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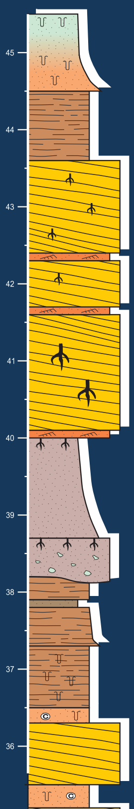
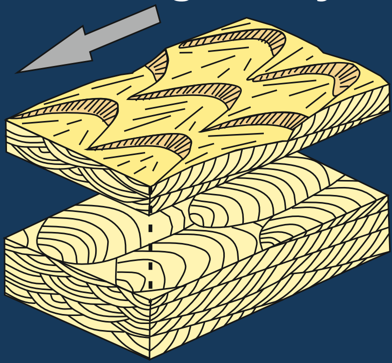


DASH: Dune Architecture & Sediment Heterogeneity



DASH is a numerical forward stratigraphic model for the reconstruction and prediction of the spatio-temporal migratory evolution of dunes and their generated deposits that accumulate as heterogeneous sedimentary successions. The model uses a combined process-based, geometric, and stochastic approach.

- develop 3D quantitative facies models for different types of dune systems;
- predict the distribution of lithofacies within dunes and barforms using rule-based methods;
- model the sedimentary architecture arising from the evolving morphology and variable migratory behaviour of a wide range of bedform types;
- evaluate the impact of variable palaeoflow, sediment supply and base-level change on resultant facies distributions and preserved stratigraphic architectures;
- model the distribution of heterogeneities & the geometries of baffle units at the sub-seismic scale
- instruct & constrain forward stratigraphic models and 3D geocellular models for enhanced characterization of subsurface successions.
- model petrophysical properties and inform connectivity analysis

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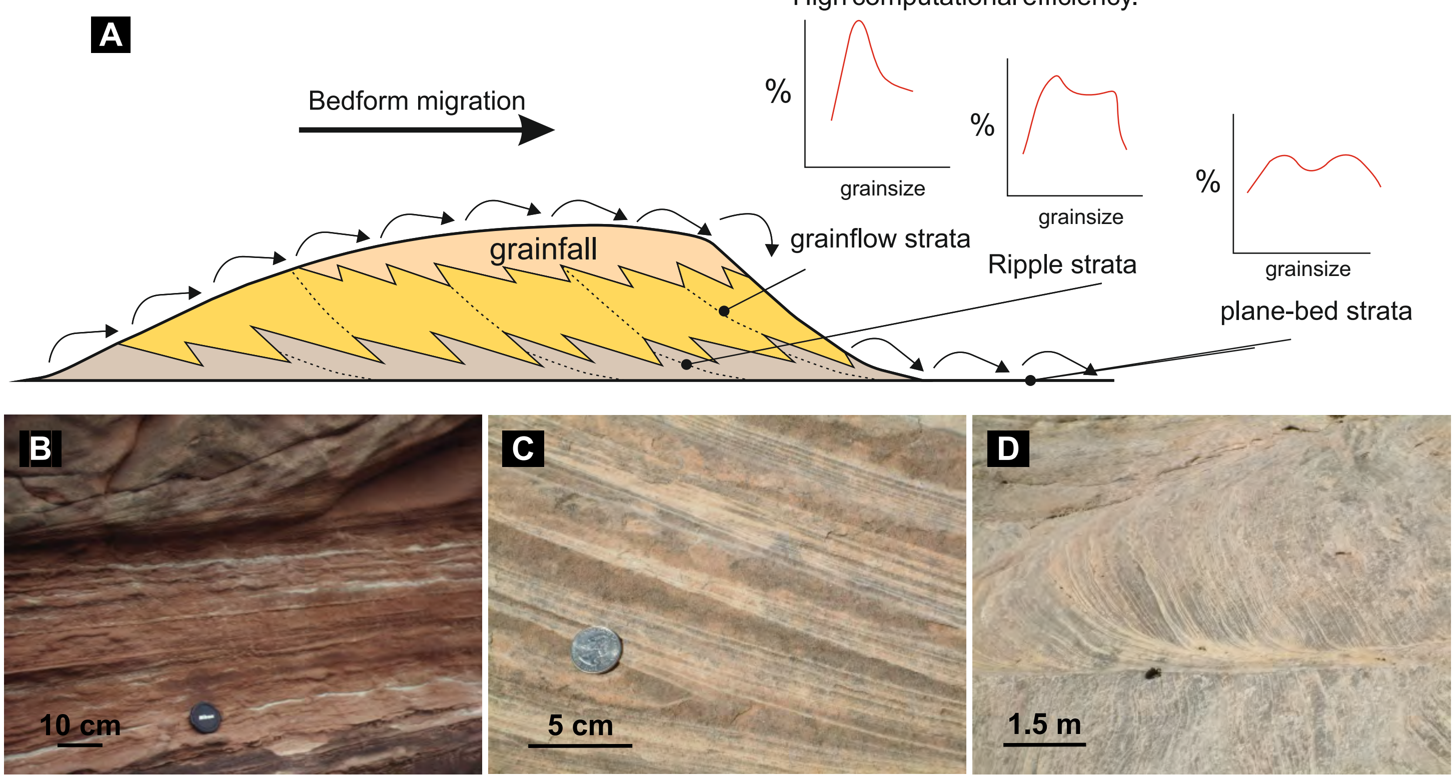
DASH: A Stratigraphic Model to Predict 3D Facies Arrangements Associated With Dune Migration

