

# Shallow-Marine Research Group

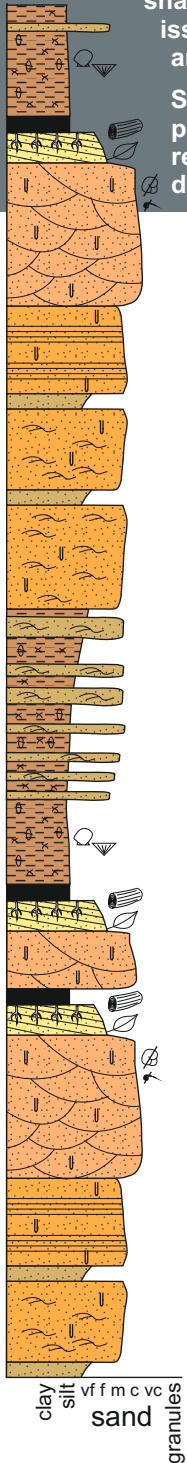
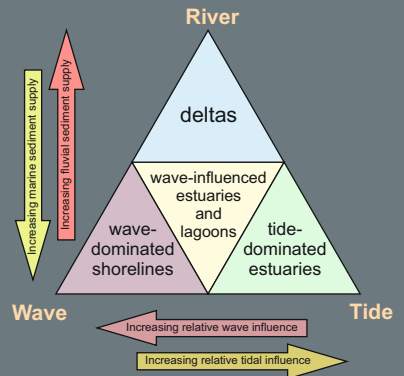
Phase 2  
Jan 2018 to Dec 2020

A recognized leader in the study and analysis of shallow-marine sedimentary systems.

An industry facing research group bringing together multi-disciplinary expertise in all aspects of applied shallow-marine sedimentary research.

Principal aim: to conduct cutting-edge research into the application of shallow-marine sedimentology for developing a better understanding of issues relating to hydrocarbon systems, mining and mineral exploration, and carbon sequestration.

Specific objectives: develop a state-of-the-art knowledge transfer programme to distil current thinking and trends in applied shallow-marine research; to present summary data and models in a format suitable for direct use by industrial sponsors.



## Overview

A Joint Industry Project research programme focussing on cutting-edge applied shallow-marine research, with emphasis on characterization of subsurface sedimentary architecture, techniques for reservoir prediction, and a web-delivered Knowledge Transfer programme. The research programme covers the following sedimentary environments and reservoir types: deltas, estuaries, paralic wave- & tide-dominated shorelines, clastic shelves.

## Principal SMRG 2018-2020 deliverables

- Company-wide access to:
  - Searchable bibliographic database and recommended literature summaries
  - Database of shallow-marine architectural-element dimensions (SMAKS)
  - Digital online training & self-learning materials
  - Video case studies and virtual outcrop guides
- Research outputs in:
  - Studies of deltaic, estuarine, paralic wave- & tide-dominated shoreline and open-clastic shelf successions and reservoir intervals
  - Shallow-marine depositional models for subsurface prediction and correlation
  - Morphology of modern shallow-marine systems
  - Process sedimentology
  - Reservoir characterization
  - External controls on shallow-marine systems
  - High-resolution studies of shallow-marine stratigraphic architecture
  - Sequence stratigraphy
  - Seismic geomorphology
  - Quantitative numerical models for bridging the gap between sedimentological datasets and reservoir models
- Specially tailored training and field courses

## Costs

New sponsors: £99k (£33k pa over 3 years)  
Returning sponsors: £90k (£30k pa over 3 years)

## Principal Investigators

- David Hodgson
- Nigel Mountney
- Bill McCaffrey
- Luca Colombera

## Petroleum Leeds

SMRG is run under the auspices of Petroleum Leeds at the University of Leeds (<http://petroleum.leeds.ac.uk>)

## Knowledge Transfer Programme: Deliverables

### SMAKS

#### Shallow-Marine Architecture Knowledge Store

A relational database tool for analysing numerical and descriptive data and information about deltaic, estuarine, paralic, shoreface and shallow-marine architecture coming from fieldwork and peer-reviewed literature, from both modern systems and their ancient successions.

