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Fluvial, Eolian & Shallow-Marine Research Group

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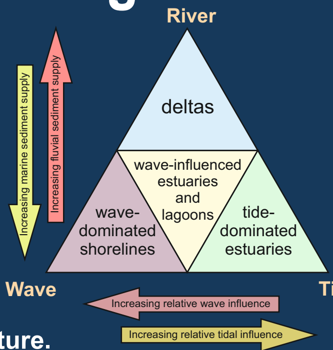
SMAKS: Shallow-Marine Architecture Knowledge Store

A database storing aspects of paralic & shallow-marine sedimentary architecture that can be applied to reservoir characterization & prediction. The database serves as a tool with which to achieve the following primary goals:

- generate quantitative facies models for bespoke coastal & shallow-marine sedimentary systems that act as subsurface reservoir bodies;
- guide well correlation of shallow-marine sandstone bodies;
- condition object- and pixel-based stochastic reservoir models;
- predict the likely heterogeneity of geophysically imaged geobodies;
- inform interpretation of lithologies observed in core and predict 3D architecture.



Sedimentary architectural expression of a shoreface parasequence, Cretaceous Blackhawk Formation, Book Cliffs, Utah, USA

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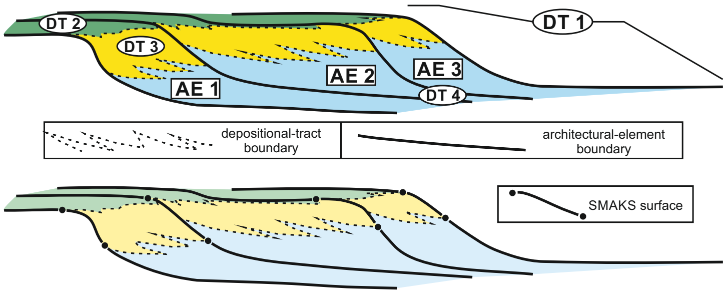
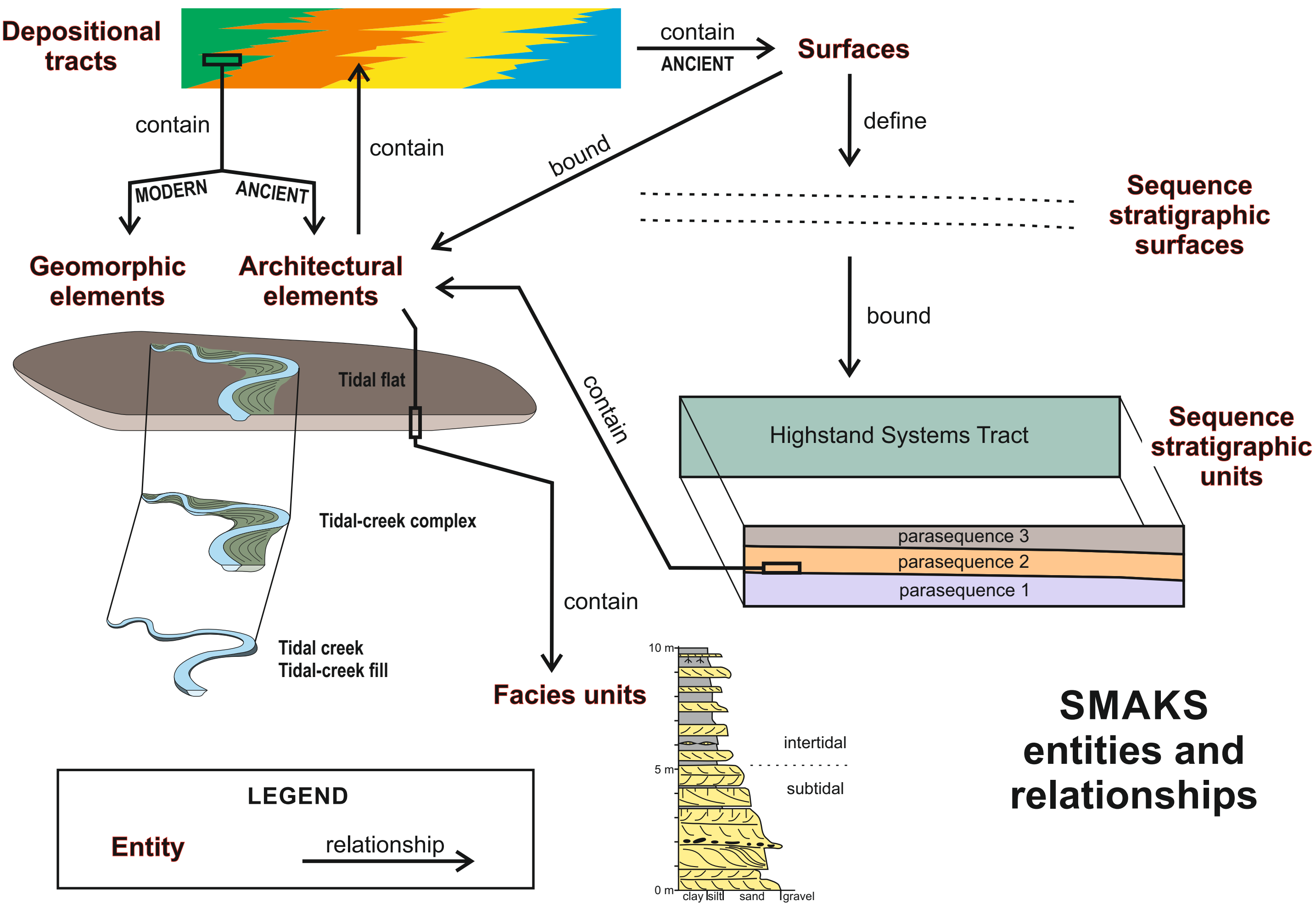
Introduction: Shallow-Marine Architecture Knowledge Store (SMAKS)

The Shallow-Marine Architecture Knowledge Store (SMAKS) is a relational database devised for the storage of hard and soft data on the sedimentary architecture of ancient shallow-marine and paralic siliciclastic successions, and on the geomorphological organization of corresponding modern environments. The database allows incorporation of data from the published literature, which are uploaded to a common standard to ensure consistency in data definition. The database incorporates data on geological entities of varied nature and scale (i.e., surfaces, depositional tracts, architectural elements, sequence stratigraphic units, facies units, geomorphic elements), including attributes that characterize their type, geometry, spatial relations, hierarchical relations, and temporal significance. Furthermore, geological entities are assigned to depositional systems, or to parts thereof, that can be classified on multiple parameters (e.g., shelf width, delta catchment area) tied to metadata (e.g., data types, data sources).

The SMAKS permits the quantitative characterization of modern and ancient shallow-marine and paralic clastic depositional systems. It aims to serves as a repository of analogue information for hydrocarbon-bearing successions, and as a research tool, applicable to aid the development of facies models or to assess the sensitivity of depositional systems to particular controlling factors, for example.



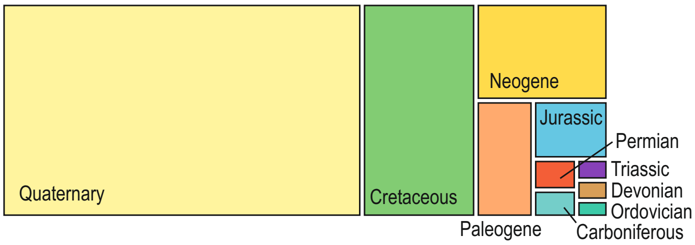
Above. Idealized example of the definition of SMAKS depositional tracts (DT), architectural elements (AE) & surfaces.



Above. Ranks of sedimentary and geomorphic units of the SMAKS database.

How does SMAKS work?

Improvement in subsurface prediction of shallow-marine and paralic siliciclastic hydrocarbon reservoirs is typically attempted through the characterization of ancient and modern depositional systems that represent potential reservoir analogues. Analogue data are applied in scenarios of reservoir exploration, development and production: (i) to predict the potential occurrence and size of stratigraphic traps; (ii) to predict the seismic resolvability of sedimentary bodies; (iii) to erect conceptual reservoir models; (iv) to guide well-to-well correlations of sedimentary units; (v) to condition static reservoir models. Ancient and modern analogues are generally characterized through a number of approaches and at multiple scales of observation (e.g., sedimentary facies and architectural-element analysis of ancient outcrop successions, mapping key stratal surfaces at outcrop or in seismic data to erect a sequence stratigraphic framework, analysis of aerial photographs or satellite imagery of modern environments).

