and efficiency in tectonically confined basins: an outcrop perspective
12.15–12.30	Bouwmeester—The evolution of a submarine canyon as a sediment conduit–outcrop study of a coarse-grained canyon fill on the Baja California Pacific margin, Mexico
12.30–14.00	Lunch break and posters
14.00–14.15	Felletti—THE TECHRIFT PROJECT: sedimentary architecture of turbidite channel-levée deposits (Tachrift System, Taza–Guircif Basin, Tortonian, NE Morocco)
14.15–14.30	Pantopoulos—Sedimentary architecture of the superbly exposed channel-levee Complex 5 of the Tachrift Turbidite System (Tortonian, Taza–Guercif Basin, NE Morocco)
14.30–14.45	McArthur—When the levee breaks: giant deep-water levee collapse into the Hikurangi Channel, offshore New Zealand
14.45–15.00	Keavney—Flow interactions with an unstable submarine canyon wall: the Rosario Formation, Baja California, Mexico
15.00–15.15	Silva—Deepwater siliciclastic processes (post-Cretaceous) along the South American and Caribbean plate boundary: implications for prospectivity in a tectonically- and process-dynamic margin
15.15–15.30	Muravchik—Gravity flow deposits from the Corinth Gulf, Greece, reveal key controls on sediment delivery into the deep sea during the glacial–interglacial cycle

15.30–16.00	Tea and posters
16.00–16.15	Apps—Sediment transport over complex salt and deepwater foldbelt topography: fill & spill revisited in a fully 3D example for the deepwater US Gulf of Mexico
16.15–16.30	Hernández-Molina—Turbidites, reworked turbidites, and contourites: diagnostic criteria and implications
16.30–16.45	Chen—Sedimentary architecture of submarine lobes affected by bottom currents: insights from the Rovuma Basin offshore East Africa
16.45–17.00	Coskun—Sediment waves as a tool to understand deep-water current evolution, Senegal Basin, NW Africa
17.00–17.15	Jobe—Quantification of the bed-scale architecture of submarine depositional environments
Evening	Conference Dinner

Day 2	Thursday, April 20
Theme: Modern Environments: modern marine and lacustrine data sets of gravity flows, bottom currents, and their deposits	
	Chairs—Gillian Apps and Elizabeth Steel
8.55–9.00	Welcome by the Organizers
9.00–9.30	Miramontes—Current-controlled sedimentation in some of the roughest oceans: the Drake Passage and the Argentine Basin **(keynote)**
9.30–9.45	Silva Jacinto—Oceanic circulation in a tide-dominated submarine canyon (Bay of Biscay): implication for transient sediment transfer and cold-water coral reefs
9.45–10.00	Beelen—Thermohaline versus gravitationally induced sediment waves: differences and similarities
10.00–10.15	Feldman—Depositional architecture of the Late Pleistocene Danube Fan
10.15–10.30	Muravchik—AUV high-resolution bathymetry of axial-transverse drainage interaction in the structurally controlled subaqueous channels in the Gulf of Corinth, Corinth Rift, Greece
10.30–11.15	Coffee and posters
11.15–11.30	Cartigny—First direct observations of a submarine landslide (Homathko Delta, BC, Canada)
11.30–11.45	Lobato—How channel–lobe and intra-channel transition zones control the depositional architecture of modern turbidite systems on a decadal scale
11.45–12.00	Holbrook—Confirmation of century-scale sequences in the debris-flow-dominated Nahal Darga Delta, Dead Sea, Israel
12.00–12.15	Adema—Turbidity current–contour current interaction across submarine channels: the effect of channel aspect ratios on flow interation
12.15–12.30	Kneller—How are slope channels affected by bottom currents?
12.30–14.00	Lunch break and posters
Theme: Modelling: new approaches in numerical and physical modelling of deep-water sedimentation	
	Chairs—Jaco Baas and Peter Burgess
14.00–14.30	Hoyal—A dimensionless framework for predicting submarine fan morphology **(keynote)**
14.30–14.45	Musso—Physical modeling of the impact of changing slope-to-basin morphology on the emplacement, erosion, and transport of sediments by along-slope continuous currents
14.45–15.00	Wang—Flow behavior of unconfined turbidity currents interacting with containing topography at different incidence angles
15.00–15.15	Slootman—Shape-dependent settling velocity of skeletal carbonate grains: implications for calciturbidites
15.15–16.00	Tea and posters
16.00–16.15	Burgess—What signals can deep-water fan strata record? A numerical experiment analysis
16.15–16.30	Downard—Linking sedimentary processes, dynamics, and the creation of stratigraphic patterns through computation
16.30–16.45	Downard—Re-evaluating the heterogeneity in deepwater fans from outcrops and the subsurface: insights from computational stratigraphy
16.45–17.00	Downard—Quantitative evaluation of deepwater fan hierarchy: insights from full physics based forward stratigraphic models

Day 3	Friday, April 21
Theme: Deep Flux: submarine canyons as conduits for fluxes of sediment, organic carbon, pollutants, and nutrients to deep water basins	
	Chairs—Elda Miramontes and F.J. Hernández-Molina
8.55–9.00	Welcome by the Organizers
9.00–9.30	Maier—Lessons from recent direct measurements and sampling of sediment and organic carbon flux through Monterey and Kaikōura submarine canyons **(keynote)**
9.30–9.45	Mienis—The important role of Whittard Canyon as pathway and sink for organic carbon
9.45–10.00	Baker—Organic carbon budget for submarine Congo Canyon: the overlooked role of canyons as temporary terrestrial organic carbon stores
10.00–11.00	Coffee and posters
11.00–11.15	Pohl—The submarine Congo Canyon as a conduit for microplastics to the deep sea
11.15–11.30	Acikalin—Organic carbon transport to deep water by extreme events: case study of Elliot Creek GLOF, BC, Canada
11.30–11.45	Sweet—What is the long-term flux of sediment off the shelf? Insights from the Cenozoic on the northern Gulf of Mexico
11.45–12.00	Łuczyński—Palaeozoic mesophotic ecosystems supplied from the shallows by deeply incised erosional channels (Silurian, Gotland)
12.00–13.30	Lunch break and posters
Theme: Petroleum and Beyond: applied uses of deep-water sedimentology	
	Chair—Stan Stanbrook
13.30–14.15	Talling—Turbidity currents: major new advances from directly measuring flows in action, and where next? **(keynote)**
14.15–14.30	Li—The hierarchical division and architectural anatomy of submarine channels
14.30–14.45	Henstra—The ability of submarine canyons to establish an initial equilibrium profile dictates depositional processes and products during canyon fill: a comparative study of contrasting styles and canyon fill in the Lower Cretaceous Agat Formation, Norway
14.45–15.00	Daniels—Downslope variability in deep-water slope channel fill facies and stacking patterns: implications for subsurface reservoir prediction and characterization
15.00	Talling and Eggenhuisen—Discussion forum on what we need to know and what we don’t know to get modelling and prediction on the next higher platform
15.30	Closure of meeting and tea

Poster Presentations (arranged alphabetically)
Posters will be presented during all three days of the meeting
Aggarwal—Organic carbon distribution in Bute Inlet (Canada) following an extreme GLOF event
Aguada—Lateral facies quantification in distal submarine-lobe deposits from litho- and chemofacies well data in the Permian Wolfcamp Formation, Delaware Basin, Texas: implications for subsurface lateral facies prediction
Bleeker—Interaction of turbidity currents and contour currents in flume-tank experiments: concentration profiles and depositional patterns linked to velocity field measurements
Cabrera Ortiz—Ichnological analysis across the Rambla the Tabernas section (Tabernas Basin, SE Spain), an approach to improve the characterization of a turbidite system
Carvajalino—An exceptional dataset of 1250 m (4000') continuous core through channelized submarine fan deposits, Eocene, San Jacinto Fold Belt, NW Colombia
Davies—Records of hybrid flow transformations: a field study from the Peïra Cava outlier, SE France
Felletti—Channel-levee transitions: insights from the Tachrift turbidite system (Complex 6, Taza–Guercif Basin, NE Morocco)
Gianese—The mass-transport deposits of the Paleogene Julian Basin (Italy/Slovenia): observations on the dynamic of emplacement and tsunamigenic potential
Glazer—The Oligocene and Miocene sands in the deep Levant Basin: provenance and sediment routing
Handford—Vertical and lateral facies successions of carbonate–shale sediment gravity flow deposits in stacked, laterally accreting slope channels, Mississippian Fort Payne Formation, Kentucky
Heinhuis—Estimating the velocity an ancient bottom currents using grain-size distributions measured in the sections of contouritic rocks with siliceous cements
Li—Quantitative and geomorphologic parameterization of megaclasts within mass-transport complexes, offshore Taranaki Basin, New Zealand
Marsh—Reactive transport modelling of CO_2 in deep-marine reservoirs: Frigg Field and outcrop analogue
Nadhim—Deep-water carbonate gravity flow deposits: relationships between fabric deformation, diagenetic alteration, and fracture characteristics
Putri—Submarine lobe deposits of the Permian Wolfcamp XY Formation (Central Delaware Basin, Texas): high-resolution core study relating chemofacies to reservoir quality
Reguzzi—Sedimentary architecture, depositional evolution, and controls factors of turbidite channel Complex 4 from Tachrift Turbidite System (Tortonian, Taza–Guercif Basin, NE Morocco)
Reguzzi—How hyperpycnal deposits and surge-like turbidites coexist? An example from the Oligocene Monastero Fm. (Tertiary Piedmont Basin, NW Italy)
Ronald—Can we store CO_2 for millions of years in deep-water rocks?
Sevy—Geochemical analysis turbidites of Pindos Basin, Greece
Sihombing—Seismic geomorphology and evolution syn-rift deep-water depositional systems: Upper Jurassic of the Snorre Fault hangingwall, northern North Sea
Slootman—Lateral facies variability in carbonate turbidites in Ionian Basin outcrops (Cretaceous, Albania)
Tahiru—Lobe hierarchy or lobe anarchy? Exploring deep-water fan stacking patterns using a numerical stratigraphic forward model
Taylor—Process sedimentology and stratigraphic architecture of submarine canyon overbank environments, Punta Baja Formation, Mexico

FRICTION IN THE RELATIONSHIP BETWEEN THE BOUMA SEQUENCE AND MUD: TIME FOR RECONCILIATION?

Jaco H. Baas*◊

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◊Keynote Presenter

ABSTRACT

After continuous use for almost 40 years since 1962, the Bouma sequence suffered a lapse in popularity at the turn of the millennium. This was triggered by the belated, community-wide, recognition that particulate density currents are more complex than the Bouma sequence implies; belated, because Arnold Bouma himself presented it as an idealised sequence of sedimentary facies. Is this lapse in popularity justified, or is there still a place for the Bouma sequence in present-day deep-water sedimentology? This presentation describes the rise and fall of the Bouma sequence and argues that the Bouma sequence is based on valuable physical sedimentological concepts that continue to be relevant in understanding the processes that govern the transport and deposition of particulate matter in the deep ocean. One reason why the Bouma sequence is out of favour is the modification of flow dynamics by cohesive clay, and possibly also by cohesive biological polymers (EPS). Clay is common in most deep-marine environments, and it has been shown in the last two decades to contribute to deposits with unique textural and structural properties, even at low concentrations in the formative flows. Although focus has shifted from Bouma-type turbidites and debris flow deposits to hybrid event beds and transitional flow deposits, individual Bouma divisions and incomplete Bouma sequences can still be recognised in these novel deposit types. This should not be surprising, because each Bouma division is associated with a balance (and interaction) of bed frictional processes, instigating different current-induced sedimentary structures, with particle settling processes. These processes are not unique to the 'classical' waning turbidity current on which the original Bouma sequence was based. It can be argued that clay and EPS modify the original Bouma divisions and add new divisions that form vertical successions across a wider range of spatiotemporal changes in flow properties.

SETTLING EXPERIMENTS OF CARBONATE SAND-MUD SUSPENSIONS

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[◊]Presenter

ABSTRACT

Keywords: settling experiments, skeletal carbonate sands, carbonate mud, grain-size sorting

This study addresses the settling behaviour of carbonate sediment suspensions using natural non-cohesive tropical carbonate sand (Moorea, French Polynesia) and natural cohesive tropical carbonate mud (slope Little Bahama Bank). The bulk settling experiments used suspensions (9%, 20% and 30% sediment concentrations) of carbonate sand mixed with various proportions, up to a quarter, of cohesive carbonate mud. Textural trends of experimental deposits were evaluated based on laser diffraction analysis and microscopic observations, and revealed three intervals, from base to top: Interval A: fairly ungraded pack- to grainstone and rudstone, occasionally with a fining-upward base for low bulk concentrations and low mud proportions; Interval B: normally graded grain- to packstone; and Interval C: normally graded wackestone to mudstone. Interval B deposits are least muddy (cleanest sand), yielding good grain sorting and high porosity values. The normalized thickness of interval B is more or less constant for all experiments and seems independent of sediment concentration or mud proportion. Interval C thickens at the expense of interval A with increasing mud proportion. This trend becomes less pronounced for higher-concentration suspension deposits, for which interval A is the dominant facies. The ungraded part of interval A is underlain by a fining-upward base in low-concentration suspension deposits, the normalized thickness of which decreases with sediment concentration and mud proportion. Grain-size segregation becomes less efficient with increasing sediment concentration and cohesive mud proportion. The presence of cohesive carbonate mud lowered the critical sediment concentration at which grain-size segregation was suppressed, as revealed by thick ungraded A intervals. The variations in grain-settling intervals for the calcareous suspensions are heterogeneous in nature (grain-size, biota), which may be related to the heterogeneity of the natural sediments used. Grain-size segregation is suppressed at lower sediment concentrations than for their siliciclastic counterparts, however, the variety in grain-sizes may have directed this trend.

UNIDIRECTIONAL AND COMBINED TRANSITIONAL FLOW BEDFORMS: PROCESSES AND DISTRIBUTION IN SUBMARINE SLOPE SETTINGS

William J. Taylor[1*◊], David M. Hodgson[1], Jeff Peakall[1], Ian A. Kane[2], and Stephen S. Flint[2]

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[◊]Presenter

ABSTRACT

Keywords: combined, transitional, mud, bedform

Sediment gravity flows form characteristic depositional bedforms that vary in texture and morphology due to the rheological behaviour of the flow. Cohesive forces from clay dampen turbulence resulting in distinctive mixed grain-size laminasets that stack into bedforms. Bedform type is governed by the balance of cohesive and turbulent forces, and the rate of flow deceleration. However, in proximal environments bedform process interpretations are typically founded on longstanding concepts of fully turbulent flows and cohesionless sediment, despite the close association of large quantities of mud and abrupt losses in confinement that lead to rapid flow deceleration in these settings. Here, we use core and outcrop examples to describe and interpret a suite of mixed grain-size bedforms. Type-A bedforms consist of asymmetric mud-prone current ripples and low-amplitude bed-waves that comprise alternating concave and planar sandstone-mudstone foresets that pass into mudstone troughs, and sinusoidal laminasets. Type-B bedforms consist of rounded ripples with sigmoidal-shaped foresets and small-scale swale- and hummock-like structures that comprise alternate sandstone-mudstone banded sets. Both bedform types are interpreted as the product of transitional flows, which demonstrate rapid flow deceleration associated with abrupt loss of channel confinement or decreased slope gradient. Type-B bedforms indicate combined transitional flows that result from flow reflection or deflection off confining topography. Furthermore, we find characteristic upward transitions between laminasets, which form distinct mixed grain-size beds that represent progressive spatio-temporal transformations in flow properties and their topographic interactions. The bedforms interpreted here cannot represent contour current deposits, as such flows cannot account for the appreciable amounts of mud in laminasets, and the Karoo basin was not ocean-facing, showing that basin context remains key in interpreting deep-marine flow processes. Our findings stress the importance of understanding mixed grain-size bedforms in turbidite sandstones across proximal settings, their distribution and formative conditions which contrast with established sand-prone bedform development.

HINDERED SETTLING VERSUS GUINNESS WAVES IN DENSE, SILT-DOMINANT FAR-TRAVELLED SUBMARINE GRAVITY FLOWS: COMPARING MODEL PREDICTIONS TO OBSERVATIONS IN CORE

Frank J Peel[1*◊], Gillian M. Apps[1], and Stan Stanbrook[2]

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ABSTRACT

Keywords: turbidites, silt, long run-out, hindered settling

We propose a new model for the long-distance transport and freezing of silt-grade sediment gravity flows.

Silt-dominated sediment gravity flows differ from sand-rich turbulent flows, because smaller grainsize causes slower particle setting velocities and lower bulk permeability.

As water is lost from a moving sediment gravity flow, water pathways between particles become progressively more constricted, hindering upward water percolation; hindered settling (HS) occurs when the downward motion of grains is limited by the rate at which water can escape upward, rather than by downwards Stokes Law particle settling.

Downward particle movement in silt flows can be several orders of magnitude slower than in equal-density sand flows. The turbulence needed to support the grains is correspondingly less, so dense silty HS flows could have much longer runout distances than equivalent sand-grade flows.

However, numerical simulations of HS flows with initially near-uniform particle concentration become spontaneously structured; upward-moving fluid-rich layers known as Guinness Waves (GWs) develop and kill the flow. When GWs form, the rate of fluid escape is limited not by the permeability to water in the bulk of the flow, but instead at the rate at which fluid-rich GW waves can move upwards through the flow. Upward passage of a set of GWs dewaters and freezes the flow.

So how can a HS flow move long distances? We suggest that flow-scale turbulence disrupts incipient GWs, allowing the flow to survive; a flow will move until a tipping point is reached, where turbulence can no longer disrupt incipient GWs. At this point, GWs propagate catastrophically; the flow rapidly dewaters and freezes.

We compare model simulations to core samples of the silt-dominated Wilcox formation in the deepwater Gulf of Mexico, and reinterpret enigmatic features of the observed sediment fabric as sheared Guinness Waves rather than conventional turbulent flow structures.