DASH (*Dune Architecture and Sediment Heterogeneity)* is a numerical forward stratigraphic model for the reconstruction and prediction of the complex spatio-temporal migratory evolution of different dune types, their generated dune and inter-dune deposits, and the associated lithofacies distributions that accumulate as heterogeneous sedimentary successions. DASH uses a combined process-based, geometric, and stochastic modelling approach. The modelling approach integrates quantified sedimentological data from real-world case-study examples stored in a relational databases, the Fluvial Architecture Knowledge Transfer System (FAKTS), the Database of Aeolian Sedimentary Architecture (DASA) and the Shallow-Marine Architecture Knowledge Store (SMAKS). DASH predicts the internal architecture and geometry of dune and interdune deposits in three dimensions. The model is used to characterize subsurface reservoir successions.

The preserved sedimentary records of dunes and barforms are determined by a range of environmental controls, such as sediment supply, palaeocurrent, base level, and substrate stabilising agents. Dune and barform deposits are commonly considered to be homogeneous architectural elements. However, many such geobodies present in fluvial, aeolian, deltaic, tidal, shallow-marine and lacustrine successions are highly heterogeneous. Such lithological heterogeneities are generated at the time of dune and barform construction and accumulation as a result of the complex interplay of erosion, deposition, and accumulation.

Benefits of DASH:

- Flexibility to control dune migration and morphology without the need to account for complicated sediment transport processes;
- Capability to incorporate temporal and spatial variations of dune migration behaviour;
- Flexibility to define facies types to constrain the model output using parameters derived directly from empirical field measurements, subsurface data, and databases;
- Ability to directly compare modelling outcomes with real-world datasets derived from outcrops or boreholes;
- High computational efficiency.



Above. (A) Dune morphology, internal stratal geometries and example facies domains seen in cross-section. No scale intended. Grainfall deposits dominate at the brink of the dune slipface. Grainflow deposits accumulate on dune lee slopes (slipfaces) at the angle of repose (24-34° for non-compacted, dry sand). Intercalated grainfall and grainflow strata can develop between the dune brink and upper foreset. Ripple deposits accumulate on low-angle-inclined dune plinths and in interdune areas. Between the foreset and toeset, packages of intercalated ripple and grainflow strata form. Direction of bedform migration is from left to right. (B-D) examples of heterogeneity in aeolian successions. (B) Damp-interdune wavy-laminated facies overlain by wind-ripple strata and grainflow in dune toeset. Triassic Helsby Sandstone Formation, UK. (C) and (D) Intercalated grainflow (darker) and wind-ripple (paler) facies in dune plinth. Permian Cedar Mesa Sandstone, Utah, USA.