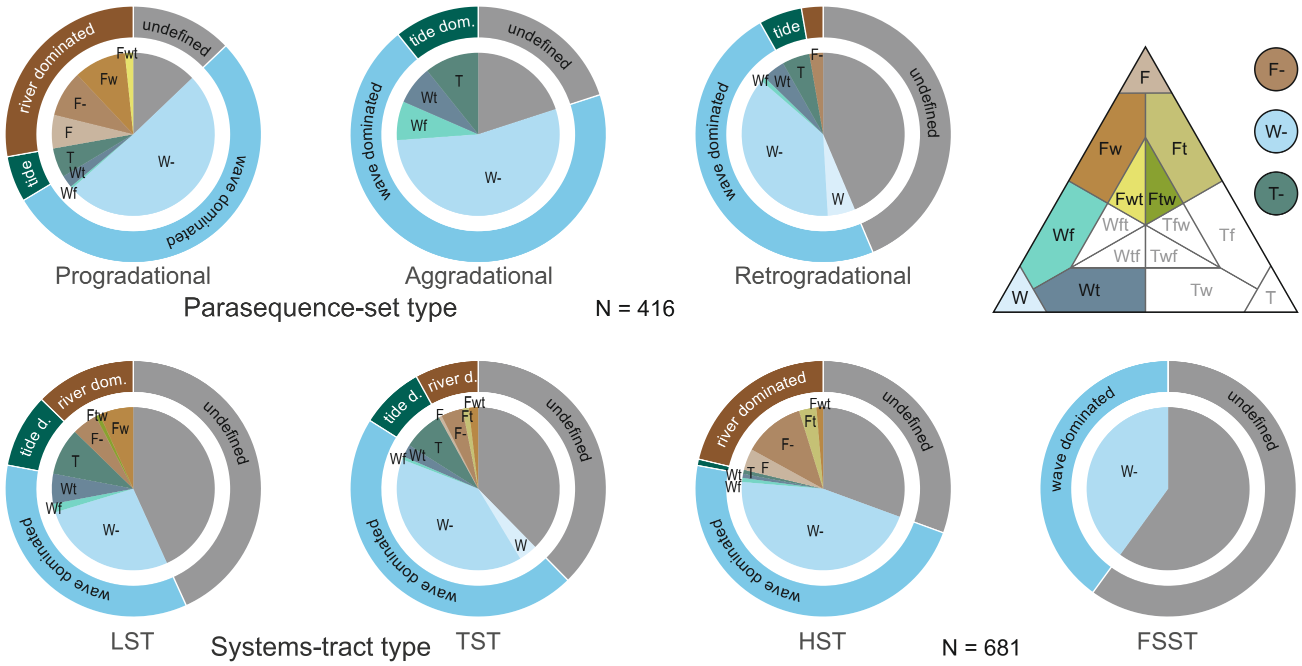


Above. Distribution of SMAKS >220 analogues through geological time.

The SMAKS database methodology brings together analogue datasets from different data types and contexts, associated with different classes of paralic and shallow-marine depositional systems.

This document (i) presents a brief description of the content database, (ii) illustrates the types of quantitative output that can be generated upon interrogation of the database through the implementation of queries of geological significance, and (iii) demonstrates how this information can be used for purposes of subsurface characterization in applied contexts.

The sedimentary and geomorphological architecture of preserved ancient successions and modern environments are translated into the database in the form of entries within tables organized in a relational schema. Some of these entries represent geological entities (e.g., sedimentary units, surfaces) at different scales of observation and which result from different, although not mutually exclusive, approaches to analogue characterization (e.g., facies analysis, architectural-element analysis, sequence stratigraphy). Other entries represent relationships between geological entities (unit transitions, surface relationships). In this way, all the significant aspects of clastic sedimentary architecture are considered in the database conceptual model.

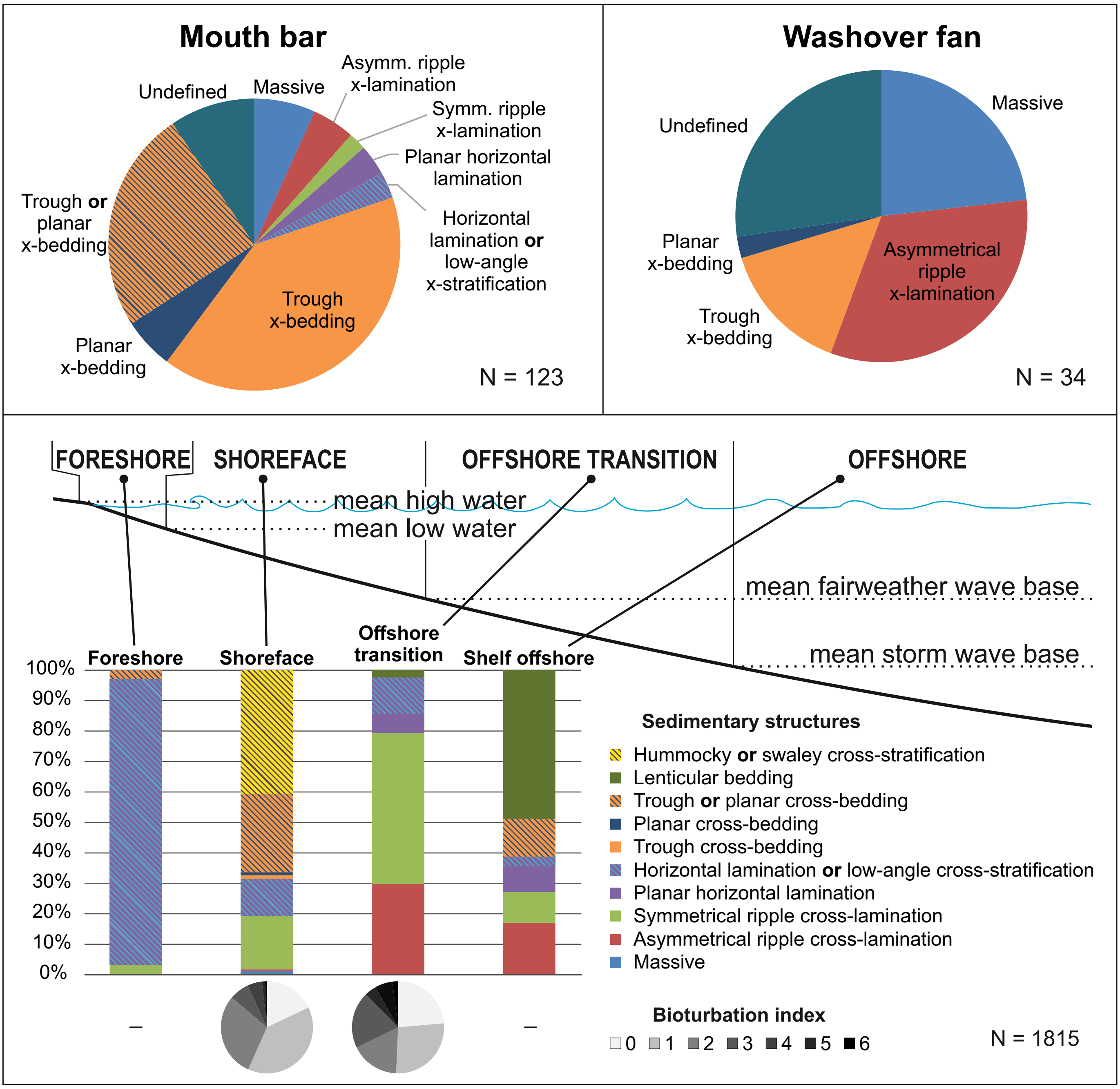


Above. SMAKS output on the relative frequency of parasequences classified on process dominance across different types of parasequence sets and systems tracts.

SMAKS

SMAKS analysis at the scale of architectural elements and lithofacies units

To demonstrate the wide applicability of the database in fields of both fundamental and applied research, example database output is presented that (i) includes data from wave-, tide-, and fluvial-dominated shallow seas and sedimentary successions, and (ii) covers a wide depositional spectrum, from backshore to shelf-edge settings. Examples of the types of output that can be retrieved from SMAKS include information on the facies organization of different types of paralic sub-environments, on the hierarchical arrangement of architectural elements that form deltaic constructional units in Quaternary deltas, on the morphometry of modern and Quaternary tidal sand ridges, and on the geometry of parasequence-scale nearshore sandstone belts, either globally or for specific depositional systems (e.g., the Upper Cretaceous successions of the Western Interior Seaway, Utah, USA).