BREAK-DOWN OF MUD CLASTS AS A TRIGGER FOR FLOW TRANSFORMATION: LINKAGES BETWEEN MUD CLAST CHARACTER AND DOWNFLOW FACIES TRANSITIONS IN HYBRID EVENT BEDS, CLORIDORME FORMATION, QUEBEC

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◊Keynote Presenter

ABSTRACT

Keywords: hybrid event bed, mud clast, sediment gravity flow, flow transformation

Hybrid event beds provide a record of sediment gravity flows that transition between turbulent and laminar flow regimes. Most interpretations of these hybrid flows invoke incorporation of mud into the flow to trigger turbulence damping and generation of zones with laminar or transitional flow behaviour. Hybrid flow deposits span a range of bed types and characteristics, however most consist of a sandy basal unit interpreted to be deposited by a turbulent gravity flow, overlain by a matrix-rich sandstone interpreted as a linked debrite, with some beds capped by deposits from a low-density turbidity current. Questions remain as to the nature of the flow transition and whether the various parts of a hybrid event bed represent longitudinal flow fractionation versus vertical flow stratification. However, incorporation of mud appears to play a key role in flow evolution. Comminution of mud clasts may hold valuable information regarding flow transformation within hybrid flows and can provide insight into the origin of matrix content of sediment gravity flows. Here, we use a Fourier power spectra-based elliptic Fourier analysis to describe vertical and downflow changes in shapes and sizes of mud clasts within hybrid event beds of the Ordovician Cloridorme Formation, Quebec. We analyze down-flow facies transitions within these beds and present preliminary results comparing the distribution, size, and morphology of mud clasts within various hybrid event bed subdivisions. Early results show that mud clasts hold promising information regarding the dynamics of sediment gravity flows and warrant further investigation.

SYN-DEPOSITIONAL GROWTH OF SEA-FLOOR RELIEFS: BOLTAÑA ANTICLINE, AINSA BASIN, EOCENE ECHO GROUP, SOUTHERN PYRENEES

Cai Puigdefàbregas[1*◊], Julian Clark[2], Josep A. Muñoz[3], Andrea Fildani[4], Josep M. Samsó[5], and Salvador Boya[6]

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[◊]Presenter

ABSTRACT

Keywords: Basin-floor reliefs, Ainsa basin

The turbidite infill of the Ainsa basin has been extensively studied and visited over decades, but the expected connection between the Ainsa channels and the Jaca basin main lobe systems remains poorly understood because of the growth (and associated dextral rotation) of the transverse structure of the Boltaña anticline in between.

Based on field mapping of sequences, bio-stratigraphy and independently obtained magneto-stratigraphy, we propose the following succession of events:

1. The pre-growth strata within the Boltaña anticline include all the Ypresian shallow marine sequences. The corresponding deeper basin systems (Fosado and Arro) extended northward, and only marginal equivalents are preserved westwards in the Jaca basin.

2. During early Lutetian, still within the pre-growth stage and in relation to the early stages of deformation in the footwall of the Peña Montañesa thrust (the Ainsa basin floor), the Gerbe, Banastón and Ainsa systems channeled sediment from Ainsa further west into the Jaca basin.

3. The syn-growth stage (folding and clockwise rotation of the Boltaña anticline) initiated in the Middle Lutetian. Facies changes and flow directions indicate an incipient relief growth during deposition of the corresponding Murillo turbidites.

4. During late syn-growth, the Ainsa basin became gradually isolated from the Jaca basin, with a distinctive dark mud pyrite-rich horizon indicating water stratification. The youngest turbidite sequences (Grao-Guaso) were partially ponded in Ainsa. Correlatively, a distinct muddy sequence deposited west of the anticline.

5. The Ainsa basin-fill shallowed-up (Sobrarbe delta) in the Bartonian, but deeper conditions persisted to the west (Bergua turbidites). The erosional unconformity at the base of the Sobrarbe delta correlates with the MT5 below the Bergua turbidites through a deep incision on top of the Boltaña anticline at its late stages of growth.

6. Shallower and non-marine conditions capped both basins with the anticline structure buried by the Campodarbe Group.

THE ANNOT CONFINED FILL & SPILL TURBIDITE SYSTEM: FROM TRANSGRESSION TO TERMINATION

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ABSTRACT

Keywords: fill & spill, minibasins, Gres d'Annot, turbidites

The classic, well exposed Grès d'Annot turbidite outcrop area in the French Alps is a good analogue for deepwater systems in structurally active slope and basin settings. We show the paleotopographic development and fill history of a suite of linked, structurally confined deepwater mini-basins. It is possible to see how turbidity currents interacted with the topography on the basin floor and on sub-basin margins, and how this in turn controlled the distribution, thickness, quality and connectivity of turbidite sands.

A range of depositional styles can be observed, from thick, proximal units to more distal, thinner-bedded units. We can observe within each mini-basin facies and architectures changes from proximal to distal, from axis to margin and through time. We can compare how these signals vary down depositional dip from one mini-basin into the next.

We make observations from large (seismic) scale to small (core) scale. These observations may be put into the mini-basin context, and used to better understand mini-basins in the subsurface in active settings, like deepwater fold and thrust belts, rift and early post-rift settings and salt provinces. The Grès d'Annot includes a range of bed-scale deposits, such as low and high concentration turbidites, debris flows as well as slumps and slides. Architectural elements include thin and thick bedded turbidite lobe elements, turbidite channels, seismic-scale mass transport deposits and onlap margin sediment bodies.

The stratigraphic evolution of facies associations, architectural elements, stacking patterns and spatial distribution in one mini-basin can be compared with the next basin down-system. An interesting mini-basin fill & spill model emerges that reflects the complex 3D geometry of the mini-basins and the dynamic changes in degree of confinement. These outcrop observations can be used to understand sub-seismic relationships in the subsurface.

TURBIDITE FACIES TRACTS AS RELATED TO FLOW CRITICALITY AND EFFICIENCY IN TECTONICALLY CONFINED BASINS: AN OUTCROP PERSPECTIVE

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ABSTRACT

Keywords: foredeep turbidites, flow criticality, seafloor morphology, efficiency

The studies carried out on tectonically-confined foredeep turbidites of the northern Apennines, have showed that these strata can be dominated by supercritical flows and by their transformation in subcritical flows. In these turbidite systems flow decelerations related to the basin confinement and morphologies at different scales (such as slope breaks or adverse slopes associated with depositional features) can favor the formation of stratified (bipartite) flows and efficient decoupling processes, with the deposition of decelerating high-density supercritical basal flows (which may suffer hydraulic jumps) and the bypass of upper subcritical turbulent flows able to produce different types of traction structures. In these settings, the passage from supercritical high-density into subcritical low-density flows can be recorded by facies sequences characterized by four recurring facies representing four depositional phases, which are: 1) crude/spaced plane to dipping upcurrent low-angle laminations representing a supercritical phase; 2) massive to crudely-graded units with flame structures and dish water escapes recording a deceleration phase that may produce a hydraulic jump. This phase may also form mud-draped scours and hybrid beds; 3) tractive-dominated facies (tractions carpets, megaripples and ripples) recording a bypass phase; 4) thin laminated fine-grained sandstone and mud recording the bypassing turbulent flows. Depositional phases 1, 2 and 3 can be well recognized in two main facies families made of two dynamic grain-size populations (i.e. coarse to very coarse- and medium-grained sands), which are mainly deposited by high-density turbidity currents. Thus this work also wants to discuss an enlarged concept of efficiency showing that lateral and vertical distributions of the bed types described above, as well as other bed types such as hybrid or contained-reflected beds, are strictly related not only to flow characteristics but also to the confinement degree and geometry of the basin (i.e. location of structural highs and depocenters in relation to the paleocurrents).

THE EVOLUTION OF A SUBMARINE CANYON AS A SEDIMENT CONDUIT – OUTCROP STUDY OF A COARSE-GRAINED CANYON FILL ON THE BAJA CALIFORNIA PACIFIC MARGIN, MEXICO

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ABSTRACT

Keywords: canyon, bypass, incision, tectonic

Submarine canyons funnel sediment from continental shelves to deep-water via gravity currents. Such conduits are often carved by events that leave little to no depositional trace, thus the sedimentary fill of a canyon rarely represents its complete formation and evolution. Hence, when and how submarine canyons form, transfer sediment, and fill remains poorly understood.

The Late Cretaceous Punta Baja Formation represents an exceptionally well-preserved fill of a submarine canyon on an active tectonic margin. World-class outcrops provide continuous strike and dip sections of the 120 m thick and 1.2 km wide feature, with 4.5 km of continuous dip exposure.

In dip-sections, we characterise up-stream-dipping to horizontal amalgamation surfaces in axial conglomerates, with superimposed bar-forms. This architecture implies erosion and reworking by powerful flows, recording an active but backfilling conduit. In strike-sections, axial conglomeratic deposits containing canyon-wall material overlie the outboard canyon wall and heterolithic overbank deposits onlap the inboard canyon wall. These geometries record canyon evolution, from an incising and bypassing conduit, to an asymmetric aggradational system. Intervals of margin and overbank failure into the axis represent thalweg deepening, reflecting temporarily increased conduit efficiency. A stepwise outboard migration of the highly amalgamated conglomeratic axis is recorded in detail by sand-rich channel margin facies and architecture. A pulse of inboard axis migration is recorded in the heterolithic overbank stratigraphy. The uppermost canyon fill shows evidence of shallower-water reworking near the canyon wall, representing complex hydrodynamic conditions near the canyon head.

This rare exposure of a complete canyon fill and its bounding surface offers new insights into the fill of a tectonically-pinned canyon. Sediment gravity flows continued to supply, rework, and erode conglomerate in the canyon thalweg while the conduit filled, bypassing large volumes of sediment basinward.

THE TACHRIFT PROJECT: SEDIMENTARY ARCHITECTURE OF TURBIDITE CHANNEL-LEVÉE DEPOSITS (TACHRIFT SYSTEM, TAZA–GUERCIF BASIN, TORTONIAN, NE MOROCCO)

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ABSTRACT

Keywords: channel, levée, Morocco, Tachrift Turbidite System, turbidite

Turbidite channel-levée complexes have been the focus of extensive research from a number of modern and ancient deep-water turbidite systems over more than fifty years. Although high-resolution 3D-seismic studies have recently yielded unprecedented imaging of these deposits, their internal facies complexity remains elusive. To fill this gap, extensive well-exposed outcrops are particularly important, as they provide information on fine-scale facies heterogeneity.

This contribution reports on the ongoing 'Tachrift-Project', which aims to explore spectacular outcrops of several superimposed channel-levée complexes belonging to the Tachrift turbidite system (Late Tortonian) of the Taza–Guercif Basin (NE-Morocco). Arid climate and deep incision by ephemeral streams make for world-class, extensive, unexplored outcrops spread over an area of ~ 16 km^2.

The objectives of the project are threefold: (i) to document and interpret the depositional architecture of deep-water channel-levée complexes, including different types of channel-fill and levée elements; (ii) to present a generalized evolution of the channel-levée complexes, from inception to their deactivation, and (iii) to establish a model for stratigraphic geometries and facies relationships in levéed-channel complexes.

These aims are achieved through the following steps: i) geological mapping of the system; ii) reconstruction of internal architecture and facies distribution by means of closely spaced detailed sedimentological logs, bed-by-bed physical correlation and interpreted 2D and 3D cross-sectional profiles; iii) statistical analysis via an exploratory data analysis (EDA). A future development of the project will aim to create building 3D digital outcrop models of selected outcrops through photogrammetric data analyses acquired from UAVs (Uncrewed Aerials Vehicles).

Preliminary results provide valuable insights into facies and geometry of channel-fills and correlative levées over a ~150 m-thick and ~4 km wide transect largely oblique to palaeoflow, which may contribute to improving existing models of turbidite channel belt sedimentary heterogeneity and stratigraphic evolution, applied to understand the composition of subsurface analogues.

SEDIMENTARY ARCHITECTURE OF THE SUPERBLY EXPOSED CHANNEL-LEVEE COMPLEX 5 OF THE TACHRIFT TURBIDITE SYSTEM (TORTONIAN, TAZA–GUERCIF BASIN, NE MOROCCO)

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ABSTRACT

Keywords: deep-marine, channels, levees, architecture

Spectacular outcrops of Miocene aged deep-marine channel-levee complexes are exposed near Tachrift (NE Morocco), deposited adjacent to the Rifian Corridor during the Tortonian. The stunning nature of the exposures allow for detailed 3D observations of sinuous channel fills. Channel Complex 5 is exposed along ~1.5 km of NW-SE oriented, laterally continuous outcrops. Excellent outcrop quality and lateral control allows confident assessment of the sedimentary architecture, which is characterized with fifty sedimentary logs. Complex 5 is comprised of four stratigraphic units, reflecting modifications of the parent channel course. The lower unit (Unit 1) is composed of thin- to medium-bedded turbidites, forming laterally extensive, locally amalgamated and laterally accreted bedsets, fringing laterally into mud-prone heterolithics. Unit 1 is interpreted to represent frontal splays and subsequent small-scale meandering channels, with subtle muddy levees. The overlying Unit 2 is erosionally-based, thicker-bedded and bounded by well-developed sand-rich levees. It comprises amalgamated sandstones, rich in mud-clasts, which pass downstream to a sigmoidal sandstone body made of more thinly-bedded and finer grained amalgamated sandstones. Unit 2 is interpreted as the asymmetrical fill of a sinuous channel, which aggraded contemporaneously to its levees. Subsequently, Unit 3 is typified by coarser, thicker and locally amalgamated cross-stratified sandstones, featuring larger-scale sigmoidal bedding, which pass down-current to non-amalgamated sandstones with bar-like geometries. Unit 3 is characterized by an irregular top surface interpreted to reflect establishment of a meandering channel, partially infilled by accretion processes at its inner banks. Finally, the heterolithic Unit 4 onlaps the top surface of Unit 3 and is characterized by a fining-upward stratigraphy, which suggests it represents a phase of channel shut-down. The documented channel-levee architecture permits new insights into sinuous channel formation and fill, and provides a high-resolution analogue for sinuous channel systems.

WHEN THE LEVEE BREAKS: GIANT DEEP-WATER LEVEE COLLAPSE INTO THE HIKURANGI CHANNEL, OFFSHORE NEW ZEALAND

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ABSTRACT

Keywords: channel-levee, mass-transport, seismic, geomorphology

Mass-wasting of deep-water channel walls and overbank deposits is commonly reported. However, these events are typically described as small-scale, occurring when flows destabilise a channel margin. However, new insights from seafloor and subsurface datasets reveal that such mass-transport deposits (MTDs) can be large-scale, damming channels, and initiating morphodynamic feedbacks for subsequent channel flows.

Here we present 3D seismic data from the Hikurangi trench-axial channel-levee system. Identification and mapping of MTDs demonstrate numerous failures, often associated with reorganisation of the channel. One exceptionally large mass-wasting event is observed in a palaeo-channel fill, recording widespread failure of both banks of the channel along a 68 km stretch, and creating an MTD at least 19 km^3. This MTD overlies a sequence of high-amplitude reflectors (HARs), which represent sand-rich deposits on the floor of the pre-existing channel. Clasts up to 4 km long record collapse of the levees into the channel associated with erosion and deformation of earlier channel deposits, which were transported both across and down channel to form imbricated HARs. Failure horizons extend up to 5.67 km into the levees. Subsequent channel-forms have erosional contacts with the MTD, particularly in the channel axial area, such that only a portion of the collapse is preserved, preferentially at channel margins.

The scale and dynamics of this channel-wall collapse differ from any previously documented. Geologically-synchronous failure along both channel flanks suggests that an external trigger likely initiated the failures. As well as eroding and deforming potential reservoir rocks below the MTD, the topography on the MTD top controls the location of subsequent channel-fills. Hence, MTDs sourced from collapsing levees can strongly influence the architecture of deep-water channels, with consequences for fluid flow through channel fills. Furthermore, this style of mass-wasting highlights the risk to seafloor infrastructure both across channels and, importantly, on their overbanks.

FLOW INTERACTIONS WITH AN UNSTABLE SUBMARINE CANYON WALL: THE ROSARIO FORMATION, BAJA CALIFORNIA, MEXICO

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ABSTRACT

Keywords: deep marine, turbidite, architecture, submarine canyon

Flow interactions with containing surfaces, such as submarine canyon walls, can profoundly influence sediment gravity flow behaviour, and therefore depositional architecture and facies variations. Sediment gravity flows can reflect, deflect and/or pond when they interact with canyon wall topography and the rugose relief atop mass-transport deposits within the canyon. The morphology of the containing surface, coupled with its susceptibility for mass wasting, produces complex stratigraphic relationships at canyon margins that are markedly different to coeval axis environments. Understanding flow process interactions is therefore crucial for the development of process-based models for submarine canyon-fills. The Upper Cretaceous Rosario Formation provides an exceptional dip-orientated outcrop exposure that captures the interaction of sediment gravity flows with a submarine canyon wall. Using high-resolution photogrammetry, and a well-constrained stratigraphic framework provided by correlation of marker beds, we document onlap and pinch-out geometries and use facies variations to interpret flow-relief interactions. The large-scale architecture exhibits draping onlap of low-density turbidites against canyon wall mudstones, whereas sand-rich turbidites pinch-out abruptly against the intra-formational onlap surface. With proximity towards the canyon wall, the presence of biconvex and climbing-ripples with average palaeo-flow direction approximately opposing to the regional palaeo-direction, supports the formation of combined flows with flow reflection and deflection. Failure of the canyon wall generated mass-transport deposits, where the resultant relief acted to capture low-density turbidity currents, resulting in marked facies variations. Our results demonstrate how variations in autocyclic flow signals generates complicated onlap and pinch-out architectures, and how sediment gravity flow interactions with containing surfaces influences depositional character. Better understanding these flow-relief interactions will support interpretations of thin-bedded canyon-fill successions from less well constrained settings.