- Web-based front-end for simple SMAKS queries to enable derivation of quantitative output applicable to: (i) developing conceptual models of subsurface heterogeneity; (ii) guiding well correlations of sand bodies; (iii) conditioning stochastic reservoir models.
- Obtain summary statistics on width-thickness-length aspect-ratio distributions for architectural elements; calculate facies transition probabilities in both vertical and horizontal dimensions (parallel & perpendicular to coastline); filter search criteria to ensure that results remain highly relevant to the reservoir interval being characterized.
- To enhance sponsor impact, the SMRG has collaborated with external partner PDS to develop a product that enables direct coupling of SMAKS with modelling workflows: Ava Clastics. (<http://www.pds.group/ava-clastics>).

### ATLAS

#### Atlas of Shallow-Marine Facies

An illustrated encyclopaedia of facies examples from a range of deltaic, estuarine and shallow-marine system types, which can be used to characterize subsurface core & consider palaeoenvironmental significance.

- Enables non-specialists to recognise and become familiar with a range of common and unusual types of shallow-marine facies, the likely processes involved in their generation, and their likely palaeoenvironmental origin and significance.
- Provides a list of possible modern and ancient outcrop analogues to assist with the interpretation of core.
- Serves as a source of images and graphics that can be used by sponsors to illustrate their own presentations.

**Research Outputs:** A growing catalogue of research documents in the form of reports, theses, papers, posters, conference presentations, videos, knowledge transfer resources and software; includes all the raw data relating to architecture and facies distributions.

**Sponsors' Meetings:** A sponsors' meeting each year (sponsor representatives to pay for their own travel and subsistence costs); the venue for this meeting will vary but may typically be in the UK or USA.

**Company Visits:** Visits to the sponsor companies by group members on a cost-only basis. Typically this might be timed to coincide with AAPG or a similar US conference in the case of US-based sponsor companies.

**SMRG Sponsors' Field Trips:** The option for members of sponsor companies to attend a group field trip to study a range of modern and ancient sedimentary successions, including deltaic, estuarine, paralic shoreline and shallow-marine systems and successions; study locations determined by the interests of the sponsor companies; trips will typically be to locations in Europe or North America.

**Workflows For Subsurface Interpretation:** Guidance in how to design and implement a workflow for the interpretation of subsurface deltaic, estuarine, paralic shoreline and shallow-marine successions.

**Taught Short-Courses:** In-house bespoke taught short-courses available as an add-on.

**Forward Stratigraphic Modelling Software:** Access to in-house-developed stratigraphic modelling software for assessing likely reservoir heterogeneity; the software serves as a set of tools to assist in reservoir modelling. Software start-up guides provide instruction on usage.

**Company-Wide Access:** All employees of the sponsor company worldwide gain access to the entire data set and full set of resources.

**Rolling Programme of Research Projects:** We aim to start an average of 2 new PhD studentships per year; projects are designed to focus our research efforts in areas of non-marine sedimentology that are of primary interest to our sponsors.

### SM-Lit

#### Shallow-Marine Literature Review & Summary

Bibliographic review databases that allow industry professionals to keep abreast of advances in the academic literature and incorporate the latest thinking into their work. Additionally, these tools allow people new to shallow-marine clastic sedimentology to quickly develop an understanding of these depositional environments. Reviews are undertaken by experts in the field, and tailored for industry-professional end-users.

- A comprehensive listing of literature relating to deltaic, estuarine, paralic-shoreline and shallow-marine sedimentary environments.
- Listings and reviews of new publications.
- SMRG ratings and lists of recommended papers by theme and key applied research criteria.
- Summaries of key recommended papers written by SMRG investigators to provide insightful overviews of important advances in the scientific field.

### FoG

#### Fundamentals of Geoscience

A set of self-contained e-learning resources designed to enable non-geologists gain knowledge in sedimentology & applied reservoir geology quickly and effectively.