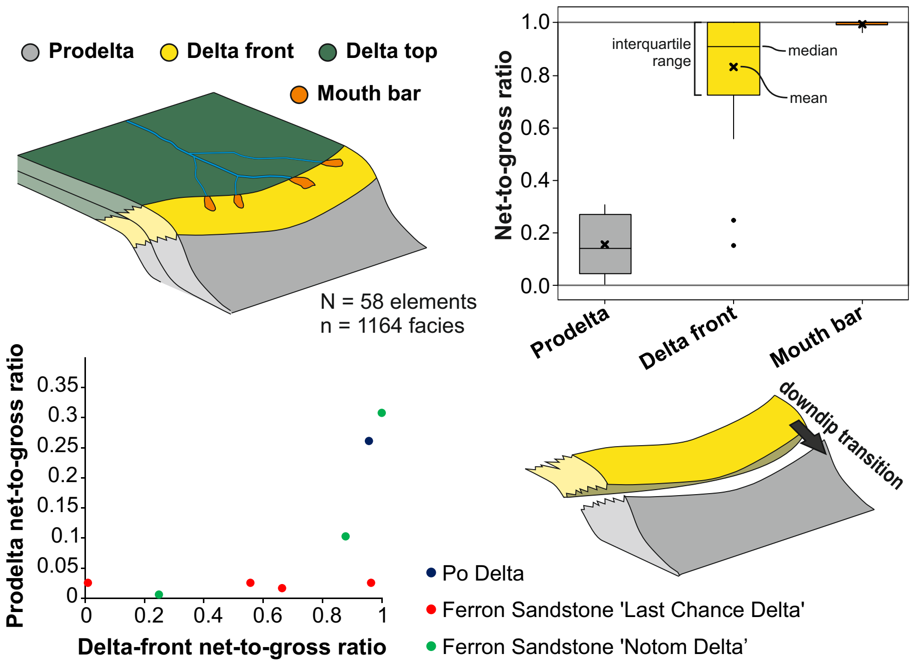
Above. SMAKS facies models quantifying the facies make-up of different types of shallow-marine sub-environments.

SMAKS

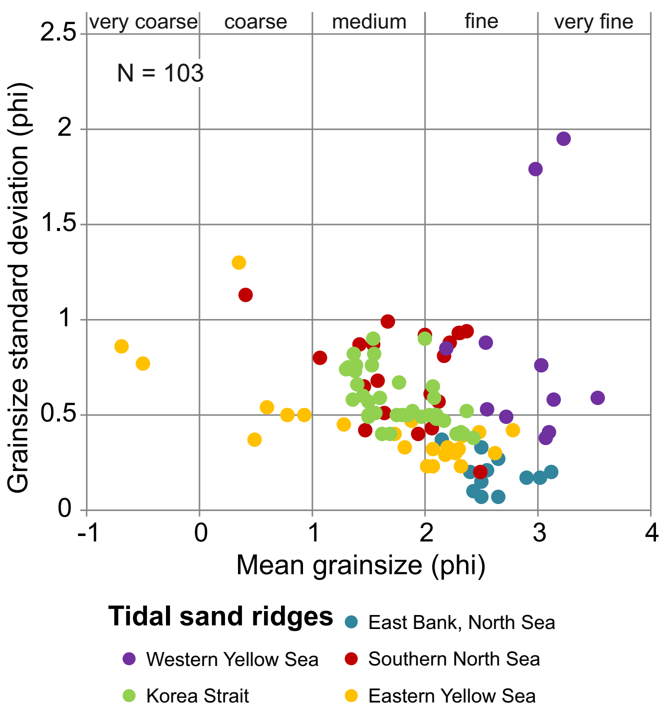
How can SMAKS be applied for subsurface characterization?

The database design and standard have been structured with consideration of the variety of approaches and data types that are taken in studying the sedimentary geology of shallow-marine and paralic depositional systems. The database allows for a convergence of datasets from studies of outcrops, of the subsurface and of the modern seabed. This convergence permits the reconciliation of facies analysis, architectural-element analysis, sequence stratigraphy and geomorphology.

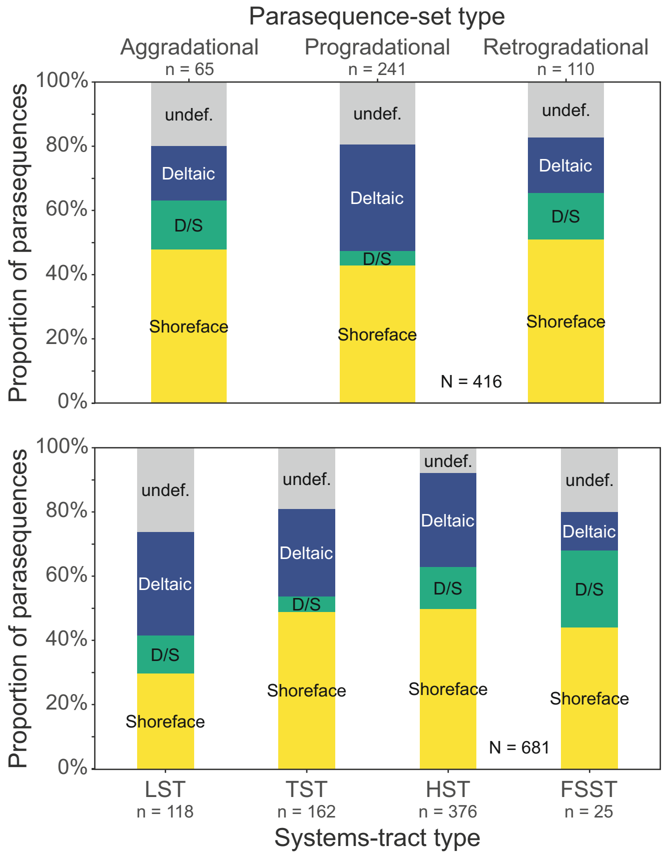
SMAKS can be applied to characterize subsurface reservoir successions for which only limited data are available. The database can also provide hard data with which to constrain reservoir models. Additionally, it can be used to develop bespoke facies models.



Above. SMAKS output that quantifies the net-to-gross ratio of deltaic elements from selected analogues.



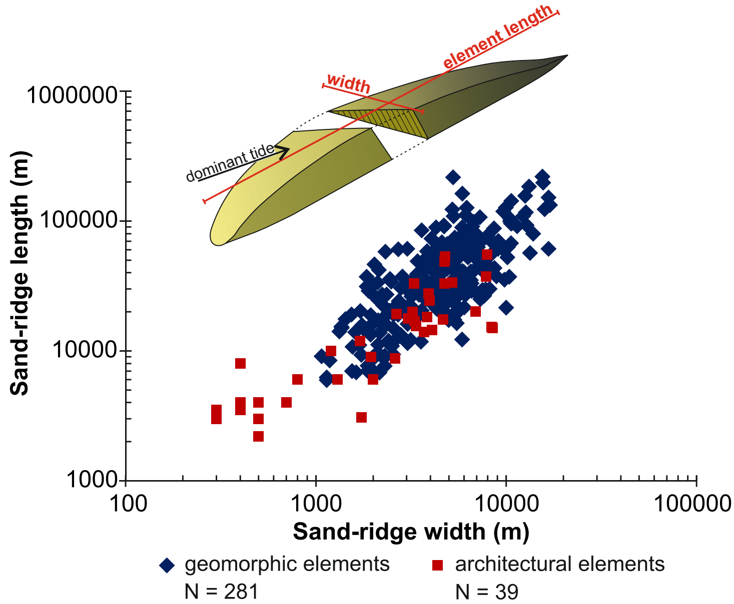
Above. SMAKS output on grainsize statistics relating to the deposits of recent shelf tidal sand ridges. this type of output contributes to the compilation of quantitative facies models, which may find application as templates for assisting with sub-environment interpretation of ancient deposits. The discrimination of grain-size domains can be applied to predict expected reservoir quality.