DEEPWATER SILICICLASTIC PROCESSES (POST-CRETACEOUS) ALONG THE SOUTH AMERICAN AND CARIBBEAN PLATE BOUNDARY: IMPLICATIONS FOR PROSPECTIVITY IN A TECTONICALLY- AND PROCESS-DYNAMIC MARGIN

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ABSTRACT

Keywords: microplastics, turbidity currents, submarine canyons, deep-sea fans

Subaqueous mass failures (MF), turbidite gravity flows and geostrophic-driven currents interact to form and fill deepwater basins around the world. The nature and timing of these fills influence not only reservoir and seal, but often control diagenesis and pressure regimes in older sediments, and establish pressure, shallow water hazards, seeps, and seafloor stability in younger sediments. The area of NE South American and the SE Caribbean Plate margin, particularly the deepwater Columbus basin, offers a dynamic setting upon which to exam these types of deposits and the processes responsible for their occurrence. Utilizing seismic and well log data in ultra-deep, tectonically- and process-active, eastern Trinidad we address the following questions:

1. What types of mass failures occur in high sediment supply fold and thrust belts, and how do they differ in character (morphometrics, erosion behavior, petrophysics)? How do they influence sedimentation? How is accommodation developed on their top surfaces and subsequently filled?
2. What role do geostrophic currents play in moving Amazonian vs Orinocan sediments to the deepwater prism, in destabilizing slopes, and in filling accommodation?
3. What is the interaction between gravity density flows and mass failures to result in the basin fills that we see in these process and tectonically active settings?

Early observations suggest leveed channel systems preferentially occupying underfilled accommodation sinks overlying mass failures. Diapiric muds up to 250 meters high on the seafloor act as buttresses forcing mass failures to thicken on the up-slope sides resulting in thinner post-emplacement sedimentation in these regions (i.e., reservoir bald spots). Large volumes of mass failures are sourced from the paleo-Orinocan shelf edge and occur along the flanks of northern thrust folds as well as off large seafloor mud volcanoes. Well data provide core, thin sections, and detailed geophysical logs to assess the petrophysical nature of these deposits.

GRAVITY FLOW DEPOSITS FROM THE CORINTH GULF, GREECE, REVEAL KEY CONTROLS ON SEDIMENT DELIVERY INTO THE DEEP SEA DURING THE LAST GLACIAL–INTERGLACIAL CYCLE

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ABSTRACT

Keywords: gravity flows, recurrence times, Corinth Rift

Deep-water deposits are considered ideal sedimentary archives of sediment delivery and their forcing mechanisms. Here we study the sedimentary record from the Corinth Rift, Greece, that was recovered during the IODP Expedition 381. The Corinth Rift comprises a spatially restricted and consistently linked source-to-sink system with very high subsidence and sedimentation rates, therefore is a unique place to study controls on sediment fluxes and stratigraphic development. We focus our analysis on the last complete glacial-interglacial cycle (upper ~180 m) from site M0079 located on the basin floor, in the central part of the Gulf of Corinth. Bed-scale analysis reveals the presence of >2500 distinctive graded beds that constitute more than half of the total stratigraphy. Graded beds vary in thickness from few mm to ~2 m, and are generally characterized by sharp, planar to erosive bases, and display fining upwards grain-size trends. We interpret these deposits to represent deposition out of low density, waning turbidity flows with the thicker beds associated to high-density turbidity currents. A high-resolution age-depth model, indicates ~89% gravity flows have a recurrence time of ~50 yr, with >70% being consecutive beds. The recurrence time between beds increases as their thickness increase. Our analysis reveals shorter recurrence times of ~70 yr during the last glacial when the Corinth Gulf was occupied by a fresh water lake. In contrast, longer times of ~200-350 yr characterize MIS5 sea-level highstands when the basin was a marine gulf. Climatic variability and associated sea-level changes can explain the observed recurrence rates rather than a tectonic controls, despite the Corinth Rift been one of the most active rifts on Earth. A prominent decline in recurrence time during the Holocene is likely related to anthropogenic activities in the broader area of the Corinth Rift.

SEDIMENT TRANSPORT OVER COMPLEX SALT AND DEEPWATER FOLDBELT TOPOGRAPHY: FILL & SPILL REVISITED IN A FULLY 3D EXAMPLE FROM THE DEEPWATER US GULF OF MEXICO

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ABSTRACT

Keywords: fill & spill, 3D seismic, salt, minibasins

Published fill & spill models focus on depositional sequences in a single 2D structural section strike to perceived sediment transport direction. However, in salt provinces and deepwater fold and thrust belts, fill & spill occurs within a strongly 3-dimensional structural topography, and the spill points change through time. This paleotopographic issue, combined with the evolution of the sedimentary deepwater sequence through time, creates a 4-dimensional challenge to predict the vertical and lateral arrangement of facies associations in a single well, in different parts of a single minibasin or across a region; with implications for reservoir quality and connectivity

We illustrate the problem with a Pleistocene-age sequence (50-100m thick), developed in a set of minibasins within a salt-detached foldbelt at the compressional toe of the Sigsbee salt canopy in Northern Gulf of Mexico. Sediment entering the foldbelt is ultimately destined for the continental rise in front of the Sigsbee.

The early sand-rich part of the depositional sequence is limited (in space) to regions where structural topography can develop, and (in time) to the topographic healing phase. As sediment flux increases, and structural topography is overwhelmed, it evolves into an erosional, then aggradational channel complex which breaks across the region, capturing all the drainage. This channel is not spatially coincident with the early sand-rich depositional region.

This evolution happens rapidly in an active fairway with high sediment flux, and therefore the major aggradational channel systems and associated MTCs tend to dominate the Pleistocene stratigraphic record, obscuring, and in places eroding, the earlier stages of sequence development, which commonly contain the best-connected sand-rich reservoirs.

TURBIDITES, REWORKED TURBIDITES AND CONTOURITES: DIAGNOSTIC CRITERIA AND IMPLICATIONS

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ABSTRACT

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

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, which represent major depositional systems on the continental margins and the adjacent abyssal plain in many of the world's oceans. A recent proliferation of both academic and industry research on deepwater sedimentation documents significant advances in the understanding of these systems, but most non-specialists remain unaware of their features in question and how they form. A paucity of examples in the ancient record and the lack of consensus on diagnostic criteria, to characterise and differentiate them from other deepwater deposits limit our understanding of how they may record past processes as global oceanic circulation, tectonic events and gateway evolution, among others. In this work example 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 allow the discrimination between deepwater facies as contourites, pelagites/hemipelagites, turbidites, reworked turbidites and mass-transport (MTDs) 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 primary sedimentary structures, microfacies and ichnological features as the best diagnostic criteria to distinguish reworked turbidites and 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 depending on paleoenvironmental conditions, especially current velocity and sedimentation rate. Petrophysical properties of such deposits can making them relevant as reservoirs in the context of energy geosciences.

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SEDIMENTARY ARCHITECTURE OF SUBMARINE LOBES AFFECTED BY BOTTOM CURRENTS: INSIGHTS FROM THE ROVUMA BASIN OFFSHORE EAST AFRICA

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ABSTRACT

Keywords: submarine fan, mixed turbidite–contourite system, sedimentary stacking pattern, SW Indian Ocean

The influence of bottom currents on submarine channels has been widely recognized, for instance by the formation of asymmetric channel-levee systems and drifts. In contrast, it is often considered that submarine lobes can be reworked by only strong bottom currents and are not affected by bottom currents during their deposition. In this study, we analyze the effect of bottom currents on different hierarchical lobe architectures that formed during the lower Oligocene in the Rovuma Basin offshore East Africa. We characterize the morphology and stacking patterns of different hierarchy lobes using well data and three-dimensional seismic data. We find that lobe complexes and single lobes show a unidirectional stacking pattern that is opposite to the direction of bottom currents. Lobe elements in single lobes display vertical accretion with no obvious relationship with bottom currents. Additionally, single lobe morphology presents an asymmetric shape, with a thicker lobe margin on the downstream side of the bottom currents. The architectural distribution reflects that the asymmetrical topography present before the depositions of the submarine lobes was controlled by previous channel-levee systems formed by the synchronous interaction of bottom currents and gravity flows. This topography controls the subsequent deposition of lobes and results in the migration of single lobes in the upstream direction of bottom currents. The results demonstrate that although weak to moderate bottom currents may not be able to rework submarine lobes, they may control the geometry and evolution of submarine channels and thus indirectly affect the thickness and migration of lobes in more environments than previously thought.

SEDIMENT WAVES AS A TOOL TO UNDERSTAND DEEP-WATER CURRENT EVOLUTION, SENEGAL BASIN, NW AFRICA

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ABSTRACT

Keywords: sediment waves, Senegal basin, bottom currents, early Cretaceous

Sediment waves have been first identified in 1950s using high resolution seismic profiles and believed to be generated by bottom water currents. But with the advance of geophysical methods such as scan sonar and multi beam and more cores sampling the waves, it is now widely accepted that sediments waves can be generated by bottom water or turbidity currents with an emphasis on the latter (Wynn & Stow, 2002).

The 3-D seismic data located offshore Senegal revealed the presence of sediment wave fields of different ages. The aim of this study is to describe their seismic facies and morphological and lithological characteristics using seismic interpretation, seismic attribute analysis and spectral decomposition, understand their origin with the aid of quantitative analysis and finally discuss the deep-water processes dominating the Cretaceous.

At least five different sediment wave fields have been recognised offshore Senegal during Cretaceous: one being in early Cretaceous (Valanginian to early Albian), two in Albian and two in Cenomanian intervals. The long-lasting presence (~ 30 Ma), the areal extent and the wave characteristics of Late Valanginian-Early Albian sediment wave field suggest that bottom currents were initiated in Early Cretaceous in Central Atlantic. Taking into account their size and shape and the presence of turbidity related features such as channels and lobes, we concluded that Albian-aged sediment waves are deposited in a down-slope current dominant environment. The RMS amplitude and spectral decomposition slices generated for Cenomanian sediment wave field interval reveals that they are not related to any apparent downslope or upslope turbidity generated feature. This implies the presence of contour currents in the area during Cenomanian time. Moreover, Cenomanian wave field differs in size and shape from previously deposited sediment wave fields in the area which strengthens the presence and dominance of the along slope currents during that time.

QUANTIFICATION OF THE BED-SCALE ARCHITECTURE OF SUBMARINE DEPOSITIONAL ENVIRONMENTS

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ABSTRACT

Submarine channel and fan deposits form the largest sediment accumulations on Earth and host significant reservoirs for hydrocarbons. While many studies of ancient fan deposits describe architectural variability along 2D transects (e.g., axis-to-fringe, proximal-to-distal), these relationships are often qualitative, and are rarely quantified at the event-bed scale. In order to enable quantitative comparison of the fine-scale architecture of submarine depositional environments, we digitized 56 bed-scale outcrop correlation panels from five broadly categorized environments (channel, levee, lobe, channel-lobe-transition-zone, basin plain). Measured architectural parameters (bed thickness, bed thinning rates, lateral correlation distance, net-to-gross) provide a large (n=28,525) and statistically robust framework to compare event-bed architectures within and between environments.

'Thinning rate' data (i.e., the lateral rate of change of bed thickness) clearly differentiate deposits from different submarine depositional environments, helping to quantify generally-accepted models for proximal-to-distal evolution of stratigraphic architecture. The thinning rates of sandstone beds and mudstone-dominated intervals vary predictably between environments. For example, the highest sandstone thinning rates occur in channel deposits (0.2-6 cm/m; P10 and P90 values here and below) and decrease to lobe (0.1-1.6 cm/m), channel-lobe-transition zone (0.2-0.9 cm/m), levee (0.0024-0.078 cm/m), and basin plain deposits (0.000017-0.0054 cm/m). These quantitative relationships provide valuable insights for downslope flow evolution and the construction of stratigraphic architecture in submarine settings. Due to intra-environment variability, net-to-gross is highly variable and thus (when considered alone) are not a diagnostic indicator of depositional environment. Submarine lobe deposits show the most variability in event bed thickness, thinning rate, and net-to-gross, likely due to the inherent facies variability and differing boundary conditions. To explore this variability, we sub-classified lobe deposits based on position (proximal, distal) and effective confinement (unconfined, semi-confined, confined) to provide a more detailed sub-environment analysis. Unconfined lobe deposits show a proximal to distal increase in sandstone thickness and decrease in mudstone thickness, supporting conceptual models. Confined lobe deposits have thicker sandstone and mudstone beds and lower net-to-gross values as compared to unconfined and semiconfined lobes, supporting a sediment trapping mechanism by confinement.

These quantified bed-scale parameter comparisons enable the recognition of architectural similarities and differences within and between environments, demonstrating the need for more quantitative studies of bed-scale heterogeneity. The results from this study are immediately applicable to parameterizing forward stratigraphic models, constraining property distribution in reservoir models, and probabilistic determination of depositional environment from outcrop and core descriptions of submarine depositional environments.

CURRENT-CONTROLLED SEDIMENTATION IN SOME OF THE ROUGHEST OCEANS: THE DRAKE PASSAGE AND THE ARGENTINE BASIN

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ABSTRACT

Keywords: deep-marine environments, contourites, bottom currents, ocean circulation

Ocean currents strongly control sedimentation and shape the seafloor in many areas of the world. The Drake Passage and the Argentine Basin are characterized by strong currents at all water depths and in general, they among the areas with the largest bottom eddy kinetic energy in the global ocean. However, when analysed at a more regional scale, there are clear spatial differences in the intensity and variability of bottom currents that are crucial for the development of contourite depositional systems. In this study, we compare the distribution and characteristics (morphology and grain size) of contourites with bottom currents in the Drake Passage and in the Argentine Basin. We use sediment cores, seismic reflection data and multibeam bathymetry to analyse the sedimentary systems. We identify water masses using hydrographic measurements (salinity, temperature and oxygen) and current velocity using direct measurements from acoustic Doppler profilers, when available. Since current measurements are scarce and limited in space and time, we use the longest time series available from 27-years GLORYS12 Mercator Ocean reanalysis at high resolution (1/12°) to evaluate the bottom current dynamics at a regional scale. In the Drake Passage, the patterns for the first modes of bottom-current variability are related with the local topography. Main sediment accumulation occurs in zones with weak and stable bottom currents, but the topography in the Drake Passage is often very irregular, with abundant seamounts and fracture zones that favour the formation of small-scale contourite deposits. In contrast, in the Argentine Basin, contourites dominate almost the entire seafloor, ranging from a series of terraces and plastered drifts on the continental slope, to the large Zapiola drift in the abyssal plain. The Zapiola drift is separated from the continental slope by an abraded surface, a zone characterized by fast and highly variable bottom currents. Bottom currents above the Zapiola drift are weak and stable.

OCEANIC CIRCULATION IN A TIDE-DOMINATED SUBMARINE CANYON (BAY OF BISCAY): IMPLICATION FOR TRANSIENT SEDIMENT TRANSFER AND COLD-WATER CORAL REEFS

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ABSTRACT

Ocean circulation and trapped waves generated inside submarine canyons (e.g. tides, inertial waves, internal waves, upwellings, cascading) are a set of hydrodynamic processes induced by the local interruption of the geostrophic balance driving currents along the continental margins. Turbulent enough to suspend sediments, they contribute to maintain slope morphologies, to transfer sediment to the deep sea and may occasionally generate turbidity currents.

Turbidity currents are rightly considered the main process to transfer sediment from land and the continental shelf to the deep sea where they build-up the larger sediment accumulations of the planet. The final fate of these turbidity-transported sediments and associated elements is modulated by the interaction with the open oceanic geostrophic circulation when the canyon-channel system becomes relatively unconfined, building up sedimentary depot-centres along the margins relatively more dispersed than abyssal fans.

Although some turbidity currents are an effective transfer process, they are not always able to travel all the way. Their deposits may be temporarily trapped inside canyons until major events pick and flush them down. These transient deposits, together with the (hemi)pelagic sedimentation favored and collected in the vicinity of canyons, may also be diffusely but certainly transported by the internal oceanic circulation in canyons. This weaker but continuous sediment transport, especially in rapid transient conditions and climate, may be determinant of deep sea environmental conditions and for the preservation of habitats, such as cold water coral reefs. In some aspects oceanic processes inside submarine canyons and the associated sediment transport may be key.

Focusing on the Lampaul submarine canyon (where coral reefs are present) and the data from the CheReef cruises, we add data from 2 other French submarine canyons (Cassidaigne, Capbreton) to set up a discussion on the forcing of oceanic circulation in canyons and their role in sediment transfer to the deep sea.

THERMOHALINE VERSUS GRAVITATIONALLY INDUCED SEDIMENT WAVES: DIFFERENCES AND SIMILARITIES

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ABSTRACT

Keywords: contourite cyclic step, abyssal dune, sediment wave

The abyssal realm is both the largest and least understood depositional environment on Earth. To better understand its sedimentological and geomorphological characteristics, we compile high-resolution bathymetry and seafloor penetrating sonar data to visualize a range of deep water bedforms. These compilations show that abyssal depositional systems contain a variety of sediment waves, which can develop under the action of thermohaline or gravitational processes. For example, continental slopes commonly contain upward migrating sediment waves that are probably formed by episodically active gravitational processes, while the abyssal plain contains continuously active sediment waves that migrate along the dominant thermohaline current. The latter type of sediment waves are herein characterized as abyssal dunes, that exist in transverse, linear, barchan, and isolated morphologies, much like aeolian dunes. In contrast, gravitationally induced deep water sediment waves are generally transverse in geometry and form in the same way as cyclic steps. In order to better distinguish these different types of deep water sediment waves, we formulate five geometric distinctions between cyclic steps and abyssal dunes: 1) Fields of cyclic steps form on steep continental slopes, while abyssal dunefields typically form on relatively level surfaces like the abyssal plain. 2) Fields of cyclic steps are narrowest at the top of the slope and become progressively wider towards the basin floor, while abyssal dunefields have no overall trend in their shape. 3) The apex of a cyclic step dunefield commonly contains a channel geometry that forms in association with the gravity flows that drive these bedforms. 5) The crests of cyclic steps are typically located on the trailing side of the bedform, as opposed to the forward facing dune crests of abyssal dunes. This difference marks a backward migrating trend of cyclic steps as compared to a forward migrating trend of abyssal dunes.