- The resources serve as a refresher of core concepts for specialist geologists.
- Acts as a point of access to more specialized and detailed discussions through the provision of a series of integrated references.
- Serves as a source of high-quality graphic artwork for use by sponsors to illustrate their own presentations.
- Illustrated with a range of case studies from well-known modern systems and ancient outcrop successions.

## Research Programme: Themes

### THEME 1. Meta-analysis of geological controls on incised-valley fill geometries and facies architecture (started 10-2016, PhD Ru Wang)

A comparative study undertaken using outcrop and geophysical data on late Quaternary and ancient valley fills, collected from published sources. Through employment of the Shallow-Marine Architecture Knowledge Store (SMAKS), the geometry and facies organization of incised-valley fills and architectural elements contained therein are analysed, with the scope of assessing established concepts regarding the relative importance of upstream, downstream and shelfal controls (e.g., shelf-edge depth, drainage area) on incised-valley characteristics and testing aspects of sequence stratigraphic models (e.g., geometry of type-1 vs. type-2 sequence boundaries).

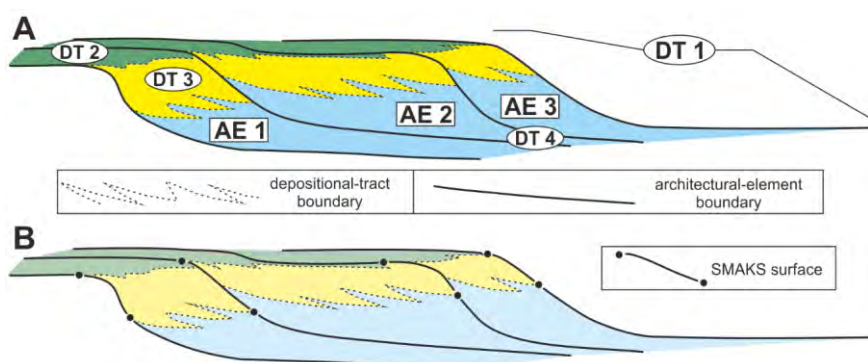
### THEME 2. Assessment of the impact of external and intrinsic controls on deltaic-system development within a range of environmental settings and sedimentary basin type (start end of 2017)

Through development of the SMAKS database, this research aims to address research questions that are exemplified by, but not limited to, the following topics:

- What is the 3D facies architecture, internal and external heterogeneity, and connectivity of sand-bodies within fluvial-dominated delta tops subject to different climatic settings?
- How does the geometry, connectivity and stacking pattern of distributary channel fills vary spatially and temporally within delta tops, and how well do these variations match with what is predicted by recent models that invoke backwater controls?
- How do allogenic factors, such as climate and relative sea-level change, influence and dictate autogenic behaviour in deltaic systems, such as frequency of delta-lobe avulsion, and how are such changes manifest in the preserved stratigraphic record?
- Are there scaling relationships between sub-components of deltaic systems that can be used predictively (e.g., mouth-bar size as a function of distributary-channel size)?
- Are there commonalities in the way attributes (e.g., geometry, timescale) of Quaternary delta-lobes and deltaic parasequences in the ancient stratigraphic record are controlled by specific boundary conditions (e.g., accommodation: sediment-supply ratio)?
- Is it possible to establish how the hierarchy of deltaic constructional units (e.g., lobes at multiple scales) vary as a function of the size of a delta and its controls (e.g., drainage area, mean yearly discharge)? Can such hierarchical stacking patterns be identified through analysis of bounding surface arrangements and stratal trends in ancient systems, and on drainage orders in modern systems?
- Are there relationships between the direction of seismic-scale shoreline trajectories and the potential sedimentary characteristics of the different physiographic elements of a delta (delta top, delta front, prodelta)?

### THEME 3. Test and re-develop classic facies models for shoreline profiles associated with different process regimes. Sedimentological and ichnological data from multiple successions and modern seas are synthesized into facies models via a database approach

The output is a suite of quantitative models that describe the texture, sedimentary structures, bioturbation intensity, ichnogenera occurrence, bed and bedset thickness, of shoreline-shelf deposits, in which information on geological uncertainty is inbuilt, and which can be employed to assist interpretation of subsurface datasets and prediction of reservoir heterogeneity.