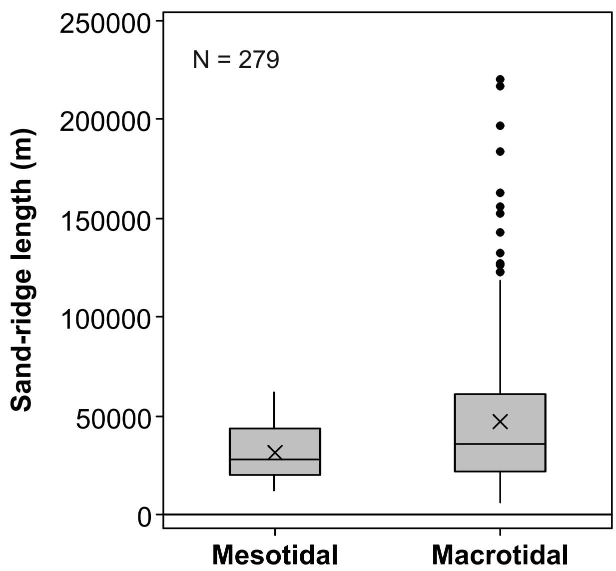


Above. SMAKS output on the relative proportion of parasequences classified on environment of origin across different types of parasequence sets and systems tracts.

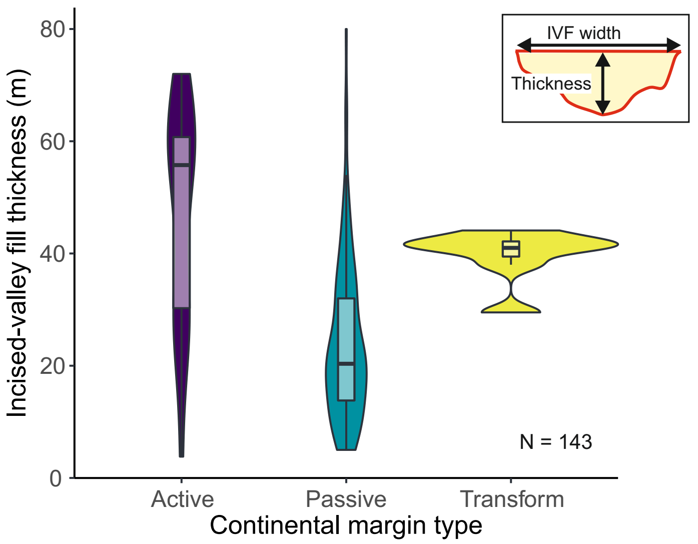
How can SMAKS be applied for subsurface characterization?

The ability to query for sedimentological properties and to apply filters to SMAKS output permits the selection of analogues that share user-specified characteristics, which could be sedimentological characteristics or parameters that describe the depositional context. The synthesis of quantitative information from multiple case studies results in the construction of composite analogues, which incorporate variability in sediment-ological and stratigraphic properties, and are therefore suitable for the quantification of associated uncertainty. These serve as quantitative facies models that can be used to predict reservoir heterogeneity, conditioning stochastic geocellular reservoir models, and guide well-to-well correlations of sandbodies.

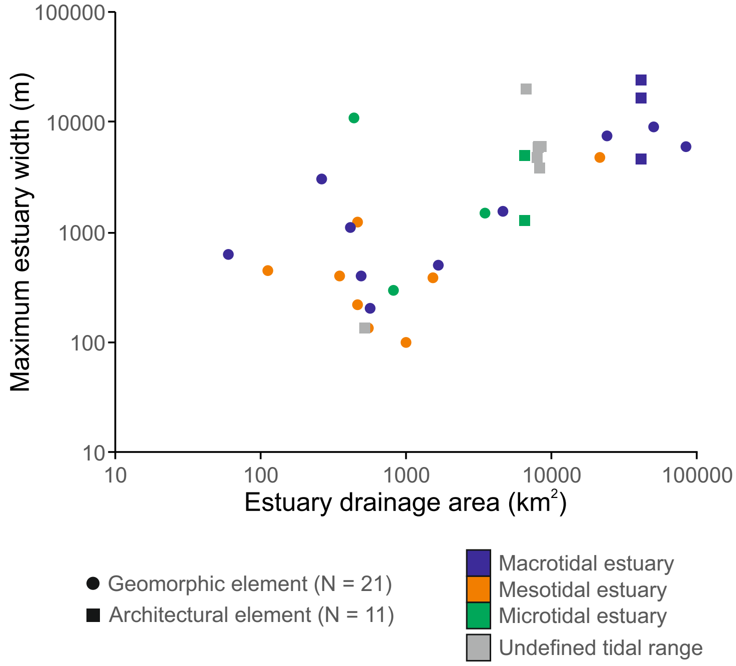




Above. SMAKS output on the geometry of architectural and geomorphic elements classified as shelf tidal sand ridges.



Above. SMAKS output on the thickness of Quaternary incised-valley fills classified by type of continental margin across which they developed. SMAKS stores information on >100 IVFs from both late Quaternary and ancient settings. The database quantifies the geometry and proportion of systems tracts, and of architectural elements of different hierarchies within IVFs. Resultant bespoke facies models aid subsurface characterization.



Above. SMAKS output on the relationship between the width of 'estuary' architectural and geomorphic elements and the size of the estuary catchment.

SMAKS

SMAKS output

All data stored within SMAKS can be filtered on analogue depositional-system parameters or associated architectural properties to match with a given subsurface system of interest. Example outputs from the SMAKS database are presented throughout this document.

In its most basic form, SMAKS output consists of quantitative information about:

- proportions of genetic units within higher-scale units or volumes;
- geometrical parameters of genetic units;
- spatial relationships of genetic units in three dimensions.

This output can be employed to generate information directly applicable to subsurface problems, such as plots of genetic-unit width-to-thickness aspect ratios, tabulated genetic-unit transition statistics, statistical distributions of user-defined genetic-unit net-to-gross values.

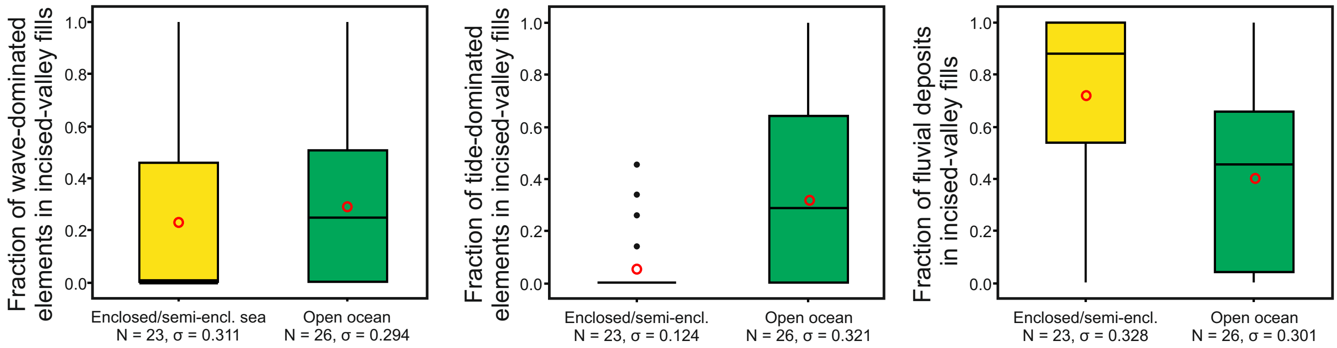
SMAKS content

SMAKS currently includes data associated with:

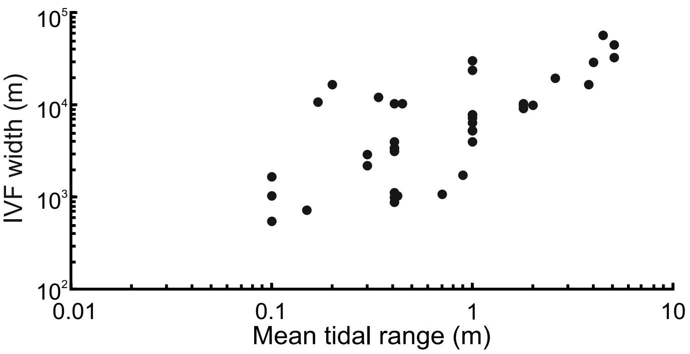
- >220 case studies;
- 581 subsets;
- 815 classified depositional tracts;
- 4,892 architectural elements;
- 1,889 geomorphic elements;
- 2,354 geological surfaces;
- 2,171 sequence stratigraphic units;
- 38,684 facies units;
- 86 datasets with substantial statistical summaries.