DEPOSITIONAL ARCHITECTURE OF THE LATE PLEISTOCENE DANUBE FAN

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ABSTRACT

Keywords: Black Sea, Danube Fan, deepwater, turbidite, levee, channel, lobe, MTC

The Late Pleistocene Danube Fan is an exceptional fan analog because of the large amount of published data, and because it is sufficiently small that single seismic lines can traverse it. Using published seismic and newly released seismic lines a complete and updated architecture of the entire fan is now possible. The seismic facies are calibrated with Ifremer drop cores and cored analogs from other similar fan.
The fan has four depositional facies:

Mass Transport Complex (MTC): A chaotic deposit resting on the sequence boundary.
Channels fills: mostly confined by levees, and likely very sandy.
Levees: Both large and small, ranging from all mud to heterolithic.
Lobes: Lobes formed by unconfined flow following an avulsion, and deposits at the terminal ends of channels. They are sandy based on analogs and seismic response.

The fan, exclusive of the MTC, has three major morphologic zones.
Proximal Zone: Exclusively on the slope consisting dominantly of a single channel flanked by large levees up to 600 meters thick and 40 kilometers wide. Cores through the levees reveal they are composed of finely laminated mud interpreted to be deposited by turbidity currents that overtopped the channel. This zone extends from the shelf edge to the toe of slope at approximately 1,400 meters deep.
Medial Zone: This zone is composed of large channel/levee complexes that formed as the result of a few large-scale avulsions. Levees decrease in size distally along the channel paths from 40 to 5 kilometers wide. Levees also become increasingly sandy distally. This zone extends from approximately 1,400 meters to 2,000 meters deep.
Distal zone: This zone is dominated by terminal lobes overlain by small channel fills with heterolithic small levees. Many avulsions result in compensationally stacked level/channel/lobe complexes interpreted to form fining upward successions from the sandy lobe to the overlying levee.

AUV HIGH-RESOLUTION BATHYMETRY OF AXIAL-TRANSVERSE DRAINAGE INTERACTION IN THE STRUCTURALLY CONTROLLED SUBAQUEOUS CHANNELS IN THE GULF OF CORINTH, CORINTH RIFT, GREECE

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ABSTRACT

Keywords: deep-water, AUV, axial and transverse submarine channels, Gulf of Corinth

New high-resolution (submeter) bathymetric data, acquired using an AUV Hugin 1000, from the Gulf of Corinth, Greece reveals unprecedent detail on the interaction between transverse and axial submarine channels in an active rift. The dataset presented was acquired using the EM2040 Multibeam Echosounder on the AUV at 300 and 400 kHz, navigating between 100 and 50 m above the seafloor. The surveyed area lies towards the western part of the Gulf of Corinth, offshore of the coastal towns of Aigio and Akrata. The area is characterized by the development of coarse-grained deltas sourced by north-flowing rivers draining the mountain ranges. The seafloor morphology shows the presence of active canyons, ca. 100 m deep, draining from the delta fronts towards north in water depths between 100 to 600 m, interacting with an axial trunk channel in water depths between 550 to 650 m, draining towards east, and which looses its expression in water depths between 700 and 800 m. These submarine channels show a strong structural control in both position and orientation by the normal faulting affecting the present-day Gulf of Corinth sea-floor. This survey includes the mapping of the three submarine tributaries derived from the Soulinous, Kerinitis and Vouraikos deltas and their link into the axial trunk channel. The survey shows the presence of large erosional scours in the axial channel, at the confluence with of some of the tributaries. This, together with the pervasive erosional features developed on the axial channel base and margins towards its exit onto the basin-floor, reveal the development of complex erosive flow patterns due to changes in the gradient of the sea-floor and the orientation of channel margins at the confluences between the tributaries and the axial channel.

FIRST DIRECT OBSERVATIONS OF A SUBMARINE LANDSLIDE (HOMATHKO DELTA, BC, CANADA)

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ABSTRACT

Keywords: submarine landslide, turbidity current generation, ocean-floor monitoring, delta-lip failures

Every year ~19 billion tonnes of river-derived sediment arrives at the world's deltas, where the sediment either remains parts of the delta, or is later remobilised and transported further toward the ocean floor. Understanding the processes that control remobilisation is therefore key to quantify the sedimentary fluxes of organic carbon, nutrients and pollutants to the ocean basins. One of the processes that remobilises deltaic sediment are submarine landslides. Although the resulting landslide scars of such landslides on the sea floor are well-known, such landslides had never been observed in action. Direct observations of submarine landslides are key as they enable the testing these different landslide models.

In August/September 2022, we setup a sensor network on the delta front of the Homathko Delta (BC, Canada) to monitor a submarine landslide. We used four anchors to moor a boat with suspended sonar instruments above the transition from the river to the delta front. We kept the boat moored for a full spring-neap tide cycle, and every day we mapped the delta front. This setup enabled us to collect the first monitoring data that captures a submarine landslide occurring. We observe how over a 30-min period a series of smaller retrograding landslides eventually build a large landslide scare. The daily sea floor maps showed that the submarine channel downstream of the submarine landslides had been activated. Additionally, a turbidity sensor deployed 2km further down the submarine channel also9 detected a sediment density flow just after the submarine landslide.

These first observations of a submarine landslide provide proof-of-concept that submarine landslides can be measured. Hopefully, these observations also provide valuable insight in the failure mechanisms that link terrestrial and oceanographic sediment transport processes.

HOW CHANNEL–LOBE AND INTRA-CHANNEL TRANSITION ZONES CONTROL THE DEPOSITIONAL ARCHITECTURE OF MODERN TURBIDITE SYSTEMS ON A DECADAL SCALE

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ABSTRACT

Keywords: turbidite, turbidite architecture, bounding surface hierarchy, channel–lobe transition zone

The stratigraphic architecture of turbidite deposits is a product of external forces (allogenic) such as sea-level changes combined with internally generated environmental processes (autogenic), such as channel avulsions. Heterogeneities in the stratigraphic architecture affect depositional connectivity on different scales. These heterogeneities in the fine, metric scale are generally associated with complex sedimentary processes. Discontinuous deposits (such as in channel-lobe transition zones) produced by such sedimentary processes can have important consequences on palaeoenvironmental reconstructions and the efficiency of resource management in subsurface reservoirs. The nature, time and continuity of the bounding surfaces limiting these fine-scale depositional architectures are essential in defining the depositional hierarchy, which is key to identifying short-term cyclicities in ancient systems. Previous studies on modern turbidite systems have identified complex alternations of erosion and deposition on an intra-system scale, however, their consequences for stratigraphic and hierarchical studies remained to be explored. Here, we analyse successive (months to decades) seafloor maps in two active turbidite systems. We show two types of spatial cycles of sedimentation (type I and II) formed by alternations of erosion, bypass and deposition to produce transition zones that separate well-defined deposition zones on the intra-system scale. These transition zones are shown to control the basal diachronic stratigraphic surfaces, the fine-scale architecture and the connectivity of turbidite deposits. We found that these transition zones that occur before the final transition of the channel into the lobe can occur multiple times. Furthermore, we found different architectures for seasonal and decadal time scales reflecting different flow power. Our results demonstrate a short-term autogenic mechanism of creation and consumption of accommodation space independently of allogenic forces which control the short-term stratigraphic record.

CONFIRMATION OF CENTURY-SCALE SEQUENCES IN THE DEBRIS-FLOW-DOMINATED NAHAL DARGA DELTA, DEAD SEA, ISRAEL

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ABSTRACT

Keywords: debris flow, century-scale sequence, delta, Holocene

Mass flows from the Judean Highlands deposit delta forests into the Dead Sea with sufficient speed to preserve century-scale sequences. Sequences are known to form at millennial time scales, but whether they can form at scales as short as centuries (7th-order *sensa* Vail, et al. 1991) was previously unconfirmed. This study uses subaqueous ROV footage of the Dead Sea bottom to define mass flow deposits on the actively depositing front of the Nahal Darga delta on the western Dead Sea rift margin. These constitute the first detailed maps of the Dead Sea floor thusfar produced. The study also maps lithofacies and sequence-stratigraphic surfaces from an ~35 m high outcrop of the post-1500 AD part of the dissected Holocene Nahal Darga falling-stage wedge using drone images. Delta foresets form by debris-flow lobes accreting onto the delta face. Debris lobes are long and narrow down slope with aspect rations over 10, increase in size with depth, have sorted cobble heads, and stack compensationally. Debris lobes dewater to form mostly erosive turbidity currents that cut channels and obstacle scours down slope from debris-lobe heads. Steep delta forests are prograded by topsets comprising fluvial, beach-ridge, and lagoonal deposits to form a Gilbert delta. Surfaces separating foreset and topset elements of this delta wedge bind systems tracts and record down-step and up-step of the shoreface associated with base-level rises and falls. These surfaces match known lake-level changes in the Dead-Sea in magnitude, timing, and direction. They confirm Medieval (~600 – 1300 AD) and Modern (~1300AD – Modern) century-scale sequences. These microsequences form in the Dead Sea because this climate-sensitive lake can generate meters-scale lake-level cycles on century scales, and because depositional systems can respond and form systems tracts at decadal scales. This confirms depositional systems can respond sufficiently rapidly to record century-scale cycles with complete systems tracts.

TURBIDITY CURRENT–CONTOUR CURRENT INTERACTION ACROSS SUBMARINE CHANNELS: THE EFFECT OF CHANNEL ASPECT RATIOS ON FLOW INTERACTION

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ABSTRACT

Keywords: mixed systems, 3D velocimetry experiments, flow interaction, channel recirculation

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 dynamic water masses, resulting in a combined flow field, forming e.g. a mixed turbidite-contourite system. These combined flows deposit large volumes of sediment on 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 flow interaction and sediment transport in these flows are scarce and diagnostic criteria linking processes to deposits are not established. Various conceptual models, mainly based on the interpretation of deposits, have now been published that 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 facility of Utrecht University. Channel depth relative to the flow depth is expected to be an important parameter because it determines the degree of confinement of the turbidity current. More confined systems such as canyons will likely experience a different type of interaction than partially or not confined flows. We therefore measured the combined flow field across sub-marine channels of 3 different depths. Results show that contour currents prevent overspill onto one side of the overbank area by keeping a lateral turbidity current front fixed in place. A secondary circulation establishes with flow against the contour current direction at bed level. The velocity maximum is displaced from the channel thalweg. We aim to use these experiments to strengthen mixed system depositional models.

HOW ARE SLOPE CHANNELS AFFECTED BY BOTTOM CURRENTS?

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ABSTRACT

Continental slopes are widely if not universally affected by geostrophic currents of various strengths, so gravity-driven systems such as slope channels that traverse the slope are inevitably affected by them. This can either involve direct interference between the concurrent downslope and along-slope currents themselves, or slight to radical remoulding of channel-related gravity flow deposits on time-scales ranging from the intervals between individual gravity current events, O(10^{-1} to 10^{1}) years, to the alternations between low-stand and high-stand systems tracts, O(10^{4} to 10^{6}) years.

I briefly show two cases. The first is where the paths of late Miocene slope channels have been determined by topography generated by pre-existing contourite sediment waves, and whose subsequent evolution through the rest of the Miocene has most likely been determined by interaction with contemporaneous contour currents. The second case is from the levees of slope channels, of which I show examples from two Late Cretaceous systems (Arroyo San Fernando, Baja California, Mexico, and Torres del Paine, Ultima Esperanza, Chile), where the dominant palaeocurrent direction indicated by ripple cross-lamination in the levees is towards the channel, and parallel to the presumed slope, despite unequivocal evidence from decay in mean bed thicknesses and sand content that the levees were formed by overspill in the opposite direction from the adjacent channel.

Thin-bedded turbidites on levees often show a marked sharp grain-size break between sand and silt, typically at the top of a set of current ripples. The evidence from these two systems suggests that the sharp grain-size break that is so common in levee turbidites is the result of re-working of the surface of the levee by weak contour currents between turbidity current overspill events, and that it is these continuous and relatively weak bottom currents are responsible for the ripples at the tops of the levee sands.

A DIMENSIONLESS FRAMEWORK FOR PREDICTING SUBMARINE FAN MORPHOLOGY

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ABSTRACT

Observations of active turbidity currents at field scale offers a limited scope which challenges the development of theory that links flow dynamics to the morphology of submarine fans. Here we offer a framework for predicting submarine fan morphologies by simplifying critical environmental forcings such as regional slopes and properties of sediments, through densimetric Froude (ratio of inertial to gravitational forces) and Rouse numbers (ratio of settling velocity of sediments to shear velocity) of turbidity currents. We leverage a depth-average process-based numerical model to simulate an array of submarine fans and measure rugosity as a proxy for their morphological complexity. We show a systematic increase in rugosity by either increasing the densimetric Froude number or decreasing the Rouse number of turbidity currents. These trends reflect gradients in the dynamics of channel migration on the fan surface and help discriminate submarine fans that effectively sequester organic carbon rich mud in deep ocean strata.

PHYSICAL MODELING OF THE IMPACT OF CHANGING SLOPE-TO-BASIN MORPHOLOGY ON THE EMPLACEMENT, EROSION, AND TRANSPORT OF SEDIMENTS BY ALONG-SLOPE CONTINUOUS CURRENTS

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ABSTRACT

Keywords: physical modeling, sedimentology, geomorphology, bottom currents

The importance of geostrophic currents moving sediments along shelf margins, the continental slope, and the ocean floor is acknowledged as a critical process to understand, however direct observations of deep-ocean currents (CC) and their deposits continue to be rare, difficult to record, and expensive. Physical experiments provide a means to test assumptions about CC processes and how they are expressed in outcrop, wellbore, and seismic reflection data.

The Continuous Bottom Current Flume was used in this study as an analogue “similarity of process” modelling facility (Hooke, R.L., 1969), to investigate how continuous bottom current morphologies and their deposits are impacted as they move along different continental slope-to-basin transition angles. While other laboratory studies have examined CC characteristics and flow velocities, no study has imposed CC flow parallel to the slope-to-basin transition. In our study, three experimental designs were tested utilizing 10°, 30°, and 50° lower continental slopes; with corresponding 170°, 150°, and 130° slope-to-basin transition angles. Currents were maintained at dynamic equilibrium velocities and sediments were introduced to create a depositional foundation for currents to build and erode.

Results show that an increase in the slope-to-basin transition angle results in increasing sinuosity of the toe-of-slope moat and the development of CC-transported deposits and bedforms with travel much further up the continental slope. Sinuosity of the moat is also seen to increase where separate water masses join to create turbulent eddies. Moats can be totally constructional without the need for erosion to form. A decrease in the slope-to-basin transition angle results in an increase in base-scalar flow speeds, a decrease in moat width, and an increase in mass failures along the slope side of the moat, especially under conditions of steeper slope angles. The later process results in the introduction of mass failure sediments to adjacent regions of the moat.

FLOW BEHAVIOUR OF UNCONFINED TURBIDITY CURRENTS INTERACTING WITH CONTAINING TOPOGRAPHY AT DIFFERENT INCIDENCE ANGLES

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ABSTRACT

Keywords: unconfined turbidity current, containing topography, incidence angle, slope gradient

Seafloor topography influences turbidity current behaviour, leading to distinctive turbidites. Understanding the interaction between turbidity currents and topography is critical for the prediction of sediment distribution and reconstruction of the physiography of deep-water basin-fills. The wide range of flow regimes, and topographic configurations, means that experimental approaches are needed to advance our understanding. However, previous experimental studies have been conducted in narrow 2D flume tanks or in large 3D tanks with partially containing topography. Here, we perform 18 scaled 3D physical experiments in unconfined settings where the flow is fully contained by a rigid confining slope. This set-up allows investigation into the effects of different topographic configurations, incidence angle of the current to the slope, and slope gradient, on flow behaviour. Key results include: (i) a lower incidence angle results in decreased flow divergence and collapse on the slope surface, weaker basal flow reversal, more intense flow deflection relative to flow reflection and lower maximum run-up height; (ii) a steeper slope results in decreased flow divergence and collapse on the slope surface, stronger basal flow reversal and more intense flow deflection relative to flow reflection. The maximum run-up height for a slope of 30˚ is higher than that for a 20˚ slope, which paradoxically is higher than that for a 40˚ slope, when the incidence angles are kept uniform; (iii) the influence of incidence angle with containing slopes is stronger than that of the slope gradient on the flow behaviour; and (iv) all configurations result in complicated flows patterns, including the presence of combined flow regimes on the slope. Results provide insights into the development of distinctive bedforms, such as hummock-like bedforms, and sediment distribution pattern, especially the process controls on 3D onlap termination styles, which can be applied to the interpretation of exhumed successions.

SHAPE-DEPENDENT SETTLING VELOCITY OF SKELETAL CARBONATE GRAINS: IMPLICATIONS FOR CALCITURBIDITES

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ABSTRACT

Keywords: calciturbidites, carbonate grains, experiments, settling velocity

Particle transport and deposition in turbidity currents is governed by the balance between turbulent suspension and gravitational settling, with settling velocity becoming dominant during the final rain-out phases of decelerated turbidity currents on lobes. For turbidites of carbonate composition, existing models do not fully incorporate the complexity of the hydrodynamics of irregular skeletal grains. Differential particle settling velocities play a role in the sorting of grains in turbidity currents. There is a preference of grains with higher settling velocities to be deposited first, yielding a settling-velocity gradient in vertical and longitudinal cross sections through turbidite beds. If sediments contain little variation in particle shape and density, such as typical for siliciclastics, then settling velocity is dominantly controlled by grain size. Carbonate sediments, in contrast, are composed of non-skeletal and skeletal grains, complete specimens and/or fragments, with various growth structures, producing a wide distribution of particle shapes. Similar-sized skeletal carbonate grains may therefore settle at very different rates, while particles of different size may settle together. This work aims to constrain the extent to which shape-dependent differential settling velocities influence sorting mechanisms in carbonate turbidity currents. Experiments using natural skeletal sand were conducted to investigate the settling of carbonate grains in (i) isolation, (ii) vertically-settling suspensions, and (iii) turbidity currents. Size, density and shape parameters were analysed using high-resolution micro-CT. It was found that the effect of particle shape on the sorting mechanism operating in carbonate sediment suspensions becomes increasingly significant as grain size increases, in particular above medium sand. Carbonate turbidites may therefore be poorer sorted than siliciclastic turbidites, which is expected to result in lower primary porosity in calciturbidites compared to siliciclastic turbidites.