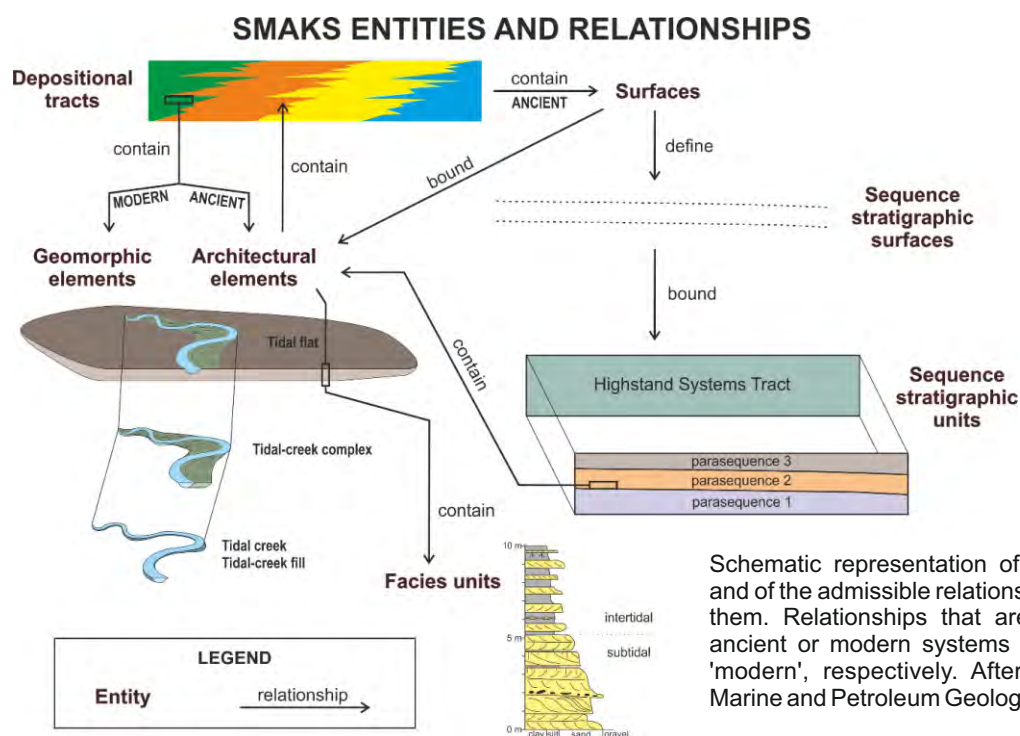
Example of possible relationships between depositional tracts and architectural elements, as seen along an idealized dip-oriented section: a 'deltaic' depositional tract (DT1: all the coloured domain) contains 3 'delta-lobe' architectural elements (AE1-3) and lower-order 'delta-top', 'delta-front' and 'prodelta' depositional tracts (DT2, DT3 and DT4, respectively) that themselves crosscut the architectural elements. (B) Ideal representation of how SMAKS surfaces may be contained in depositional tracts, and of how they may form the base or top (or a part thereof, in this particular example) of architectural elements. No vertical or horizontal scale implied. After Colombero et al. (2016) *Marine and Petroleum Geology*, 75, 83-99.



## Research Programme: Themes

### THEME 4. Revisiting the origin and significance of siliciclastic shallow-marine parasequences

A meta-analysis of outcrop and subsurface datasets of shallow-marine parasequences is carried out using a database approach. The following research objectives are identified: (i) assessing the importance of accommodation regime and sediment-supply rates in shaping the geometry and stacking patterns of parasequences; (ii) establishing relationships, or lack thereof, between the temporal significance of parasequences and the inferred duration of fluvial- and or wave- or storm-dominated packages of Quaternary shallow-marine deposits, and quantifying the temporal punctuation of parasequences in parasequence sets, systems tracts, and sequences; (iii) determining recurrent interpretational or observational biases in the attribution of nearshore deposits to parasequences.