Over 500 additional peer-reviewed articles have been identified as containing architectural data suitable for database input, which is on-going. Figures are correct as of June 2020.

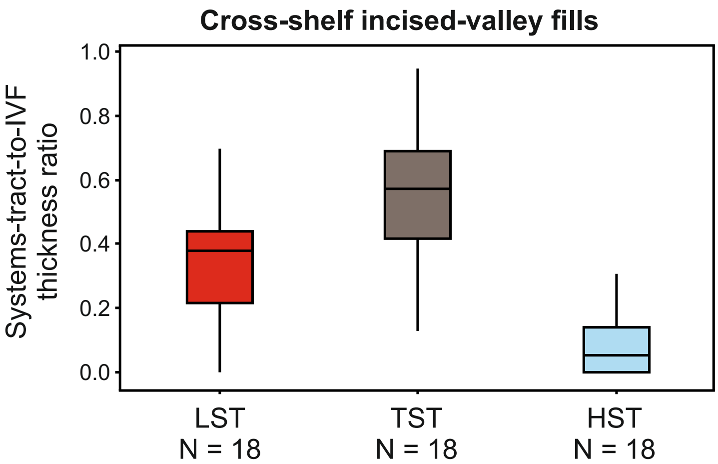
The following pages present example output to demonstrate how SMAKS can be applied.



Above. SMAKS output on the proportion of wave-, tide- and river-dominated deposits in incised-valley fills classified according to their physiographic setting.

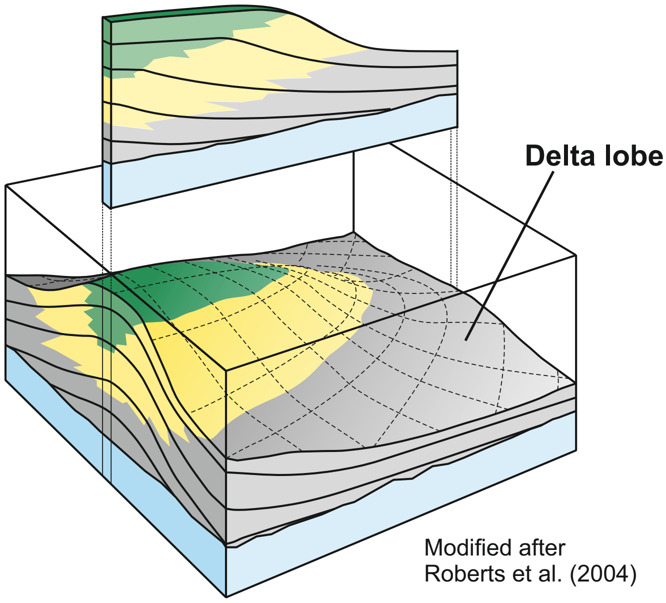


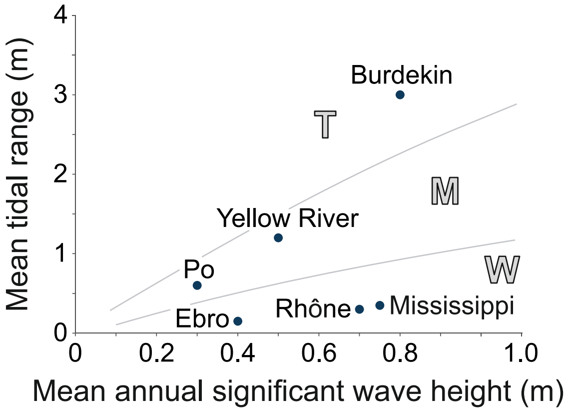
Above. SMAKS output relating incised-valley fill (IVF) width to mean tidal range at the shoreline. Information such as this can be used to help refine gross depositional environment models in exploration targets. Where sand-prone geobodies are present in IVFs, knowledge of regional tidal regime is important for predicting potential reservoir scale.

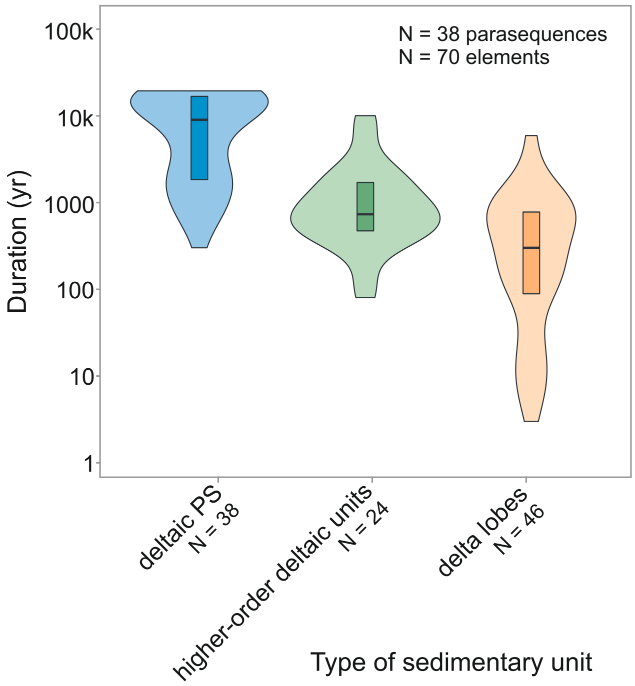


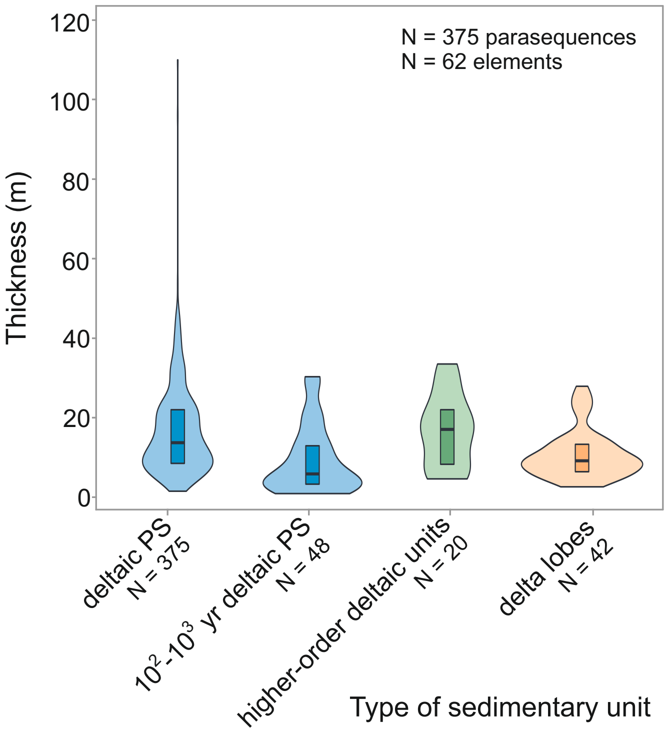
Above. SMAKS output on the relative preservation of deposits associated with different systems tracts in cross-shelf incised-valley fills.

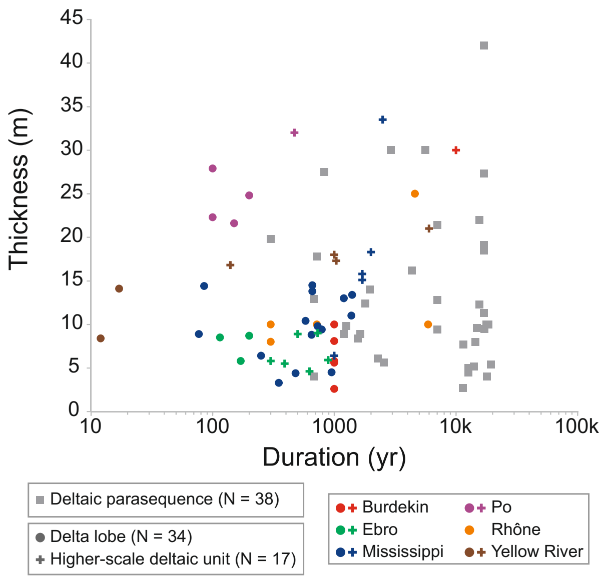
SMAKS application 1: analysis of delta lobe progradation and stacking











SMAKS output quantifying the spatio-temporal significance of different ranks of deltaic constructional units recognized in the stratigraphy of active deltas; a comparison is made with recent and ancient deltaic parasequences. Violin plots show distributions in the length of time over which these types of units have developed and in their maximum observed thickness. The boxes in the plots represent interquartile ranges and horizontal bars represent medians. The scatterplot (D) shows the maximum thickness of both parasequences and deltaic units versus the duration of time over which they have developed.