WHAT SIGNALS CAN DEEP-WATER FAN STRATA RECORD?
A NUMERICAL EXPERIMENT ANALYSIS

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ABSTRACT

Keywords: allogenic, autogenic, modelling

Understanding how external signals are preserved to be present or absent in strata is an important aspect of deciphering Earth history. Key questions are the type of signal most likely to be preserved, and how input signals may be shredded, over-printed or otherwise reduced before preservation, by stochastic or autogenic processes. Here we show that Lobyte3D, a reduced complexity numerical forward model of down-slope sediment erosion, transport and dispersive deposition of submarine fan strata, produces reasonably realistic strata that can be robustly analysed for signal content across model realisations with a range of external forcing amplitudes and periods. Three different initial topographic surfaces with increasing influence of random noise also allow comparison of the signal preserved with different levels of random influence on the deterministic model. Spectral analysis with rigorous testing for statistical significance shows that the signal recorded depends strongly on the level of noise present in the underlying topography, and complex autogenic dynamics in the model have the potential to mask even long-period high-amplitude input signals. This analysis suggests that we might be substantially underestimating the complexity involved in extracting a signal of external forcing from deep-water submarine fan strata, and potentially any strata where autogenic processes operate, to the extent that the two different effects may be practically indistinguishable.

LINKING SEDIMENTARY PROCESSES, DYNAMICS, AND THE CREATION OF STRATIGRAPHIC PATTERNS THROUGH COMPUTATION

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ABSTRACT

Keywords: computational stratigraphy, process-based modeling of deep-water depositional systems, controls of deep-water fan morphology, avulsion types and deep-water channel formation

A fundamental application of stratigraphy is to enable predictions of rock properties away from wells. Sedimentary deposits are archives of physical processes on the Earth's surface; identification and linkage of these processes to stratigraphic patterns provides a framework for subsurface prediction.

Computational stratigraphy (*CompStrat*) are forward depositional models based on fundamental physics of fluid dynamics and sediment transport. Depositional processes in all siliciclastic environments can be simulated, including fluvial, shallow marine (both tides and waves), and deep water. Input and boundary conditions can vary in time and space to simulate extrinsic controls. The simulation results are in alignment with data from outcrops, well logs, cores and high-resolution seismic.

Using *CompStrat*, we linked flow and sediment transport processes to emergent geomorphologies and predictable stratigraphic patterns at multiple scales. Specifically, flow, sediment concentration, and basin topography can be linked directly to the growth of deep-water fans that are predominantly sheet, channel lobe, or distributed channel systems. In sheet deposits, the higher flow region shifts in space resembling the shift of flow paths due to avulsion in distributive channel systems, though in a more continuous and gradual manner. This results in compensationally stacked lobes with significant spatial continuity. Stratigraphically, the slow and continued shift of the high flow region leads to upward-fining grain size distributions at one location, but continuously transition to upward-coarsening at another location for the same sheet deposit. In linked channel-lobe systems, flow expands more rapidly from channels, developing more finger-like lobes as the terminal channel mouth gradually extends further into the basin. In distributed channel systems, avulsion occurs at multiple scales, leaving complex but organized stratigraphic patterns. This investigation of the linkage between simulated depositional processes and the resulting stratigraphic deposits enhances our understanding of patterns and properties present in subsurface data, enabling more robust predictions away from wells.

RE-EVALUATING THE HETEROGENEITY IN DEEPWATER FANS FROM OUTCROPS AND THE SUBSURFACE: INSIGHTS FROM COMPUTATIONAL STRATIGRAPHY

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ABSTRACT

Keywords: fans, heterogeneity, outcrop, computational

Deepwater fans are key targets for conventional and unconventional development and more recently a critical focus for CO_2 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 highlighting distinct variations 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 CO_2 sequestration.

Here, we present an integrated study linking key heterogeneities in well-studied 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. We apply these learnings to outcrop (e.g., Karoo, Ross) and subsurface (e.g., Gulf of Mexico) data, to (1) re-evaluate and improve recognition of the channelized, transitional, and sheet-dominated areas within fans, (2) link 1D (well/core) patterns to 3D spatial heterogeneity, and (3) assess the implications on 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 robust development-strategy optimization, requires deepwater fans be characterized and modeled as complex but with predicable heterogeneities that vary across multiple levels of stratal hierarchy.

QUANTITATIVE EVALUATION OF DEEPWATER FAN HIERARCHY: INSIGHTS FROM FULL PHYSICS BASED FORWARD STRATIGRAPHIC MODELS

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ABSTRACT

Keywords: process, hierarchy, modeling, clustering

The identification of deepwater fan systems as hierarchical has improved the predictability of rock property distributions from sparse (well log) and low resolution (seismic) datasets. Underlying the definition of geologic hierarchy is the assumption that units within a level of the hierarchy (e.g., elements) display similar characteristics while units across hierarchical levels (e.g., elements vs. complexes) display different characteristics. Therefore, within a deepwater fan complex, we expect elements to have similar geometries, property distributions (e.g., net-to-gross), and spatial transitions (e.g., channel axis to channel off-axis). Due to the limited resolution and spatial coverage of subsurface datasets and the incomplete nature of outcrop datasets, quantitative validation of hierarchy within deepwater fan systems and associated conceptual models has been limited.

Recent advancements in forward stratigraphic modeling (i.e., computational stratigraphy) provide ideal datasets to quantitatively evaluate element-scale hierarchy using high resolution, fully sampled models of deepwater fan systems. In this work, we apply an unsupervised machine learning workflow to elements interpreted within a deepwater fan to test the scale-dependent consistency in reservoir volumes and properties (e.g., net-to-gross, sand quality, thickness).

Specifically, this approach assigns a label (cluster number) to each element identified within the deepwater fan complex, from which we evaluate map-based geometries, property distributions, and spatial transitions of clusters, allowing us to assess the variability and degree of hierarchical organization in deepwater systems. The novelty of the approach lies in its methodical translation of geologic concepts to a quantitative machine learning workflow and the application of this workflow to state-of-the art models of depositional environments. Collectively, this work closes the gaps in our understanding of deepwater hierarchy that previously had not been possible given the limitations of subsurface and outcrop datasets; the learnings from which reduce the uncertainty associated with predicting key reservoir property distributions from low resolution and sparsely sampled datasets.

LESSONS FROM RECENT DIRECT MEASUREMENTS AND SAMPLING OF SEDIMENT AND ORGANIC CARBON FLUX THROUGH MONTEREY AND KAIKŌURA SUBMARINE CANYONS

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ABSTRACT

Keywords: turbidity current, organic carbon, monitoring, submarine canyon

Submarine canyons are important deep-sea environments and conduits for transferring and accumulating sediment. Recent advances in observing, sampling, and analyzing modern canyon-channel-fan sediment transport systems have illustrated surprising near-seafloor dynamics. These advances highlight the potential roles of submarine canyons in transporting and storing organic carbon, nutrients, and contaminants in the deep sea, with implications for deep-sea ecosystems and global carbon budgets.

This presentation highlights two canyon systems with contrasting organic carbon contributions and recent direct measurements and sampling – (1) Monterey Canyon, offshore central California, USA, and (2) Kaikōura Canyon, offshore northeastern Te Waipounamu South Island, Aotearoa New Zealand. These examples illustrate the complexity of submarine canyons and their role in organic carbon flux to the deep ocean, even under high-stand sea-level conditions. Evolving insights underscore the need for more observational data and samples to further test conceptual models and generate global evaluations.

A dense instrument array in Monterey Canyon aimed to measure near-seafloor (~10m) turbidity currents captured fine-grained sediment and organic carbon largely transported by internal tides. Despite changes in canyon morphology, flows, and organic carbon flux, stable isotope signatures showed no down-canyon trend in organic carbon composition to nearly 2000m water depth. Comparisons to previous seafloor samples dominated by coarser-grained turbidites suggest low burial efficiency and preferential deposition and preservation of terrestrial compared to marine organic carbon.

Kaikōura Canyon experienced an earthquake-triggered canyon-flushing event in 2016 and deposited a distinctive Kaikōura event bed with predominantly marine organic carbon. A subsequent experiment in Kaikōura Canyon paired near-seafloor sediment traps (mooring: ~15-16m; benthic lander: ~2m) with multicores at canyon floor sites ~900-1500m water depths, providing a detailed view of near-seafloor dynamics between canyon-flushing events. Preliminary results show variation in sediment flux and organic carbon content and composition down-canyon and over time, on much shorter timescales than earthquake recurrence.

THE IMPORTANT ROLE OF WHITTARD CANYON AS PATHWAY AND SINK FOR ORGANIC CARBON

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ABSTRACT

Keywords: submarine canyon, hydrodynamics, nepheloid layers, organic matter

Submarine canyons create conduits for rapid transport of dissolved and particulate organic matter from shelf to deep ocean. To determine which processes affect organic matter dispersal and deposition, moored observatories were deployed for periods of one year, suspended matter samples from the water column were collected and sediment cores were taken in the eastern most branch of the Whittard Canyon (Bay of Biscay). Distinct and permanent nepheloid layers were observed between 1200 and 2500 m water depth, which are related to resuspension of (organic) matter by tidal currents interacting with the sloping topography. These nepheloid layers play an important role in continuous lateral transport of organic carbon to greater depths. Long term (>12 months) measurements showed that significant amounts of particulate matter were transported by intermittent gravity flows some of which were related to major storms, resulting in the transport of large volumes of matter as shown by elevated mass and organic carbon fluxes. Some events were characterized by peaks in fluorescence, indicating the supply of relatively fresh organic matter to 3000 m water depth, likely providing an important food supply mechanism to deep-sea faunal communities. Analysis of surface sediments showed that the head of the canyon and slopes of the canyon are characterized by low organic matter contents, while the deepest part (>2000 m water depth) of the canyon is dominated by marine derived material, containing high amounts of organic matter. A depo center was found at 2100 m water depth, showing extremely high sedimentation rates up to 11.6 cm per year. Our data, when compared to other submarine canyons in the North Atlantic, shows that Whittard Canyon is an active system being a pathway and sink for organic matter, emphasizing the important role of submarine canyons in the global marine carbon cycle.

ORGANIC CARBON BUDGET FOR SUBMARINE CONGO CANYON: THE OVERLOOKED ROLE OF CANYONS AS TEMPORARY TERRESTRIAL ORGANIC CARBON STORES

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ABSTRACT

Keywords: submarine canyons, organic carbon, turbidity currents

Submarine canyons are the conduit through which turbidity currents transport huge volumes of terrestrial organic carbon to the deep-sea, burying the material for geological timescales and contributing to atmospheric CO_2 sequestration. Within canyons, organic carbon can undergo a complex mixture of erosion, transport, and deposition via turbidity currents. These processes are poorly understood for canyon environments, which are often assumed to be sand-rich and organic carbon-poor. Here we present an organic carbon budget for the Congo Canyon (West Africa), over a year when the canyon experienced two powerful >1000 km runout turbidity currents.

Time-lapse bathymetric maps collected in 2019 and 2020 demonstrate that turbidity currents deeply eroded the Congo Canyon by up to ~70 m. Flows were identified using seismic instruments and cable breaks. 70 samples from 1.5-9.2 m-long canyon thalweg cores, collected prior to the identified flows, were analysed for total organic carbon (TOC) content, carbon stable-isotope, and radiocarbon composition.

These thalweg cores show that the canyon contains a range of sedimentary facies, and carbon stable-isotope compositions indicate a terrestrial origin of the organic carbon. 45% of the cores comprised of clay with an average TOC of 3.5%, followed by silt (21%, average TOC 2.6%) and muddy-sand (18%, average TOC 1.8%). The cores contained only 12% of TOC-poor sand. Vegetation-rich muddy sand comprised 4% of the cores and contained densely packed, well-preserved plant material and a high average TOC of 8.2%.

Budget analysis combined the facies proportions, facies TOC and eroded sediment volumes. In one year, flows eroded ~240 Mt of sediment and ~6 Mt of terrestrial organic carbon in a 110 km stretch of the canyon, equivalent to three years of organic carbon export from the Congo River. We conclude that canyons can contain TOC-rich deposits and act as a significant temporary store of terrestrial organic carbon.

THE SUBMARINE CONGO CANYON AS A CONDUIT FOR MICROPLASTICS TO THE DEEP SEA

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ABSTRACT

Keywords: microplastics, turbidity currents, submarine canyons, deep-sea fans

The increasing plastic pollution of the world's oceans represents a serious threat to marine ecosystems and has become a well-known topic garnering growing public attention. The global input of plastic waste into the oceans is estimated to be approximately 10 million tons per year and predicted to rise by one order of magnitude by 2025. More than 90% of the plastic that enters the oceans is thought to end up on the seafloor, and seafloor sediment samples show that plastics are concentrated in confined morphologies and sedimentary environments such as submarine canyons. These canyons are occasionally flushed by powerful gravity-driven sediment flows called turbidity currents, which transport vast volumes of sediment to the deep sea and deposit sediment in deep-sea fans. As such, turbidity currents may also transport plastics present in the canyon and bury plastics in deep-sea fans. These fans may therefore act as sinks for seafloor plastics. Here we present a comprehensive dataset showing the spatial distribution of microplastics in seafloor sediments from the Congo Canyon, offshore West Africa. Multicores taken from 16 locations along the canyon, sampled different sedimentary sub-environments including the canyon thalweg, canyon terraces, and distal lobe. Microplastics were extracted from the sediments by density separation and the polymer type, size, and shape of all individual microplastic particles were analysed using laser-direct infrared-spectroscopy (LDIR). Microplastic number concentrations in the sediments of the distal lobe are significantly higher than in the canyon, indicating that the Congo Canyon system is a highly efficient conduit for microplastic transport to the deep sea. Moreover, microplastic concentrations of >20,000 particles per kg of dry sediment were recorded in the lobe, which represent some of the highest ever recorded microplastic number concentrations in seafloor sediments. This shows that deep-sea fans can serve as hotspots and potential terminal sinks for seafloor microplastics.

ORGANIC CARBON TRANSPORT TO DEEP WATER BY EXTREME EVENTS: CASE STUDY OF ELLIOT CREEK GLOF EVENT, BC, CANADA

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ABSTRACT

Keywords: organic carbon, fjord, glacial lake outburst flood, turbidity current

Burial of organic carbon (OC) in marine sediment is important as it forms the second-largest sink of atmospheric CO_2, and thus contributes to long-term regulation of climate. Fjords play a key role in the burial of OC in marine sediments, as they are responsible for burying 11% of global OC flux into the oceans. Our previous work has shown that the exclusion of coarse-grained sediment make the 11% a strong underestimate and OC input from the extreme events are not considered.

Elliot Creek Glacial Outburst Flood event occurred on 28th November 2020 due to a massive landslide (~50 million tonnes of sediment, equivalent energy released to Mw4.9 earthquake) and triggered a ~100m high displacement-wave in the glacial lake. This wave in turn broke through the lake's moraine-dam, releasing tremendous amounts of water and sediment, which scoured Elliot Creek before entering Bute Inlet fjord. Large volumes of sediment and OC were transported and delivered into the fjord. Fortuitously, Bute Inlet is the site of the most detailed time series of seabed surveys for any fjord worldwide, as it was mapped ten times in between 2008 up to 2020. The exceptionally detailed pre-event baseline data makes it possible to locate GLOF deposits in throughout the fjord.

Between 2021-2022 we sampled the submarine channel system after the Elliot Creek event, which deposited extensive coarse-grained deposits over the fjord. Preliminary results show that these GLOF deposits have an OC content of over twice (~10%) that in "normal" coarse grained deposits, and hence might be even more important in the long-term burial of OC in fjords. Overall, it is clear that coarse-grained sediment deposited in fjords during normal and extreme events will host a significant part of the global flux of OC buried in marine sediments, however, full quantification of the relative amounts is yet to be explored.

WHAT IS THE LONG-TERM FLUX OF SEDIMENT OFF THE SHELF? INSIGHTS FROM THE CENOZOIC OF THE NORTHERN GULF OF MEXICO

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ABSTRACT

Keywords: continental margin, sediment flux

As geologists studying sedimentary basins through a source-to-sink lens, we want to track sediment movement into the basin, measuring how it is partitioned between sedimentary environments. We are especially interested in quantifying the fraction of sediment that passes the shelf-slope break into deep water. Because we have access to a perfusion of subsurface data, the Cenozoic depositional systems of the Gulf of Mexico Basin are an excellent laboratory to study sediment flux and routing at the basin scale. In this talk, we focus on the period between the Paleocene and Middle Miocene that we have subdivided into eleven depositional sequences. Using over one thousand wells, we determined environments of deposition, thicknesses and sand/mud ratios. Analysis of these data showed that sedimentation rates ranged by a factor of 10 from a high of $1.3x10^5$ km^3/Ma in the Paleocene to a low of $1.3x10^4$ km^3/Ma in the Eocene. Consistently over 60% of the total sediment supplied to the basin was deposited below the shelf-slope break in deep water. While the portion of total sediment routed to deep water has remained relatively constant through time, the portion of ***sand*** transported into deep water varied dramatically ranging from 53% in the Paleocene Middle Wilcox Sequence to 10% or less in the Eocene and Oligocene. While there are multiple drivers for the differences observed in the percentage of sand routed to deep-water, we have seen that periods like the Paleocene where sand is preferentially routed into deep water are times with large, active submarine canyons in proximity to major deltaic depocenters. In contrast, periods like the Eocene and Oligocene where most of the sand that entered the basin was deposited in fluvial or shallow marine environments lack well-developed submarine canyons.