Schematic representation of SMAKS database entities and of the admissible relationships that may exist between them. Relationships that are exclusively applicable to ancient or modern systems are labelled as 'ancient' or 'modern', respectively. After Colombero et al. (2016) *Marine and Petroleum Geology*, 75, 83-99.

### THEME 5. Prediction of stratigraphic trapping in tide-dominated transgressive systems tracts

This study integrates sedimentological data from ancient and Quaternary deposits with geomorphological data from modern seas, compiled in SMAKS from a number of published case studies, to offer a quantitative characterization of the sedimentary architecture of tidal sand-ridge deposits. This work has 2 main objectives: (i) assess the value of modern sand-ridge landforms as analogues for stratigraphic traps and reservoir units, by determining the roles of morphodynamic evolution and preservation potential in controlling the architecture of preserved stratigraphic products; (ii) demonstrate the sensitivity of sand-ridge morphometry to plausible controlling factors, thereby enabling predictions of likely reservoir continuity or trapping potential from knowledge of depositional boundary conditions (e.g., tidal range, transgression rate).

### THEME 6. Analysis of coupled tidal-inlet and barrier-island morphology and evolution, and implications for facies and sequence stratigraphic models of transgressive systems tracts

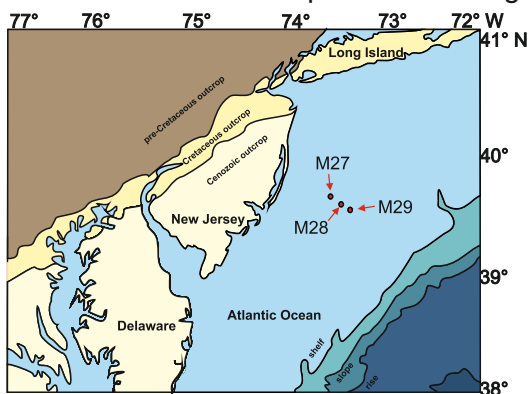
A database analysis will be undertaken using data collated from existing time series of bathymetric and remote-sensing data, on the geomorphologic characteristics and morphodynamic behaviours of tidal inlets, barrier islands, and genetically related flood and ebb tidal deltas, part of which will feed into the SMAKS database. Data on tidal-inlet depth, width spacing/density, lifetime and migration rates, and on barrier-island geometries and backstepping rates are combined with the aims of (i) developing conceptual models of the preserved expression of transgressive barrier-island deposits in wave-dominated, tide-influenced transgressive successions, (ii) assessing the value and limitations of modern analogues for understanding and predicting the stratigraphic architecture, (iii) establishing a foundation for developing geometric-based forward stratigraphic models of barrier-island architecture.

## Research Programme: Themes

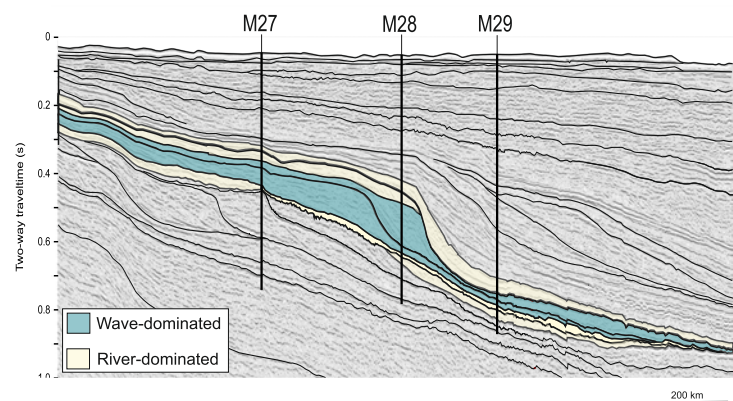
### THEME 7. The continental shelf: a conveyor or filter of sediment deep water (started 10-2015, PhD Grace Cosgrove)