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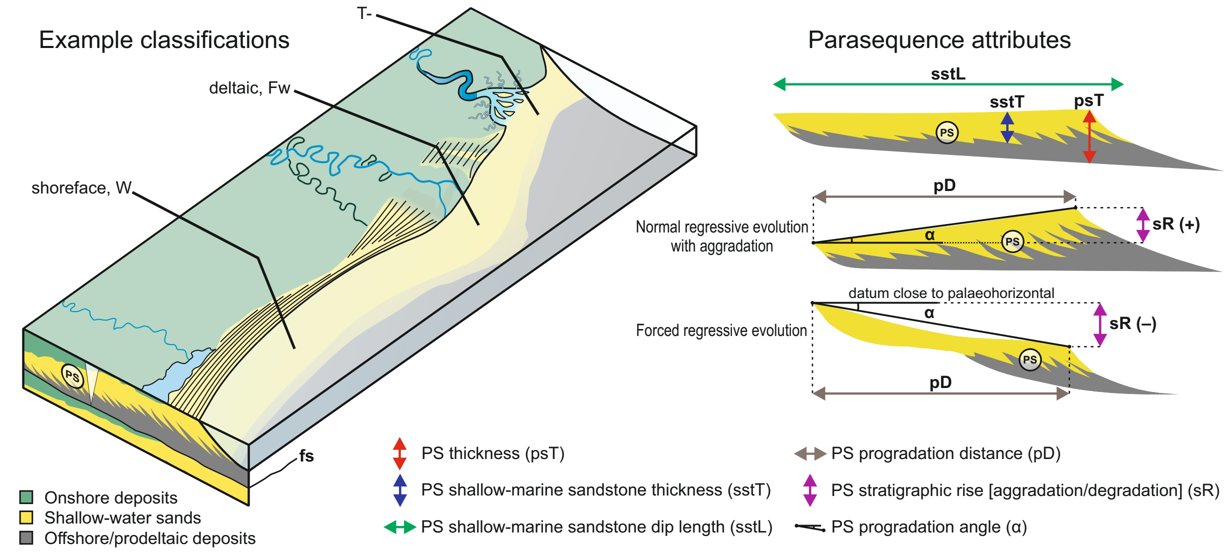
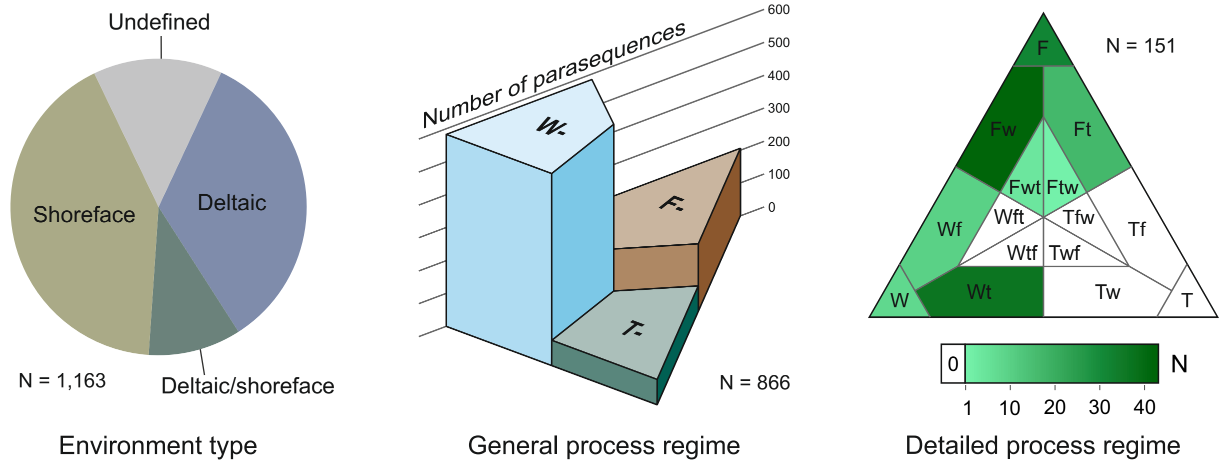
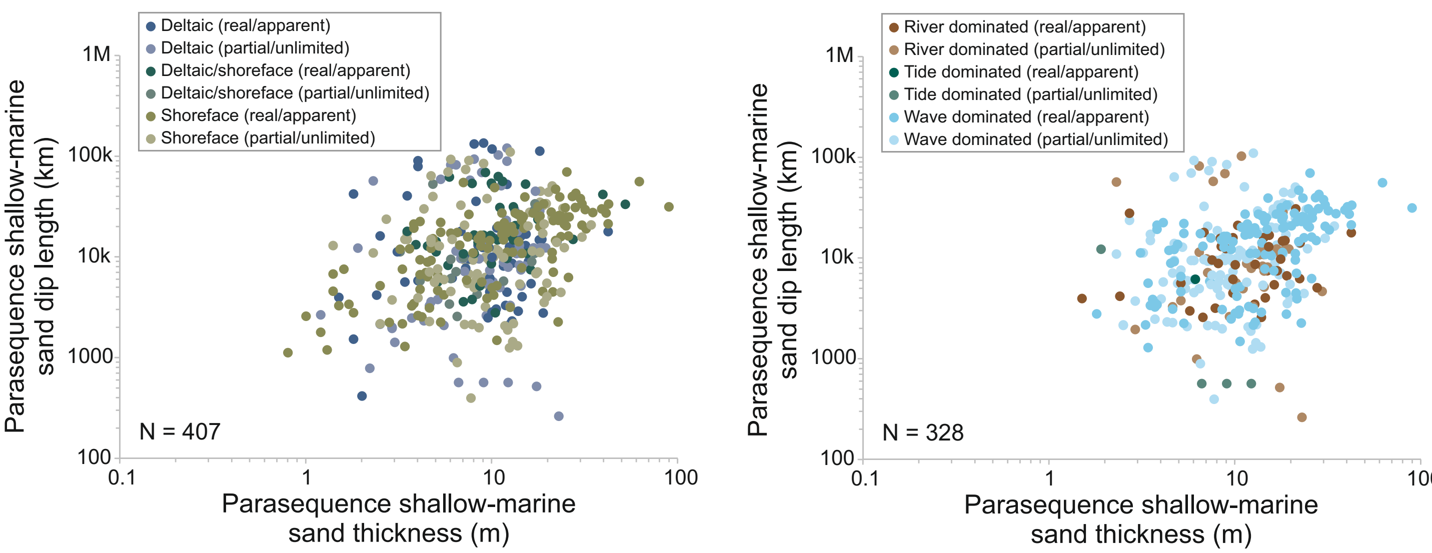
SMAKS application 2: analysis of the geometry of shoreface parasequences



Quantitative characterization of clastic parasequences in SMAKS.



Relative frequency of different classes of SMAKS clastic parasequences.



Above. Geometry of different classes of parasequence-scale nearshore sandbodies.