PALAEOZOIC MESOPHOTIC ECOSYSTEMS SUPPLIED FROM THE SHALLOWS BY DEEPLY INCISED EROSIONAL CHANNELS (SILURIAN, GOTLAND)

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ABSTRACT

Keywords: deeply incised erosional channel, mesophotic ecosystem, fauna mixing, Silurian

The Lower Silurian Visby Beds exposed on the island of Gotland (Sweden) and developed as argillaceous limestones and marls with some scattered bioherms and detrital beds yield the oldest so far described MCE's (mesophotic coral ecosystems) in the world. Several basic questions concerning these ecosystems, including their extend, positioning, and particularly their genetic and spatial relation and affinity with the shallow water reefs, remain unanswered.

The succession of the Visby Beds outcropping on Rövar Liljas Häla pseudoraukar south of the town of Ygne hosts a large and deeply incised erosional channel infilled by redeposited detrital and biodetrital material including corals and stromatoporoids. This represents a unique example of a fossil depositional structure connecting shallow- and deep-water reef environments, which gives an insight into the mechanisms of fauna redistribution and the consequences of its mixing. The mesophotic environment is embodied by the Visby Beds, in which the channel is incised, while the shallow water habitats are represented by the redeposited material infilling the channel. The erosional channel contains material derived from hypothetical adjacent coeval shallow-water reefal settings, which indicates that it served as an interconnecting zone between shallow- and deep-water benthic communities. The connectivity of the shallow-water reefs and the adjacent mesophotic ecosystems results in a significant taxonomic and genetic overlap between these communities. This is especially important when taking into account that the Visby Beds are the oldest example of a fossil mesophotic ecosystem described so far and that thus the presented example probably illustrates the process of its establishment. This indicates that the development of the earliest mesophotic ecosystems should not be attributed solely to eustatic sea level changes and/or gradual expansion of corals and stromatoporoids into greater depths, but took place by means of redistribution of shallow water taxa during high-energy sedimentary events.

TURBIDITY CURRENTS: MAJOR NEW ADVANCES FROM DIRECTLY MEASURING FLOWS IN ACTION, AND WHERE NEXT?

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ABSTRACT

Turbidity currents form the largest sediment accumulations, deepest canyons, and longest channels on Earth, and one turbidity current can transport more sediment than the annual flux from all rivers. Turbidity currents break seabed cables that carry >99% of global data on which daily lives depend. They play a critical role in global organic carbon cycles that affects drawdown of atmospheric CO_2 and global climate. This organic carbon underpins marine life, and rapid accumulation of organic-rich turbidites produces distinctive ecosystems. Turbidity currents transfer microplastic and other pollutants to the deep-sea, and may produce valuable long-term records of other major geohazards.

It was once thought turbidity currents were impractical to measure in action, but turbidity currents have recently been measured in detail at sites worldwide. Monitoring started with smaller flows in shallower water. But in 2020, turbidity currents were measured that accelerated from 5 to 8 m/s whilst travelling > 1,150 km offshore from the Congo River. They eroded ~2.65 km^3 of sediment, equivalent to ~19-35% of global river sediment flux down one submarine canyon in a single year.

Direct monitoring is leading to major advances; these are exciting times, analogous to obtaining first measurements from rivers. Turbidity currents are more active than once thought and triggered in newly understood ways. They play a globally important role in organic carbon cycling, which may rival the surface ocean pump. New sensors show fast flows are driven by dense near-bed layers, and flows evolve in unexpected ways. Time-lapse surveys show how flows sculpt canyon and channels, including via fast-moving knickpoints, and how flow processes link to deposits. This presentation is a rally call both flow monitoring at a wide range of locations, using novel sensors, and emphasises how monitoring data must be combined with other approaches to tell the full story of turbidity currents.

THE HIERARCHICAL DIVISION AND ARCHITECTURAL ANATOMY OF SUBMARINE CHANNELS

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ABSTRACT

Keywords: deep-water channels, internal architecture, hierarchical division, architectural anatomy

Deep-water channels are an important type of reservoirs of deep-sea petroleum. Due to their complicated depositional processes and variable facies, it is urgent to establish a method to divide hierarchies and anatomy the internal architectures of deep-water channels. In this paper, considered the characteristics of various turbidite channels, an efficient method is proposed to characterize and evaluate the sediments of deep-water channels by using seismic data. When the bottom boundary of seismically resolvable channel-complex set is recognized, the methodology of “three boundaries plus six facies” can be used to divide hierarchies and anatomy the internal architectures of the submarine channels. According to three types of geological interfaces (bottom boundary of channel system, the bottom boundary of channel-complex set, and the interface of sediment facies), six facies (basal lags, axial filling, marginal filling, slumps and debris flows, levee, turbidite mud) can be delineated in this type of submarine channels. While, the methodology of “two boundaries plus two facies” can be used in the anatomy of internal architectures of deep-water channels without the recognition of the bottom boundary of seismically resolvable channel-complex set. Two facies (channel filling and levee) can be delineated by two boundaries (bottom boundary of channel system and boundary of levee) in this type of deep-water channels. Among these facies, “basal lags and axial filling of the six facies” and “channel filling of the two facies” could be good reservoirs, and their sand-rich property can be evaluated by the convexity (relatively sand-rich when the top convex seismic reflection is visible, and relatively mud-rich when it is invisible). Applying the methodology of “three boundaries plus six facies” and “two boundaries plus two facies” in the investigation of the deep-water channels in Qiongdongnan Basin, the results indicate that this methodology could better achieve the hierarchical division and architectural anatomy of submarine channels. This also shows that this methodology can be used in other regions, and has some industrial application prospects.

THE ABILITY OF SUBMARINE CANYONS TO ESTABLISH AN INITIAL EQUILIBRIUM PROFILE DICTATES DEPOSITIONAL PROCESSES AND PRODUCTS DURING CANYON-FILL: A COMPARATIVE STUDY OF CONTRASTING STYLES OF CANYON-FILL IN THE LOWER CRETACEOUS AGAT FORMATION, NORWAY

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ABSTRACT

Keywords: submarine canyon, canyon-fill, slope, mass transport deposits

We combine 3D seismic reflection data with wells to map and characterize a series of adjacent, Lower Cretaceous slope conduits in the northern North Sea. Spectral decomposition of seismic data shows the conduits and their sub-environments in plan-view whereas seismic profiles reveal canyon(-fill) architecture in section-view. Cored wells present a record of depositional products and associated environments and processes.

Seismic mapping indicates two contrasting types of slope conduit. Firstly, where antecedent drainage existed in the form of an older, Jurassic canyon-fill, the Cretaceous turbidite system (re-)excavated this. In doing so it successfully established an equilibrium profile that extended for several 10's of kilometers. The freshly excavated Cretaceous canyon was subsequently backfilled by the Agat Formation. Where drilled, this backfill is 150m thick and cored in its entirety. There it represents a text-book example showing an upward transition from predominantly amalgamated, conglomeratic channel-fills dominated by bedload transport to more aggradational, sand-prone channel-fills with heterolithic overbanks dominated by deposition from turbulent suspension.

Conversely, where such pre-existing Jurassic canyons did not exist the Cretaceous turbidite system met with slope-parallel, basement-cored footwall highs that had not yet been subjected to deep erosion. This prevented the system from establishing a continuous equilibrium profile. Seismic mapping reveals a stepped profile and along-strike intra-formational erosional truncations that are interpreted as knickpoints that migrated up-slope with time. Cored wells in this type of canyon-fill consist of stacks of up to 30m thick, unsorted, mud-prone and/or sand-prone mass transport deposits that apparently formed from re-mobilization and complete disaggregation of sand and gravel deposits that were initially emplaced as turbidites farther upstream, occasionally mixed with mud that likely originated from excavation of overbanks and/or older mudstone formations.

The lack of a pre-established equilibrium profile resulted in a complex canyon-fill characterized by successive cycles of erosion and re-deposition of earlier deposits.

DOWNSLOPE VARIABILITY IN DEEP-WATER SLOPE CHANNEL FILL FACIES AND STACKING PATTERNS: IMPLICATIONS FOR SUBSURFACE RESERVOIR PREDICTION AND CHARACTERIZATION

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ABSTRACT

Keywords: turbidites, slope channels, stratigraphic stacking, subsurface reservoirs

Lithologic variations in deep-water slope channel systems offer key insight into sedimentary processes on deep-water slopes, and are a primary control on performance and updip stratigraphic trap formation in subsurface reservoirs associated with ancient deep-water systems worldwide. While many studies have described these variations at outcrop-scale along depositional strike (across-channel), few have focused on deciphering down-depositional-dip changes due to: (1) the paucity of downslope perspectives afforded by outcrops; or (2) limited resolution subsurface data. In this study, characterisation of slope channel elements (≤30 m thick; ≤400 m wide) and composite channelform bodies composed of ≥2 stacked channel elements (channel complexes and channel systems; >30 m thick; >400 m wide) was conducted along a 50-km long depositional-dip-oriented outcrop belt of the Campanian-Maastrichtian Tres Pasos Formation (Chile) to constrain longitudinal changes in channel fill character and stacking patterns. Results show that channel elements in updip regions of the system contain abundant siltstone, whereas channel elements in downdip regions are sandstone-rich. Outcrop observations are supported by channel element net-to-gross ratios (measures of sandstone proportion), which increase downdip. The proportion of sandstone-rich channel elements within channel complexes and channel systems also increases downdip; however, channel element stacking pattern variability results in a poor correlation between net-to-gross values and palaeoslope position when composite channelform bodies are considered. These findings indicate that the along-slope distribution of coarse-grained detritus in channel systems is tied to the degree of coarse-grained sediment bypass and erosion that occurs along a slope. The results of this study provide a uniquely detailed record of changes in slope channel fill and stacking patterns, and help inform various aspects of analogous subsurface reservoirs, including the nature of updip stratigraphic traps, as well as sandstone proportion trends at numerous scales.

ORGANIC CARBON DISTRIBUTION IN BUTE INLET (CANADA) FOLLOWING AN EXTREME GLOF EVENT

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ABSTRACT

Keywords: Organic Carbon, Fjord, Glacial Lake Outburst Flood, Turbidity Current, Stable Isotope

Bute Inlet is one of the sites with the most detailed time series of seabed surveys for any fjord worldwide, having been mapped ten times in between 2008 up to 2020, creating exceptionally detailed baseline data. Between 2013-2018, data was collected to study the drivers, dynamics, and deposits of the turbidity currents in British Columbia (BC) fjords. Results show that organic carbon (OC) burial in fjords was thought to represent 11% of the global OC flux into the ocean, however, this estimate may be significantly underestimated as deposits of the aforementioned turbidity current were not directly included.

On the 28th of November 2020, a landslide event dislodged 30 million tonnes of sediment into a glacial lake (Elliot Creek) in British Columbia (BC), Canada, resulting in a ~100m high displacement-wave that broke through the moraine-dam on the lake's embankment. Consequently, a significant part of the glacial lake flooded and eroded the valley beneath before entering the Bute Inlet fjord 15km downstream of Elliot Creek. A large volume of sediment was transported into the fjord floor, down to the distal lobe.

Such extreme events seem able to directly bury large amounts of OC in these distal sites and deep-water locations**.** Dating of these distal deposits indicates that extremely large events occur on a centennial timescale. Possibly, infrequent glacial lake outburst floods, like the recent one, could represent such extreme events. However, the efficiency of such events in OC burial remains unexplored, hence giving the unique opportunity to study OC burial in relation to the current event. The first step to full quantification is tracing and confirming the sediment origin of the distal lobe deposits that were sampled, done through correlation between data for stable isotope, total carbon, and total organic carbon content of the deposits. Preliminary result suggests very high (almost 10 times more) organic carbon sequestration by the extreme event.

LATERAL FACIES QUANTIFICATION IN DISTAL SUBMARINE-LOBE DEPOSITS FROM LITHO- AND CHEMOFACIES WELL DATA IN THE PERMIAN WOLFCAMP FORMATION, DELAWARE BASIN, TEXAS: IMPLICATIONS FOR SUBSURFACE LATERAL FACIES PREDICTION

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ABSTRACT

Keywords: turbidite, chemofacies, lateral heterogeneity, machine learning, submarine fan

Ancient submarine lobes are significant targets for the exploration and production of subsurface hydrocarbons and, recently, for carbon storage. Even though classical conceptual models of submarine lobe architecture exhibit a systematic longitudinal and transverse decrease in bed thickness, grain size, sand content, and amalgamation, new studies indicate complex lateral facies heterogeneity, challenging these simplistic models. At the centimeter to meter scale, event beds (e.g., turbidites, debrites, and hybrid beds) are the building blocks of submarine fans, and therefore, quantitative evaluation of lateral event-bed statistics (e.g., bed thickness and thinning rate) enables improved understanding of depositional processes on submarine lobes, which eventually lead to more realistic models for conventional and unconventional hydrocarbon reservoirs hosted in these systems. Accordingly, this work presents a case study in a mixed carbonate-siliciclastic sea-floor fan in the Permian Wolfcamp A Formation in the Delaware Basin of Texas. The two wells studied here, one vertical and one deviated 145 m apart, were kindly provided by the Gas Technology Institute Hydraulic Fracturing Test Site 2. The data sets include core photos, CT imagery, XRF data, and routine core analysis. Lithofacies were described and attributed to event-bed and background packages in the 54-foot section selected for preliminary analysis in the vertical well. This analysis reveals different trends in the composition of event-bed sequences, which typically comprise calcareous-rich sandstone at the base transitioning upwards into siliceous-rich mudstone. This study's ultimate goal is to link the event-beds architecture previously recognized in the vertical well with the slant well, exploiting the short distance between them to assess lateral heterogeneity and the applicability of supervised machine-learning techniques. Motivated by a strong relationship between CT density and XRF values, this study evaluates composition prediction, which can be helpful for lithofacies interpretation, especially in the slant core, which is unslabbed and lacks XRF data.

INTERACTION OF TURBIDITY CURRENTS AND CONTOUR CURRENTS IN FLUME-TANK EXPERIMENTS; CONCENTRATION PROFILES AND DEPOSITIONAL PATTERNS LINKED TO VELOCITY FIELD MEASUREMENTS

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ABSTRACT

Keywords: mixed systems, flume-tank experiment, flow interaction, grainsize trends

Turbidity currents carry large amounts of sediment, nutrients, pollutants, organic carbon and even plastics to the deep-sea and store them in basin-floor fans forming the largest sediment accumulations on Earth. Turbidity currents may interact with dynamic ambient water masses in the deep sea forming a mixed system. One type of this interaction is turbidity current – contour current interaction. Several conceptual models have been published that hypothesize how this interaction works and how this affects depositional patterns. These models remain largely untested. Furthermore, a clear link between process and deposit is missing. Experiments can add to the current understanding of depositional patterns of mixed systems by linking the flow dynamics to concentration and deposits, which is often not possible in field measurements. This study focused on 3D experiments of turbidity current – contour current interaction to find out how variations in channel depth and contour current intensity affect: 1) grainsize distributions and thickness of the deposits, 2) concentration of the turbidity current at different elevations above the bed, inside and outside the channel. We will show concentration profiles and grainsize distributions of the different experiments and propose a depositional model for mixed systems. We show that with stronger contour currents or a less confined turbidity current more and coarser sediment is advected out of the channel and is deposited on the levee at the downstream part of the channel. Our results can be a first step in describing a source mechanism of the sortable silt proxy.

ICHNOLOGICAL ANALYSIS ACROSS THE RAMBLA THE TABERNAS SECTION (TABERNAS BASIN, SE SPAIN), AN APPROACH TO IMPROVE THE CHARACTERIZATION OF A TURBIDITE SYSTEM

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ABSTRACT

Keywords: turbidites, trace fossils, paleoenvironment, ichnofacies

Turbiditic deposits from the Neogene Tabernas Basin (SE Spain) have been mainly studied focusing on sedimentological and tectonic aspects, but other features, as the ichnological content has not been analysed in detail. This study focuses on one of the most representative turbiditic sections from the Basin, the Rambla de Tabernas section, allowing interpretation of palaeoenvironmental conditions and differentiation of sub-environments within the turbiditic system. Sedimentological analysis shows that Rambla de Tabernas section is mainly composed on mudstone interbedded with fine- to medium-grained sandstone, with presence of Tab/Tabc Bouma sequences. Ichnological analysis reveals a trace fossils assemblage composed on 14 ichnotaxa, differentiating post-depositional (i.e., *Chondrites*, *Ophiomorpha*, ?*Palaeophycus*, *Phycodes*, *Planolites*, *Scolicia* and *Thalassinoides*) and pre-depositional (i.e., ?*Circulichnis*, *Scolicia strozzii* and graphoglyptids as *Cosmorhaphe*, *Desmograpton*, *Helminthorhaphe*, *Megagrapton*, *Paleodictyon* and *Urohelminthoida*) associations. The trace fossils assemblage can be assigned to *Nereites* ichnofacies, commonly related to turbiditic deposits, with characterization of ichnosubfacies that can be associated to different sub-environments within the turbiditic system. Intervals dominated by *Cosmorhaphe*, *Helminthorhaphe*, *Paleodictyon* and *Urohelminthoida*, are assigned to *Paleodictyon* ichnosubfacies and linked to lower energy environments, like outer fan areas. Those characterized by a major presence of *Ophiomorpha*, *Scolicia*, *Thalassinoides* and *Chondrites*, are assigned to *Ophiomorpha rudis* ichnosubfacies, and interpreted as associated to proximal areas, like channels and proximal lobes. This study supports the usefulness of the ichnological analysis to improve the interpretation of turbiditic deposits, providing additional information of palaeoenvironmental conditions and sub-environments into the turbiditic system.