The continental shelf can act as both a conveyor and a filter during sediment transfer from the continents to the deep oceans. However, the up-dip controls on the character of sediment deposited in deep-water are poorly understood due to the lack of sampling of coeval shelf deposits. There is a need to better constrain the buffering role played by the shelf on sediment dispersal patterns in terms of both morphological and sedimentological parameters. The key question to address is how and when is sediment of different calibre and maturity is transported off the continental shelf. The aim of this theme is to critically evaluate the conventional process-based facies model for wave-dominated and river-dominated shelf-systems, through quantitative bed-scale grain character analysis. Sediment samples have been collected from three cores (M27/M28/M29) recovered during IODP Expedition 313, Offshore New Jersey, USA. This location is an ideal 'natural laboratory' for studying the continental shelf and its function as a staging area for sediment delivery to the deep sea, due the preservation of chronostratigraphically linked, complete clinothem sequences tied to a eustatic sea-level curve.

Since the development of the sequence stratigraphic paradigm researchers have been attempting to quantify the delivery of sand from the shelf-edge into deep-water settings. However, understanding the driving mechanisms that govern sand deposition in deep-water basins remains poorly constrained. Significant emphasis has been placed on accommodation and sediment delivery rate. In recent years, greater emphasis has been placed on the dominant shelf-process regime as the principal means of regulating sediment transfer to deep-water. Accompanying these recent advancements is an increased reliability on the traditional models describing deposition within these shelf settings. However, statistical analysis of this high-resolution grain character dataset indicates significant departures from the expected grain character profiles associated with wave-dominated and river-dominated clinothem deposition. This highlights the need for caution when applying these models.



Locality map of the New Jersey margin, indicating the position of the cores taken during IODP Expedition 313. Adapted from Monteverde et al. (2008).



Seismically imaged Miocene clinofolds on the New Jersey margin. The black lines indicate sequence boundaries; the shaded area indicates the boundaries of the area being investigated for each core. Adapted from Monteverde et al. (2008).

### THEME 8. Stratigraphic architecture of shallow-marine systems in syn-rift to post-rift settings

Syn- to post-rift shallow-marine systems are active during thermal subsidence and marine transgression, and preserve a complicated depositional architecture. For these systems, it is challenging to develop widely applicable stratigraphic models. A further factor is the role that different rock types exposed in the nearby sediment source area has on the lateral variability of sediment flux and calibre along the length of partially submerged footwall highs. In contrast, many exhumed paralic systems are supplied by a far-field hinterland across wide and low gradient shelves with limited lateral variability resulting in organised successions and simple predictive models. This aim of this theme is to develop stratigraphic models that consider a range of parameters important in syn- to post-rift systems in order to improve the prediction of subsurface reservoir systems. This will be completed through the analysis of exhumed (e.g., Loreto Basin, Baja California and Neuquén Basin, Argentina) and subsurface (e.g., Fulmar Formation, North Sea) syn- to post-rift shallow-marine systems. This project will build on and incorporate well-studied exhumed syn- to post-rift shallow-marine systems (e.g., Gulf of Corinth, Greece and Sinai Peninsula, Egypt).