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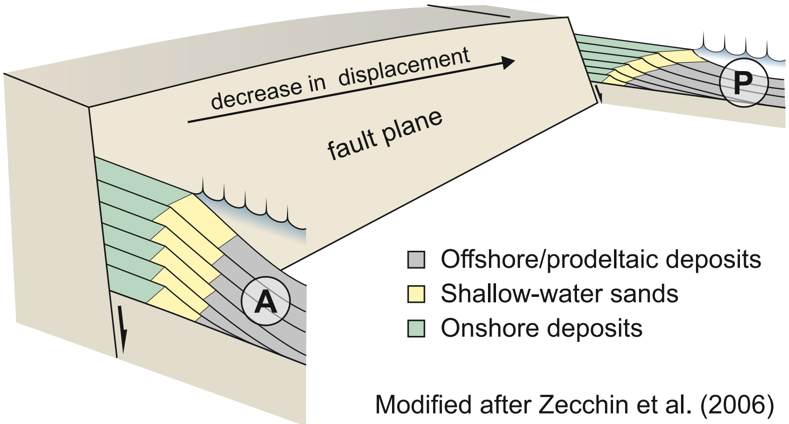
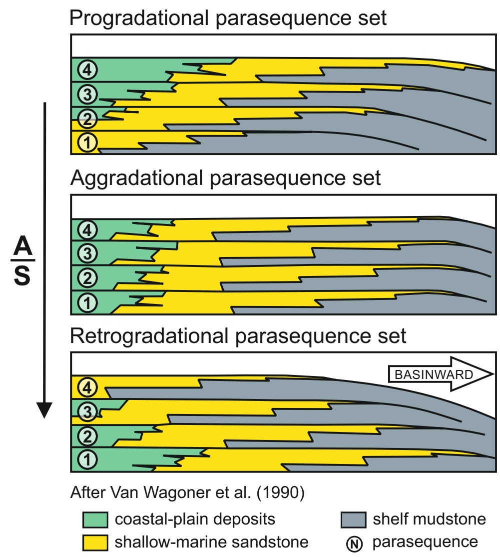
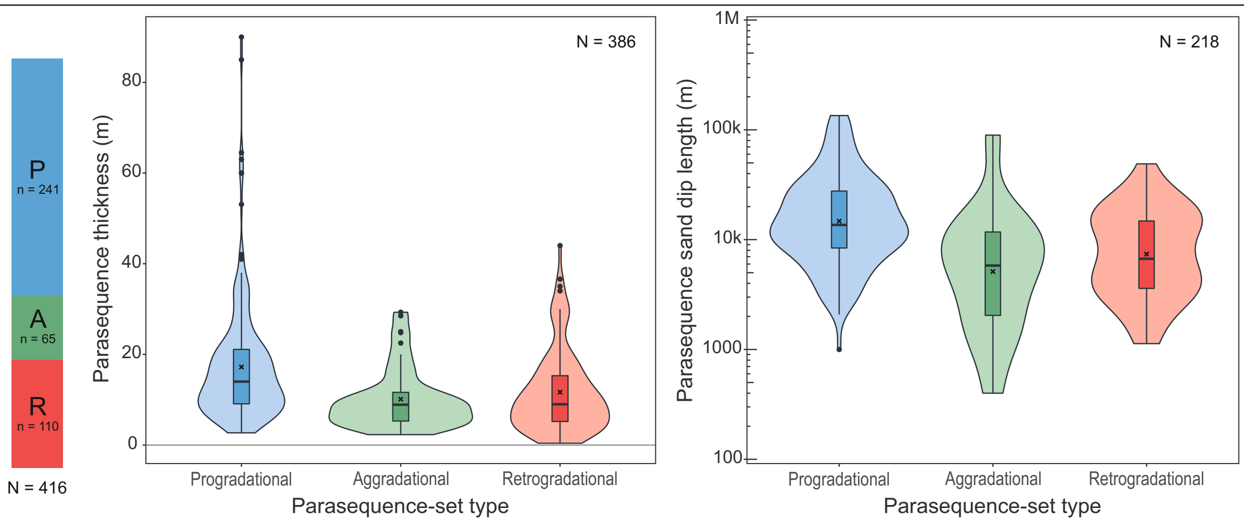
SMAKS application 3: controls on parasequence set stacking patterns

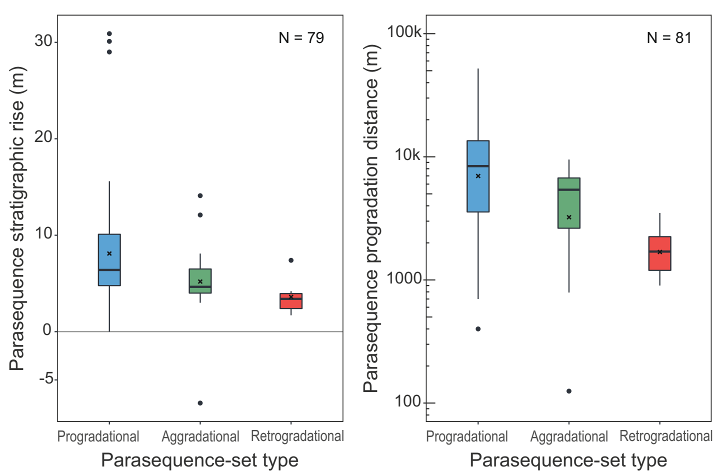


Above. Idealized example illustrating a tectonically driven mechanism for the co-variation of parasequence thickness and stacking pattern.





Above. SMAKS output on the geometry of clastic parasequences in parasequence sets classified on stacking pattern.



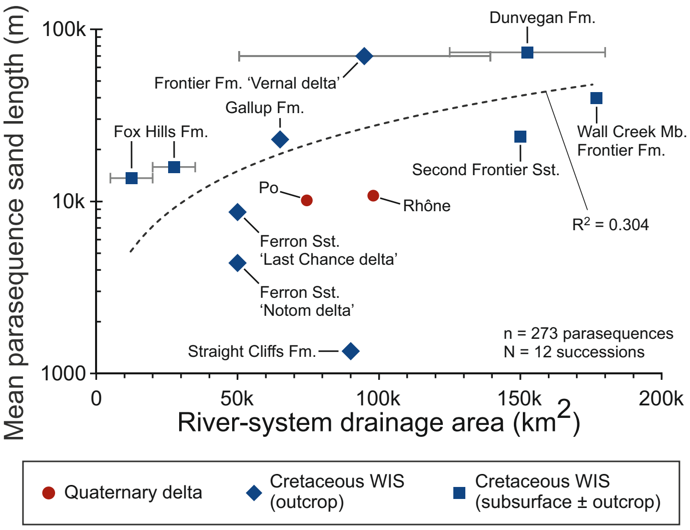
Above. SMAKS output on the progradation style of clastic parasequences in parasequence sets classified on stacking pattern.

SMAKS has been applied to investigate how accommodation, sediment supply and autogenic sediment-storage dynamics are recorded in the sedimentary architecture and stacking patterns of shallow-marine sand bodies. Results are used to evaluate the validity of paradigms and models that are routinely used to explain and predict trends in the anatomy and arrangement of parasequences.

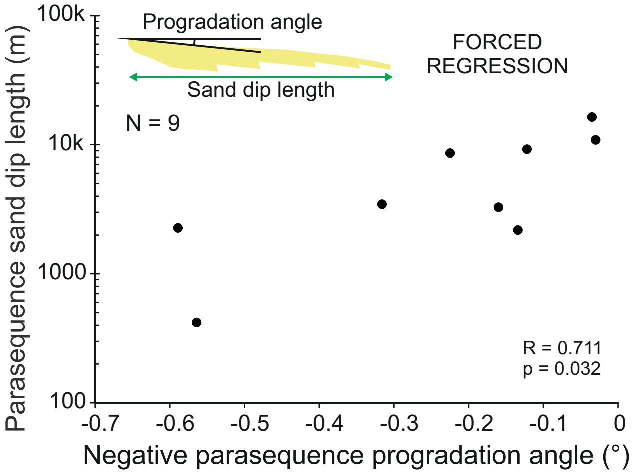
Data on 957 parasequences from 62 case studies of clastic, shallow-water successions are incorporated in this analysis. Database outputs indicate which proxies of accommodation, sediment supply and accommodation/sediment-supply ratio are significant as predictors of parasequence architecture, and allow for interpretations of the importance of allogenic and autogenic factors. Results have implications for how subsurface successions are interpreted from limited well data.