AN EXCEPTIONAL DATASET OF 1250M (4000') CONTINUOUS CORE THROUGH CHANNELISED SUBMARINE FAN DEPOSITS, EOCENE, SAN JACINTO FOLD BELT, NW COLOMBIA

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ABSTRACT

Keywords: Colombia, Eocene, channelized submarine fan, ichnology

An Eocene succession of deep-water clastic deposits is reported in the San Jacinto Fold Belt (SJFB), NW Colombia. These deposits are a thick sequence of conglomerates, sandstones, and mudstones cored in the ANH-La X-1 stratigraphic well, that records multiple stacking patterns of facies changes controlled by sediment density flow processes.

The sequence is composed of three distinctive successions: 1) ungraded conglomerates with outsize mud-clasts with sporadic development of massive sandstones (Ta/Sand debrite) and laminate sandstones (Tb) at the top. This is interpreted as deposits of debris flows with some development of dilute sediment suspension.

2) Massive sandstones (Ta/Sandy debrite), laminated sandstones (Tb) and rippled sandstones (Tc), and fine sandstones with mud laminae (Td). Typical trace fossils are *Ophiomorpha*, *Thalassinoides*, and *Scolicia*. This interval is interpreted as debris flows deposits with high and low density turbidites (Ta-Tb & Tc-Td).

3) Predominantly mudrocks and minor sandstones; ungraded siltstones/mudstones (Te), laminated siltstones with current ripples sandstones lenses (Te-1), and some thin-bed laminated sandstones (Tb), rippled sandstones (Tc), and fine sandstone with mud laminae (Td). The main trace fossils *Phycosiphon*, *Planolites*, *Scolicia*, *Nereites*, *Palaeophycus heberti*, and *Thalassinoides*. These deposits are interpreted as turbidity currents and density mud.

ANH-La X-1 well is an exceptional example to understand the interaction of turbidite and debris flow during in deep-marine deposits of the Eocene of onshore Colombian Caribbean basins. Our findings are key to guide the exploration efforts in the basin, understanding reservoir distribution and properties will help to lower the risk of reservoir presence and quality.

RECORDS OF HYBRID FLOW TRANSFORMATIONS: A FIELD STUDY FROM THE PEÏRA CAVA OUTLIER, SE FRANCE

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ABSTRACT

Keywords: hybrid event beds, confined basins

Turbidity currents have the ability to undergo flow transformations due to changes in internal factors such as sediment concentration and clay content, and external factors such as basin confinement or transport over a rugose seafloor. The deposits formed from such transformations are termed hybrid event beds (HEBs). The occurrence of HEBs is well documented in unconfined basin fills. However, the stratigraphic and palaeogeographic distribution of HEBs in confined basins differ from that of unconfined basins.

Building upon existing detailed studies of the Peïra Cava outlier, a confined and contained mini-basin outcropping in SE France, a preliminary field study was conducted. At least six HEB types were identified and logged at a high resolution within previously well-defined stratigraphic intervals. Identified HEB types vary from sand-and mud-clast rich to slurried clast poor debritic components and have been found to occur in proximal regions but extending throughout the basin.

The identification of HEBs in inaccessible regions has been made possible by processing digital photogrammetry from unscrewed aerial vehicle images into high resolution 3D models. These models provide an increased data set in addition to a large-scale view of lateral and stratigraphic bed variations, allowing HEBs and therefore flow evolution to be traced longitudinally due to the sheet-like architecture of the basin.

Future analysis on mudcaps and mudclasts on HEBs will determine the role muds play in flow transformations within the basin by determining the mud source. The expression of HEBs at different levels of data resolution will also be explored by utilising offshore data sets from a confined basin fill in the Gulf of Mexico. Finally, the data will be compared to other confined basin fills with the Deep Marine Architectural Knowledge Store (DMAKS) database to help understand how the distribution of HEBs varies from confined to unconfined basins.

CHANNEL-LEVÉE TRANSITIONS: INSIGHTS FROM THE TACHRIFT TURBIDITE SYSTEM: (COMPLEX 6, TAZA–GUERCIF BASIN, NE MOROCCO)

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ABSTRACT

Keywords: turbidite channel fill, levee, lateral accretion package, Tachrift system, Taza–Guercif basin

Studies of modern and subsurface deep-water systems provided significant insights into turbidite channels in terms of their morphologies, origin, multi-scale stratigraphic architecture and evolution. However, bed-scale variability, such as changes in facies architecture from channel axis to channel margin and levée, and their depositional processes, are in general poorly constrained by these datasets due to limitations of scale or data resolution. The characterization of channel-fill and accordant overbank sediments in turbidite channel-levée complexes needs extensive and well-exposed outcrops, since the modern seismic still does not resolve the facies transition and small-scale heterogeneity in these deposits. Nevertheless, outcrop examples of deep-water channels and correlative levées are sparse and the facies transition between these elements can only be inferred.

This contribution reports on an exceptionally well exposed deep-water channel-levée complex (Complex 6) of multiple complexes making the Tachrift system (Taza-Guercif Basin, Miocene, NE Morocco), where the correlative architectural elements are clearly seen and may help interpreting the evolution of these depositional systems. Geological mapping was integrated with facies analysis on 46 logs and physical stratigraphic correlations. Complex 6 consists of three sandstone-rich units labelled A, B, and C that progressively increase in grain-size and are laterally stacked in a SE-ward shifting fashion. Particularly, channel-fills and correlative levées of Units B and C have contrasting architectural styles which likely reflect changes in flow parameters (e.g., grain size, volume, density stratification etc.), channel sinuosity, and morphodynamics. Owing to magnificent 3D exposures, the ongoing study of Complex 6 outcrops will provide sedimentological characterization of channel-fills and correlative levée deposits, insights into evolution of their parent channel from inception trough abandonment, and sub-seismic lithological calibration of subsurface analogues.

THE MASS-TRANSPORT DEPOSITS OF THE PALEOGENE JULIAN BASIN (ITALY/SLOVENIA): OBSERVATIONS ON THE DYNAMIC OF EMPLACEMENT AND TSUNAMIGENIC POTENTIAL

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ABSTRACT

Keywords: carbonate mass-transport deposits, tsunami backwash, bipartite flow, geochemical fingerprinting

The External Dinarides between Italy and Slovenia feature some exceptional exposures of Paleocene-Eocene Mass-Transport Deposits (MTDs) formed by repeated catastrophic events, in which large sectors of the Adriatic Carbonate Platform collapsed and redeposited in a foredeep basin system, the Julian Basin. The sedimentary succession of the basin contains at least 25 major MTDs. The largest can be up to 260 m thick and can be traced laterally for at least 100 km. The mechanism of emplacement of these “megabeds” consists of a bipartite flow of material with a cohesive blocky/debris flow at the base, and a grain to turbulent flow on top. Each MTD features basal units of calcareous breccias embedding carbonate, siliciclastic-carbonate and marly slide blocks, topped by graded calcirudite, calcarenite and marlstone deposits.

Here we discuss new interpretations of some representative megabeds, exposed in the area’s main open-pit quarries, based on X-ray fluorescence spectrometry (XRF), Powder X-ray diffraction (Powder XRD) and Total Organic Carbon (TOC) data, together with outcrop analysis carried out in the field and on Virtual Outcrop Models (VOMs).

Results provide new insights into the emplacement dynamics and tsunamigenic potential of the MTDs in the Julian Basin. The inferred shape of the basin, the dimensions of the main "megabeds" and the data analysis from the above outcrops suggest that some of these submarine landslides may have triggered tsunami waves, with possible subsequent rebound deposits on top of them, traces of which are possibly recorded by multiple geological-geochemical proxies.

THE OLIGOCENE AND MIOCENE SANDS IN THE DEEP LEVANT BASIN: PROVENANCE AND SEDIMENT ROUTING

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ABSTRACT

Keywords: eastern Mediterranean, Levant Basin, provenance, source-to-sink

The Levant Basin in the Eastern Mediterranean contains a ~3 km-thick, predominantly siliciclastic section of Oligocene-Miocene age, which hosts large hydrocarbon reservoirs ("Tamar Sands Play"). A fundamental question raised with respect to this siliciclastic section concerns its origin and the sedimentary pathways into the deep basin. Here we present an advanced provenance study, including detrital zircon U-Pb-Hf and heavy mineral assemblage investigations, of Oligocene-Miocene siliciclastic sediments retrieved from four boreholes across the Levant Basin. Our investigations reveal that the studied sediments are dominated by Neoproterozoic and older Precambrian zircons and were mainly reworked from Paleozoic-Mesozoic sandstones of Afro-Arabia with minor derivation from other sources such as the basement of the Arabian-Nubian Shield. However, variations in the proportion of pre-900 Ma zircons were encountered in various levels of the siliciclastic section, being markedly enriched in Early Oligocene and Early Miocene intervals, escorted by abundant detrital apatite peloids in the heavy mineral fraction, and rather mild in Late Oligocene-lowest Early Miocene and Middle-Late Miocene intervals alongside scarce Mesozoic-Cenozoic zircons. These findings allow to associate the deep-basin detrital record with two sedimentary transport systems recognized on land and indicate that the Levant Basin was fed simultaneously by sediments derived from Arabia through submarine canyons that incised the Levant continental margin and from NE Africa via the Nile Delta. Nonetheless, while Early Oligocene and Early Miocene sediments, including the main section of the "Tamar Sands", were mainly derived from Arabian sources, Late Oligocene-lowest Early Miocene and Middle-Late Miocene sediments were mainly sourced from NE Africa. Detrital contribution from the Eurasian side of the Eastern Mediterranean was not identified, suggesting that sand originated in the Arabian-Eurasian collision belt did not reach the Levant Basin.

VERTICAL AND LATERAL FACIES SUCCESSIONS OF CARBONATE-SHALE SEDIMENT GRAVITY FLOW DEPOSITS IN STACKED, LATERALLY ACCRETING SLOPE CHANNELS, MISSISSIPPIAN FORT PAYNE FORMATION, KENTUCKY

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ABSTRACT

Keywords: slope channels, HEBs, accretion

The Lower-Middle Mississippian Fort Payne Formation in south-central Kentucky consists of carbonate-shale clinothems, which initiated along the abandoned, subaqueous delta front of the Borden Formation and prograded ~50-70 km seaward over a span of about 10 my. Although the water depths were less than 150-200 m, the foresets-toesets are inclined 1-8^{o} basinward (S-SW) and contain numerous slope channels filled with a wide variety of sediment gravity-flow deposits.

This study documents lateral/vertical facies relationships and 2d architecture of the slope channels exposed in 4 closely spaced roadcuts. Aligned nearly parallel to depositional strike, the roadcuts expose stacked and laterally offset channel-fills and muddy slope facies with vertical changes in architecture and fill interpreted to record a basinward stepping history. Lowest channels are filled with heterolithic laterally accreting bedsets made up of low-high density turbidites and HEBs interbedded with shale. These are toe-of-slope, high-aspect-ratio channels that were weakly confined. They are overlain by a channel complex filled with laterally accreting thick, crinoidal HEBs along one margin, muddy debrites with blocks, foundered grainstone beds, shale injection features in the thalweg, and lateral accreting beds of dolomitic mudstone and shale on the other margin. These channels represent a lower slope setting, but are more confined than the underlying shaley channels. The highest channel complex consists two stacked channel storeys filled with thick, laterally accreted, laminated beds of a crinoid rudstone interpreted as high-density turbidites. The lower channel cuts out 4-5 m of slope shale but lacks shale clasts. The upper channel terminates with a slumped channel-margin and heterolithic fill that may represent channel abandonment. Both are confined axial channels with interpreted low-aspect-ratios and they represent middle slope setting.

An interpreted middle- to upper-slope bypass zone made up of slope mudstones and shale separates the channel complexes from the upper slope and toplapping grainy carbonates.

ESTIMATING THE VELOCITY OF ANCIENT BOTTOM CURRENTS USING GRAIN SIZE DISTRIBUTIONS MEASURED IN THIN SECTIONS OF CONTOURITIC ROCKS WITH SILICEOUS CEMENTS

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ABSTRACT

Keywords: contourite, grainsize, Jurassic, image analysis

Contourites, the deposits of bottom currents in the ocean, provide us with a window into ocean circulation in deep time. The grain size of the coarser mud fraction of contourites is often measured in disaggregated samples and used as a proxy for bottom current velocity. This sortable silt proxy has so far required that the sediments be in a disaggregated state, which is difficult to achieve in older well-lithified Mesozoic and Paleozoic deepwater rocks.

The Hettangian (Lower Jurassic) upper member of the McCarthy Formation, deposited in tropical Panthalassa, is exposed in large outcrops on the valley walls of Chitistone Mountain, near McCarthy, Southcentral Alaska. The member has been interpreted as a deepwater sediment drift, and its siliceous mudstones and sandstones have been interpreted as contourites. Unfortunately, these rocks have siliceous cements and disaggregate poorly, which hampers grain size analysis using conventional methods, as well as the application of the sortable silt proxy.

In this study, we tested the application of the sortable silt proxy on grain size distributions obtained from micrographs of well-lithified contouritic rocks. Micrographs of thin sections of samples of the upper member of the McCarthy Formation were processed using ImageJ, an image analysis software. Binary images were produced, separating >20 µm grains from finer mud and cement. Grain outlines were drawn, and ellipses were fit on top of the grain outlines. The major axis of each ellipse was measured, and these were collectively used to establish the grain size distribution of each sample.

The ability to accurately analyse the grain size distribution of well-lithified contouritic rocks and apply the sortable silt proxy to these data is expected to improve Mesozoic and Paleozoic paleoceanographic reconstructions.

QUANTITATIVE AND GEOMORPHOLOGIC PARAMETERIZATION OF MEGACLASTS WITHIN MASS-TRANSPORT COMPLEXES, OFFSHORE TARANAKI BASIN, NEW ZEALAND

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ABSTRACT

Keywords: mass-transport complexes, megaclasts, deformational styles, quantitative analysis

Mass-transport complexes (MTCs) in sedimentary basins record the gravitational transport of mass flows from the shelf edge and submarine slope. Deformation structures in megaclasts, large (100s m in length) sedimentary blocks within MTCs, are an underused record of kinematic and sedimentary process in operation during emplacement of mass flows. This study uses high-quality, three-dimensional (3-D) seismic reflection data from the deep-water Taranaki Basin offshore New Zealand to analyse the morphological character of 123 megaclasts to propose a new classification scheme based on their morphometric properties. The megaclasts are up to 400 m tall, 1900 m long, and 1200 m wide. In the study area, they are high- to moderate-amplitude features owing to their different lithologies and continuous-to-contorted seismic facies. Based on the internal deformational styles, the megaclasts can be classified as 4 types: (1) undeformed megaclasts, characterized by undeformed and non-rotated reflections; (2) rotated megaclasts, featured by rotated internal reflections; (3) deformed megaclasts, distinguished by deformed internal reflections; and (4) highly deformed megaclasts, characterized by both deformed and rotated reflections. Two different styles of morphological depressions formed by megaclasts-substrate interaction are identifed, and support whether the megaclasts were transported or formed in situ. Our study demonstrates that quantitative parameterization of the megaclasts provide important information about their deformational processes and a more complete understanding of megaclast emplacement along continental margins.

REACTIVE TRANSPORT MODELLING OF CO_2 IN DEEP-MARINE RESERVOIRS: FRIGG FIELD AND OUTCROP ANALOGUE

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ABSTRACT

Keywords: CO_2 storage, deep-marine lobes, reservoir heterogeneity, mineral reactions

Long-term geological storage of CO_2 is viewed as a key climate change mitigation technology and is thought essential for many net-zero carbon transition models. When selecting target reservoirs for CO_2 storage it is becoming increasingly evident that grain-scale heterogeneity is a key criterion. This is at odds with the typical homogenous sandstone target that is ideal for hydrocarbon extraction. Heterogeneous targets feature intra-reservoir baffles to upwardly migrating CO_2, increasing CO_2 trapping by physical trapping mechanisms. Additionally, heterogeneity is thought to enlarge the CO_2-brine contact area, therefore optimising the process of solubility trapping. Here, the effect of reservoir heterogeneity is investigated with regards to its effect on the rate and extent of CO_2 mineral trapping that permanently sequesters CO_2. Heterogeneity could potentially enlarge the CO_2-resrvoir-brine reaction front and provide a greater abundance of reactants, particularly clay minerals, for sequestration reactions. This facies-based study quantifies the mineralogy and pore-scale heterogeneity of the Early Eocene deep-marine lobe system of the Frigg Field within the Northern North Sea. Deep-marine reservoirs are known to feature mineralogical heterogeneity both laterally and vertically, due to factors such as spatial variation of facies deposition and lobe stacking patterns. Wire-line data investigation, core-logging, physical sample collection and thin section mineralogical analysis are used to produce a bespoke reactive mineral transport model for deep-marine facies, coupled with laboratory reaction experiments, to understand the mineral, structural and pore-scale changes that these facies will undergo with long-term exposure to CO_2. Data will be supplemented with outcrop sample data from similar facies within the Ainsa-Jaca Basin, Spanish Pyrenees. This project aims to examine the suitability of deep-marine lobe facies for long-term and safe CO_2 storage.

DEEP-WATER CARBONATE GRAVITY FLOW DEPOSITS: RELATIONSHIPS BETWEEN FABRIC DEFORMATION, DIAGENETIC ALTERATION, AND FRACTURE CHARACTERISTICS

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ABSTRACT

Keywords: deepwater carbonates, diagenesis, fracture characteristics

Carbonate slope deposits comprise a significant component of hydrocarbon-bearing reservoirs in carbonate buildups around the globe. Within slope carbonate packages, most hydrocarbon production is attributed to non-matrix porosity (i.e., fractures and karsts). Unfortunately, the influence of gravity-driven sedimentation processes on the distribution of non-matrix porosity/fracture characteristics and the effect of carbonate diagenesis on rock alteration and mechanical packaging in these deposits is poorly understood. This study combines a diagenetic-process-based approach with fracture network characterization, with the aim to link diagenesis alteration to mechanical properties and fracture nature of carbonate slope deposits.