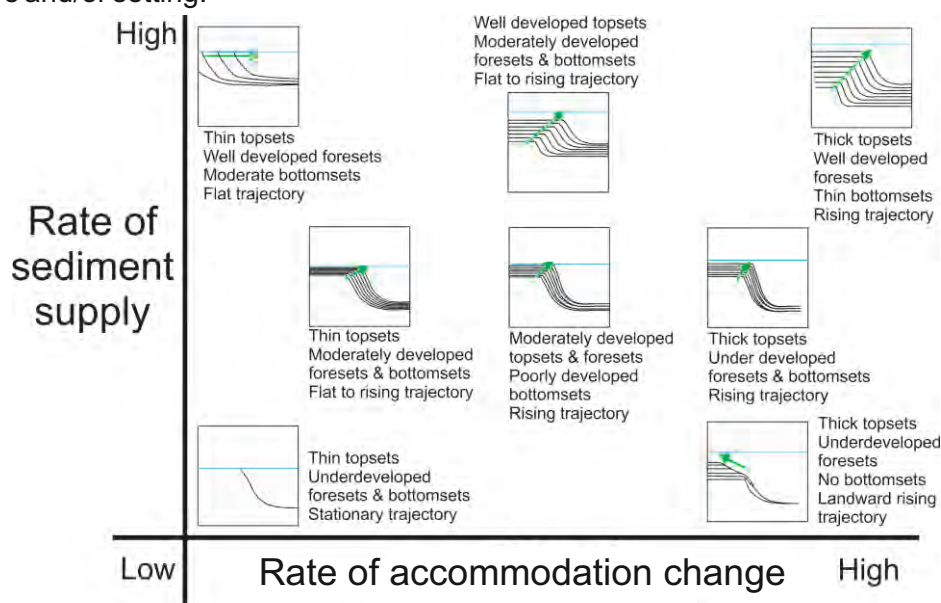


## Research Programme: Themes

### THEME 9. Quantitative characterization of shelf architecture

Investigations, and models, on the architecture of continental shelves are dominated by excellent outcrops of ancient greenhouse mid-latitude systems. How can the wider range of continental shelf architecture be constrained to improve the choice of analogues for subsurface systems? The most intensively studied paralic sedimentary successions are exhumed ancient systems supplied by a far-field hinterland across wide and low gradient shelves with limited lateral variability over several kilometres. The large distance from the sediment source area and the simple physiography of these systems leads to organised successions that have resulted in the development of stratigraphic models with predictive strengths that can be applied to suitable subsurface analogues. This theme will identify ancient and modern systems in a variety of tectonic and latitudinal settings, and establish a more realistic range of architectural facies models. The data collected will be fed into the SMAKS database, and the research findings from the database will be exploited to constrain variations in shallow-marine architecture and through identification of previously neglected combinations of boundary conditions.

- Syn- to post-rift shallow-marine systems are active during crustal stretching and thermal subsidence, and marine transgression. Such systems preserve complicated depositional architectures for which it is more challenging to develop widely applicable stratigraphic models. In syn- and post-rift settings, parameters such as dynamic gradients and depocentres that influence sediment dispersal patterns and processes need to be considered. A further factor is the role that different rock types exposed in the nearby sediment source area has on the lateral variability of sediment flux and calibre along the length of (partially submerged) footwall highs. This will be completed through the analysis of exhumed (e.g., Loreto Basin, Baja California and Neuquén Basin, Argentina) and subsurface (e.g., Fulmar Formation, North Sea) syn- to post-rift shallow marine systems.
- Restricted shallow-marine basins are a common hydrocarbon play due to widespread stratigraphic and tectonic trap potential, and the proximity of reservoir to source rocks. However, published stratigraphic models of shelf construction are biased towards observations from ocean-facing, shallow shelves in mid-low latitude settings from ancient outcrop (e.g., Cretaceous Western Interior seaway, USA), ancient subsurface (e.g., New Jersey margin) and modern (e.g., US Pacific coast) settings. This is despite the marked differences in tidal amplitude, current strength and directions, and the potential for anoxia. Non-conventional shale gas and oil plays bring an additional focus to the analysis of these system types. For example, an important research objective is to establish whether there is anything systematic about the preservation of high primary TOC concentrations and particular combinations of architecture and/or setting.
- High-latitude and icehouse shelves have complicated accommodation and sediment supply relationships with isostatic and sediment flux changes in response to the waxing and waning of ice sheets. These margin types are becoming a focus of interest from an exploration (and associated geohazard) point-of-view. In the last decade, there has been a large amount of subsurface data collected from late Pleistocene to Holocene mid- to high-latitude continental shelves in relation to the offshore wind farm industry. These data will permit this type of margin to be characterized, and allows the high-resolution analysis of the process response to marine transgression.



Cartoon plotting rate of sediment supply against rate of accommodation change (increase) to convey the range of basin margin architecture. How does the topset (shallow-marine) sedimentology and stratigraphy change in relation to the larger-scale architecture? Adapted from Jones (2013).