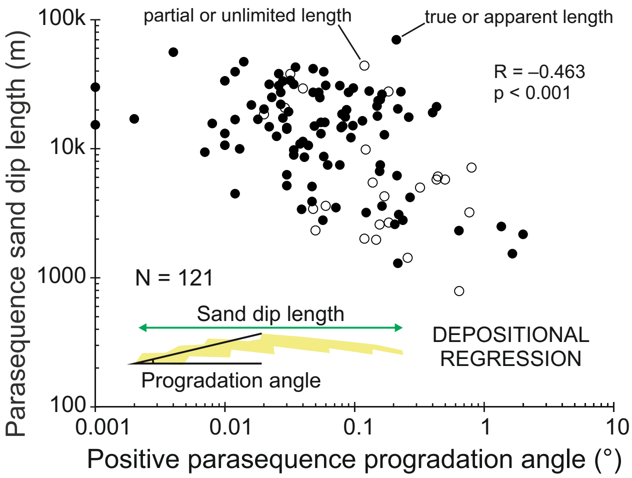
SMAKS application 4: determination of the role of relative-sea-level change and rates of sediment delivery in governing shoreface sandstone trajectory

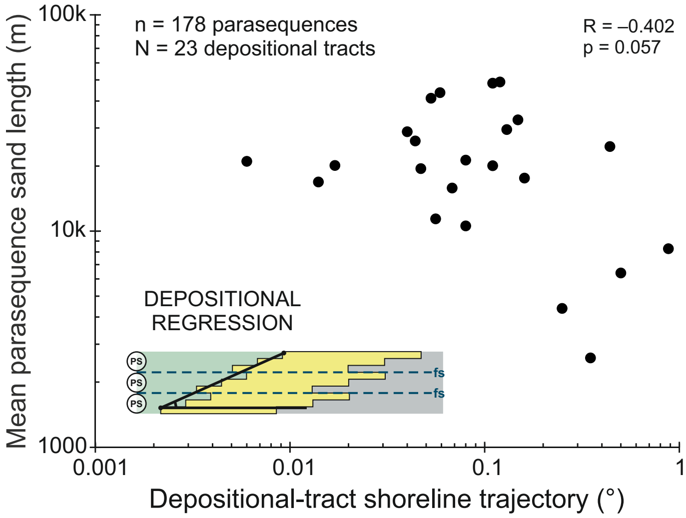
Analysis using the SMAKS database has yielded the following novel insights: (i) parasequence thickness varies as a function of water depth, accommodation generation and erosional truncation, and these variations are also reflected across types of systems tracts and parasequence sets; (ii) the dip length of parasequence sand bodies demonstrates scaling with measures of accommodation/sediment supply ratio at multiple scales, partly in relation to the possible effect of sediment supply on progradation rates; (iii) in systems tracts, stratigraphic trends in parasequence stacking due to autogenic mechanisms or to acceleration or deceleration in relative sea-level fluctuations are not revealed quantitatively; (iv) some association is seen between the abundance of deltaic or river-dominated parasequences and progradational stacking; (v) positive but modest correlation is observed between measures of river-system size and the dip length of shallow-marine parasequence sand bodies. The resulting insights can be applied to guide sequence stratigraphic interpretations of the rock record and the characterization of sub-seismic stratigraphic architectures of subsurface successions. The quantification presented in this work can be referred to when attempting predictions of likely volume, geometry and compartmentalization of shallow-marine sand bodies, on the basis of constraints of accommodation and sediment supply that may be available in subsurface studies, particularly from those based on regional seismic stratigraphy and source-to-sink analyses.



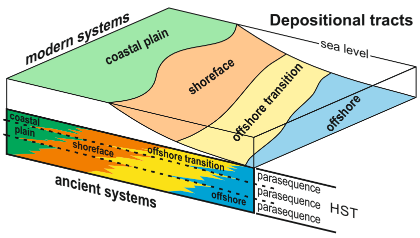
Above. SMAKS output on the relationship between feeder-system type and dip length of deltaic parasequence sandbodies. WIS = Western Interior Seaway, Cret., USA.





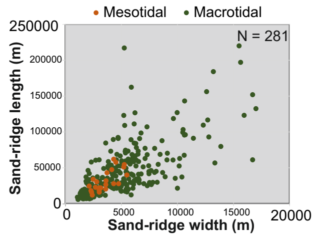


Above. SMAKS output on relationships between regressive shoreline trajectory (at parasequence and depositional-tract scales) and dip length of parasequence sandbodies.



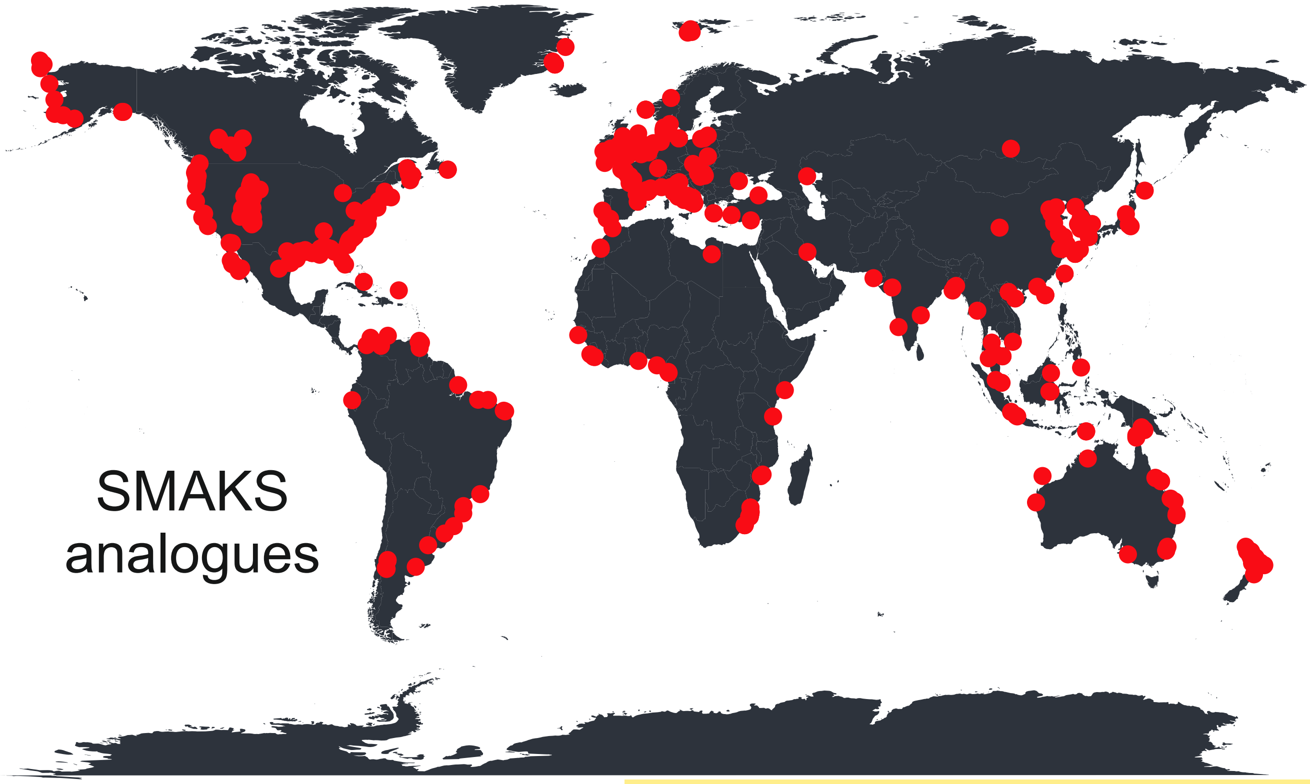
SMAKS

Shallow-Marine Architecture Knowledge Store



The **Shallow-Marine Architecture Knowledge Store** is a relational database devised for the storage of hard and soft data on the sedimentary architecture of ancient shallow-marine and paralic siliciclastic successions, and on the geomorphological organization of corresponding modern environments. The database allows incorporation of data from the published literature, which are uploaded to a common standard to ensure consistency in data definition. The database incorporates data on geological entities of varied nature and scale (i.e., surfaces, depositional tracts, architectural elements, sequence stratigraphic units, facies units, geomorphic elements), including attributes that characterize their type, geometry, spatial relations, hierarchical relations, and temporal significance. Geological entities are assigned to depositional systems, or to parts thereof, that can be classified on multiple parameters (e.g., shelf width, delta catchment area) tied to metadata (e.g., data types, data sources).

- Examine data from wave-, tide-, and fluvial dominated shallow seas, from backshore to shelf-edge settings.
- Quantitative characterization of modern and ancient shallow-marine and paralic clastic depositional systems.
- Serves as a repository of analogue information for subsurface reservoir successions.
- Can be applied to aid the development of depositional models for particular types of paralic and shallow-marine reservoirs.
- Assess the sensitivity of depositional systems to particular controlling factors.
- Predict element shape & size as a function of independent external controls (sea level history, basin type, subsidence rate).
- Build bespoke facies models for particular classes of paralic and shallow-marine sedimentary succession.



Above. Geographic distribution of some of the >220 analogue studies contained in SMAKS, as of June 2020. Database population is on-going.

To enhance sponsor impact, FRG-ERG-SMRG has collaborated with external partner PDS to develop Ava Clastics, a product that enables direct coupling of FAKTS & SMAKS with modelling workflows: www.pds.group/ava-clastics/