Some of the key questions to be answered through this study are: How are early syndepositional fractures controlled by early diagenesis and fabric deformation? And how do early fractures influence later burial fractures and matrix diagenesis, if at all? Differentiating between early syndepositional versus later tectonic/burial fractures and early marine versus later burial diagenesis are keys to understand how diagenetic texture creates geomechanical packages and early syndepositional fractures, and how both syndepositional and later tectonic fractures create fluid pathways for later matrix diagenesis.

Outcrop sections are being measured to capture deformation fabric variability and diagenetic fills along the Permian slope of the Guadalupe Mountains. Clumped and conventional isotopes, fluid inclusion and petrographic analysis will then be utilized to differentiate early versus late fracture formation and filling, and early meteoric versus marine and late burial diagenesis. Early diagenetic textures are compared to early fracture characteristics, and late diagenetic texture is compared to the fracture fill composition of early and late fractures. These comparisons test the hypothesized genetic relationships between early diagenesis, early fractures, and matrix diagenetic phases. The goal is to identify the type of fractures that serve as fluid pathways for matrix diagenesis throughout the history of slope development, to improve non-matrix porosity and permeability predictions.

SUBMARINE LOBE DEPOSITS OF THE PERMIAN WOLFCAMP XY FORMATION (CENTRAL DELAWARE BASIN, TEXAS): HIGH-RESOLUTION CORE STUDY RELATING CHEMOFACIES TO RESERVOIR QUALITY

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ABSTRACT

Keywords: chemofacies, heterogeneity, mixed siliciclastic–carbonate mudstone, submarine lobe deposit

Submarine lobe deposits in the Wolfcamp Formation are among the primary unconventional reservoir targets in the Central Delaware Basin of Texas. The Wolfcamp Formation is comprised of siliciclastic and carbonate sediment gravity flow deposits, including turbidites and debrites that were sourced from multiple uplifted areas during the early Permian (Wolfcampian, ~285 Ma). Despite numerous recent reservoir characterization studies in this area, integrated multi-scale core-based studies relating to reservoir quality are sparse. This research aims to better predict source rock and reservoir distribution by using geochemistry and petrophysical data from this deep-water depositional system.

This study focuses on the depositional processes, reservoir heterogeneity, and associated chemofacies from a rich dataset consisting of well logs, 218 ft of core, and continuous (1 cm resolution) X-ray fluorescence (XRF) data from the core. We use 17 elements from the XRF data for *k*-means clustering and principal component analysis to derive five chemofacies that characterize geochemical heterogeneity: (1) anoxic calcareous mudrocks, (2) oxic-suboxic calcareous mudrocks, (3) oxic-suboxic argillaceous mudrocks, (4) anoxic argillaceous mudrocks, and (5) oxic siliceous mudrocks. In addition, scanning electron microscopy (SEM) and petrography quantify mineral composition and diagenetic processes. Our results indicate that vertical, bed-scale variations in chemofacies and petrography accurately represent depositional facies changes and variations in total organic carbon (TOC). This research demonstrates the relationship of chemofacies to petrophysical properties (porosity, permeability, and water saturation) and geomechanical response (brittleness and unconfined compressive strength), which can be used for log-based reservoir prediction of the Wolfcamp Formation, as well as for other mixed clastic-carbonate deep-water reservoirs.

SEDIMENTARY ARCHITECTURE, DEPOSITIONAL EVOLUTION, AND CONTROL FACTORS OF TURBIDITE CHANNEL COMPLEX 4 FROM THE TACHRIFT TURBIDITE SYSTEM (TORTONIAN, TAZA–GUERCIF BASIN, NE MOROCCO)

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ABSTRACT

Keywords: turbidite channel, channel morphodynamics, equilibrium profile

The sedimentary architecture of channelised turbidites can be highly complex as it reflects the response of submarine channels to several interplaying factors. Although largely studied through seismic imaging, turbidite channel fills are not definitely calibrated for sedimentary facies and small-scale architectures at a sub-seismic scale.

This contribution reports about the sedimentary architecture and the controls on the evolution of a ca. 20 m-thick channel-levee complex ('Complex 4') of the Tachrift System (Tortonian), which accumulated along the southern slope of the Neogene Taza-Guercif Basin (Rifian Corridor, NE Morocco). The studied channel-levee complex consists of, from base to top: (i) a ca. 7 m-thick mud-prone interval containing relatively small and vertically stacked channel fills with poorly developed muddy levees, (ii) a ca. 4 m-thick and >1 km-wide sandstone-rich middle interval made of lateral accretion packages (LAPs), which is progressively less amalgamated top ward and overlain by ca. 5 m of cm-thick sandstone intercalated with hemiplegic marlstones, and (iii) ca. 9 m-thick upper interval constituted by vertically stacked channel fills, made of variously directed LAPs, associated with well-developed levees.

This architecture suggests that, following a phase of inception (i), the channel underwent extensive meandering with very minor vertical aggradation, prior to be blanketed by 'retrogressive' muddy lobes (ii) during a phase of reduced sediment input. In turn, the uppermost interval (iii) records a late phase of channel re-establishment and aggradation. Bering this evidence in mind, changes of architectural style are interpreted as in response of variations in sediment supply and flow properties at a various range of temporal scales. These changes can modulate longer-term adjustment of submarine channels to profile of equilibrium, resulting in a large variety of architectures.

HOW HYPERPYCNAL DEPOSITS AND SURGE-LIKE TURBIDITES COEXIST? AN EXAMPLE FROM THE OLIGOCENE MONASTERO FM. (TERTIARY PIEDMONT BASIN, NW ITALY)

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ABSTRACT

Keywords: hyperpycnites, delta-fed turbidites, Tertiary Piedmont Basin

Although poorly studied in the sedimentary record, deposits of sediment gravity flows generated at river mouths are being increasingly recognised as an important component of deep-water clastic successions. Yet, distinguishing them from surge-like turbidites might be problematic and requires accurate facies and architectural analyses besides the thorough contextualisation within the palaeodepositional framework.

This contribution focusses on 1100 m-thick succession of the Monastero Fm. (Rupelian, MF hereafter), which crops out in the eastern Tertiary Piedmont Basin (NW Italy), representing the fill of a partly confined basin supplied with sediments by coeval conglomeratic fan-deltas.

Facies analysis of representative sections shows that nearly 65% of the MF thickness is constituted by thin-bedded medium/fine-grained normally graded sandstones fining up into mud caps with repeated grain size breaks and sedimentary structures. This facies forms the background of volumetrically subordinate coarse-grained and thicker-bedded amalgamated sandstone sheets and erosional-based lenticularly-shaped gravel bodies (lobe and channel deposits, respectively).

Correlations and relative facies proportions indicate that the background facies is hardly interpretable as laterally equivalent to coarser-grained facies (e.g., turbidite lobe fringes or levees), and hardly matches with short-lived surge-type flow models. Rather, repeated normal grading, grain size breaks, and sedentary structures suggest deposition by long-lived pulsating flows of hyperpycnal origin.

Several lines of evidence indicate MF was deposited on a laterally confined clastic ramp supplied with sediments by multiple entry points that conveyed hyperpycnal flows and, subordinately (at times of high-sediment input and/or degradation of up-dip sections of the system) more classical surge-like turbidity currents. Ongoing research on MF seeks to provide criteria for distinguishing hyperpycnal deposits from classical surge-like turbidites and assess whether the two can coexist as a result of parent flow transformations.

CAN WE STORE CO_2 FOR MILLIONS OF YEARS IN DEEP-WATER ROCKS?

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ABSTRACT

Keywords: CCS, reservoir characterization, lobes

Carbon Capture and Storage is an essential technology which will likely need to be deployed at a significant scale to reach Net Zero. Sedimentary rock formations are particularly attractive sites for CO_2 storage, in the form of saline aquifers and depleted oil and gas fields. Detailed characterisation of these reservoirs is needed to safely and efficiently inject CO_2 for permanent storage.

Reservoirs within deep-water deposits are relatively well understood for hydrocarbon production, but specific parameters important for CO_2 storage are less well constrained. This project is focused on deep-water lobe systems and will increase our understanding of specific reservoir characteristics that are primary controls on CO_2 injection and storage. For example, the thickness and lateral extent of intra-formational baffles will influence the pressure exerted on the primary seal while also controlling the available surface area for CO_2 to react with formation fluids. Additionally, the spatial distribution of clay minerals in deep-water reservoirs will also influence injected CO_2 as these minerals can both aid and inhibit storage efficiency. An output of this research will be a predictive model of facies distribution and associated reservoir characteristics important for CO_2 storage within deep-water lobe systems.

The utilised dataset is a suite of core and well data from the abandoned Frigg field, representing an early Eocene-aged submarine fan system, and Eocene-aged outcrop analogues in the Jaca Basin (Spanish Pyrenees). The Frigg field is located in the northern North Sea, straddling the boundary between Norway and the UK, and was abandoned in 2004 after 27 years of gas production. This research aims to constrain the geological and sedimentological controls on reservoir quality applicable to CO_2 injection and long-term geological storage in reservoirs made up of deep-water lobe deposits. This will highlight the utility of abandoned conventional hydrocarbon reservoirs and aquifers for this purpose.

GEOCHEMICAL ANALYSIS TURBIDITES OF PINDOS BASIN, GREECE

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ABSTRACT

Keywords: geochemistry, mudstones, Pindos, paleoenvironment

Cretaceous siliciclastic turbidites of the Katafito Formation are exposed across large areas of the Pindos Mountains in Greece, recording early onset of the greater Alpine orogenic event. These turbidites were deposited along the northern margin of the closing Tethys Seaway and are associated locally with the Hellenic Orogeny, which initiated in the mid Late Cretaceous and continued through the late Eocene-Oligocene. The Cretaceous turbidites of the Pindos Basin are sedimentologically and stratigraphically complex, with siliceous, carbonate and siliciclastic turbidite lithofacies commonly preserved.

To better understand the processes and paleoenvironments associated with these deposits, detailed geochemical analysis of mudstones associated with the siliciclastic sections of the Pindos turbidites were performed. Over 100 mudstone samples were collected for analysis at six outcrop localities. All mudstone samples were analyzed using Rock-Eval Pyrolysis and X-Ray Fluorescence (XRF). Selected samples were run through X-Ray Diffraction (XRD) coupled with polyvinylpyrrolidone (PVP) sorption for quantification of minerals, including clay minerals.

Rock-Eval pyrolysis and XRF data indicate sedimentary organic matter is largely terrestrial in origin, with Type III kerogens common and common enrichment of detrital trace metals such as titanium. Additionally, low preserved total organic carbon (TOC), low preservation of redox-sensitive trace elements, and high relative iron abundance when normalized with carbon and sulfur (C-S-Fe) all show that the siliciclastic turbidites of the Katafito Formation were likely deposited in oxic waters, with relatively high bioactivity. This is true for all localities and stratigraphic levels sampled. These results suggest that a) the Pindos Basin was still in good communication with the greater Tethys during the Cretaceous, leading to normal marine conditions and oxic waters, and b) that there was likely a strong connection between stream systems associated with the Hellenides Uplift and turbidite depositional fairways offshore to the south of the orogenic front.

SEISMIC GEOMORPHOLOGY AND EVOLUTION SYN-RIFT DEEP-WATER DEPOSITIONAL SYSTEMS: UPPER JURASSIC OF THE SNORRE FAULT HANGINGWALL, NORTHERN NORTH SEA

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ABSTRACT

Interaction between structural evolution and sedimentary depositional processes is an essential aspect of rift basins, driving basinal and landscape changes in space and time. The Late Jurassic Pancake Basin and adjacent footwalls in the northern North Sea rift, imaged in well-calibrated 3D PSDM seismic data, allow source-to-sink analysis of a rift basin. The Pancake Basin is a W-tilted half-graben, bound by the E-dipping Snorre fault to its west, with the Visund fault to its east. Seismic stratigraphy, sediment thickness and subcrop maps, and well-calibrated seismic geomorphology allow documentation of the geomorphology of sediment source areas, and the characterization of sedimentary processes in the Pancake Basin depocenter. The geomorphology and subcrop of the Snorre footwall crest highlight significant erosion, indicating that it acted as a local sediment source for the Pancake basin. Mapping of key unconformities and stratal units allow us to quantify this footwall crest eroded volumes, which allow local (adjacent footwall crest) vs regional (distant footwall crests and rift hinterland) sediment source contributions. A series of transverse fault scarp canyons are considered to be the major transport sediment pathway for base-of-slope fans along the bounding Snorre fault. Opposing, transverse, and oblique depositional systems occur along the dip slope, off the Visund fault block on the east side of the Pancake Basin. Integration of cored wells with seismic geomorphology demonstrates important deep-water sedimentary facies variability across the basin dependent on the location and character of dominant sediment input points. The study provides a detailed, seismic-scale example of coeval deep-water syn-rift depositional systems and improved conceptual models for the prediction and quantification of stratigraphic architecture within deep-water syn-rift depocentres.

LATERAL FACIES VARIABILITY IN CARBONATE TURBIDITES IN IONIAN BASIN OUTCROPS (CRETACEOUS, ALBANIA)

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ABSTRACT

Keywords: calciturbidites, facies analysis, inter-well variability, outcrop analogues

Carbonate slope deposits form an important part of modern carbonate platform-slope-basin systems and ancient counterparts. Carbonate sediment sourced from platform margins, and remobilisation of the slope itself, may accumulate in slope aprons or submarine fans, depending on the system morphology and the nature of the carbonate factories involved. This work investigates the deposits of unconfined carbonate sediment gravity flows derived from the margins of the southern province of the rudist-dominated Cretaceous Apulian carbonate platform. The studied deposits are part of the Ionian Basin succession that crops out today over ca. 25 km along strike, in a fold-and-thrust belt in southern Albania. The basal part of the succession (130 m, Campanian) comprises undeformed, sheet-like calciturbidites. This package is abruptly overlain by a series of five 10-50 meters thick mass transport deposits (MTDs) and intercalated calciturbidites (>200 m, Maastrichtian–Paleocene) that restore the MTD-inherited topography.

Here we focus on a 50 meter thick interval of the undeformed turbidite package, which is composed dominantly of grainy and muddy calciturbidites and occasional calcidebrites and hybrid beds. Bed thickness ranges from a few centimeters to over three meters. Grains are principally of bioclastic origin and dominated by rudist fragments, but coarser grains include carbonate intraclasts. Deformed mud clasts are common, in particularly ‘floating’ in a muddy matrix. Complimentary thin sections facilitate the occasionally problematic discrimination between muddy turbidites and hemipelagic deposits rich in planktonic foraminifers.

Three sedimentological logs of the same interval are presented at very high-resolution (sub-cm-scale) from three localities with several kilometers along-strike spacing from each other. Three marker beds are used for correlation between localities. The distribution of process-based facies is discussed using statistical methods to provide insight into the variation and predictability away from one-dimensional observations as for example encountered in exploration wells.

LOBE HIERARCHY OR LOBE ANARCHY? EXPLORING DEEP-WATER FAN STACKING PATTERNS USING A NUMERICAL STRATIGRAPHIC FORWARD MODEL

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ABSTRACT

Keywords: hierarchy, submarine fan, modeling

Flow-topography interaction in submarine fans, and how these interactions influence and create fan strata, remains a key area to understand in deep-water depositional systems. Several authors have described submarine fan strata as a three-or-four-order hierarchical arrangement, from bed or bed-set scale to lobe and lobe set scales. However, terminological discrepancies make these classifications difficult to compare and it is not clear if these lobe classifications really do describe fundamental properties of deep-water strata, or are just arbitrary, imposed models. We explore this question here using Lobyte3D, a reduced-complexity numerical stratigraphic forward model of turbidity flow routing and stacking patterns that evolve as sediment accumulates on a submarine-fan surface. For each model run, model behaviour was analysed by plotting down-slope flow routes and area deposition maps. Plots show how lobe formation is closely linked to avulsion history occurring due to a simple steepest-descent model algorithm and deposition thresholds.

We use several types of cluster analysis techniques, including KMeans, DBSCAN, and hierarchical clustering algorithms in order to test for natural grouping in the Lobyte3D output data that might provide more robust quantitative definition of what lobes are. Of the methods tested, the DBSCAN (Density-Based Spatial Clustering of Applications with Noise) algorithm performed best defining quantifiable groupings in the deposited strata that might define lobes. The results reveal that deposition from flows stacking both laterally and vertically prior to a considerable change in flow route owing to avulsion can be shown to belong to the same class, but this grouping breaks down in some circumstances, for example when flow volumes or seafloor topography are more variable.

PROCESS SEDIMENTOLOGY AND STRATIGRAPHIC ARCHITECTURE OF SUBMARINE CANYON OVERBANK ENVIRONMENTS, PUNTA BAJA FORMATION, MEXICO

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ABSTRACT

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Submarine canyons are incisional features that cut continental shelves and serve as conduits for deep-ocean currents that transport sediment, carbon and pollutants to deep-marine basin floor environments. For the majority of a canyon's life cycle, overbank settings such as terrace deposits, and internal and external levee successions, provide a valuable depositional record of overspill and flow stripping from bypassing currents in the adjacent axis. Many types of deep-ocean currents, including sediment gravity flows, internal tides and contour currents have been directly measured, however differentiating the deposits of these flows in the stratigraphic record provides a unique challenge, as deciphering the fine-scale sedimentary record of channel-overbank settings require exceptional outcrops. The Punta Baja Formation, Baja California, is a well-exposed submarine canyon-fill with good 3D constraints, which consists of coarse- and fine-grained domains that represent the canyon axis and overbank environments, respectively. Sedimentary logging and drone-captured photogrammetric models support the presence of internal levee successions with distinct fining-and thinning-upwards packages that decay in thickness away from the channel axis. Locally, these are disturbed by slides. Furthermore, we identify a range of distinctive bedform types that support flow interactions between turbulent, transitional, combined and tidal flow types, which include sandstone-mudstone banding, mixed grain-size laminasets, upstream-migrating laminasets, discontinuous sand and silt laminae, small-scale swale- and hummock-like structures and biconvex ripples. The spatio-temporal distribution of these sedimentary structures can be used to inform novel process models to unlock the potential of submarine canyons as archives of palaeoenvironmental change.