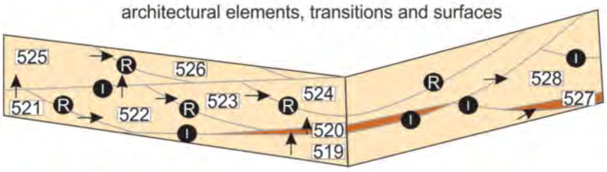
DASH

DASH: Integrated Numerical Modelling Approach and Workflow

Literature-Derived Data

Field and Subsurface Data

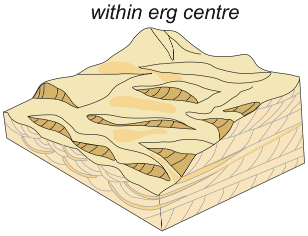
trans. ID	arch. el. ID	vertical trans. ID	lateral trans. ID (parallel to foreset azimuth)	lateral trans. ID (perpendicular to foreset azimuth)
619	521	525	522	
620	522	525	523	
621	525		526	
622	519	520		527
623	520	523		528



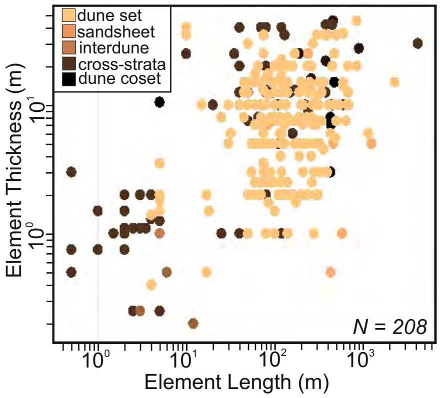
Example: data stored in the Database of Aeolian Sedimentary Architecture (DASA) digitalised from literature and field studies (Cosgrove et al., 2021)

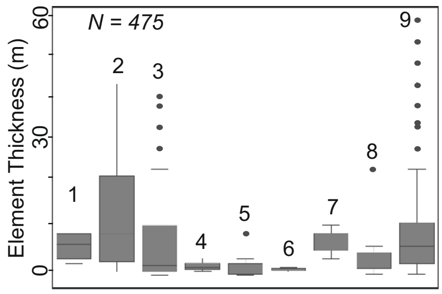
Databases (FAKTS, DASA, SMAKS)

architectural elements within erg centre



In this example, multiple aeolian architectural element types from the erg centre are selected.





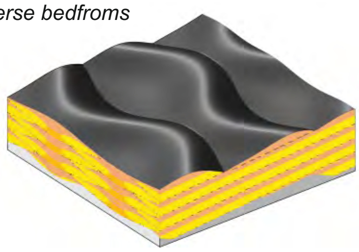
1: compound dune set; 2: dune coset; 3: cross-strata package; 4: reworked aeolian; 5: damp interdune; 6: wet interdune; 7: dry interdune; 8: sandsheet; 9: dune set

The properties of selected architectural-element types within a central dune-field setting are summarized; results demonstrate the relationships between recorded element length and thickness and the range of recorded thicknesses for these element types.

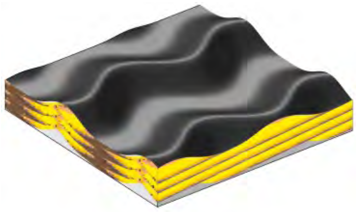
Example of data and relationships extracted from the DASA database

Numerical Modelling (DASH)

transverse bedfroms



longitudinal bedforms



- wind-rippled and grainfall deposits
- grainflow deposits
- grainflow dominated strata
- intercalated wind-rippled and grainflow strata
- wind-rippled sandstone

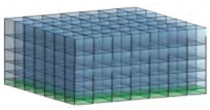
Model Outupts

- High-resolution facies characterization
- Facies distribution
- Bounding surfaces
- Probability of possible scenarios
- Sensitivity of major environmental controls
- Prediction of 3D architecture
- 2D and 3D model outputs
- Gridded output as ASCII-format text files suitable for input into industry-standard software

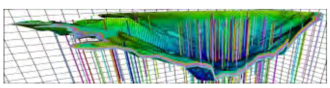
Examples of modelling outputs from DASH. See marked difference of 3D geomorphology, and lithofacies distributions and sedimentary architecture between two types of modelled bedforms. Facies properties can be constrained by data from architectural databases.

Reservoir Modelling (CCUS, Geothermal)

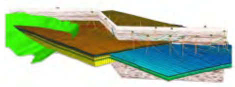
Grid-based models



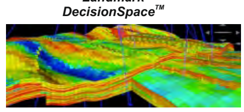
Schlumberger Petrel™



Baker Hughes JewelSuite™



Landmark DecisionSpace™



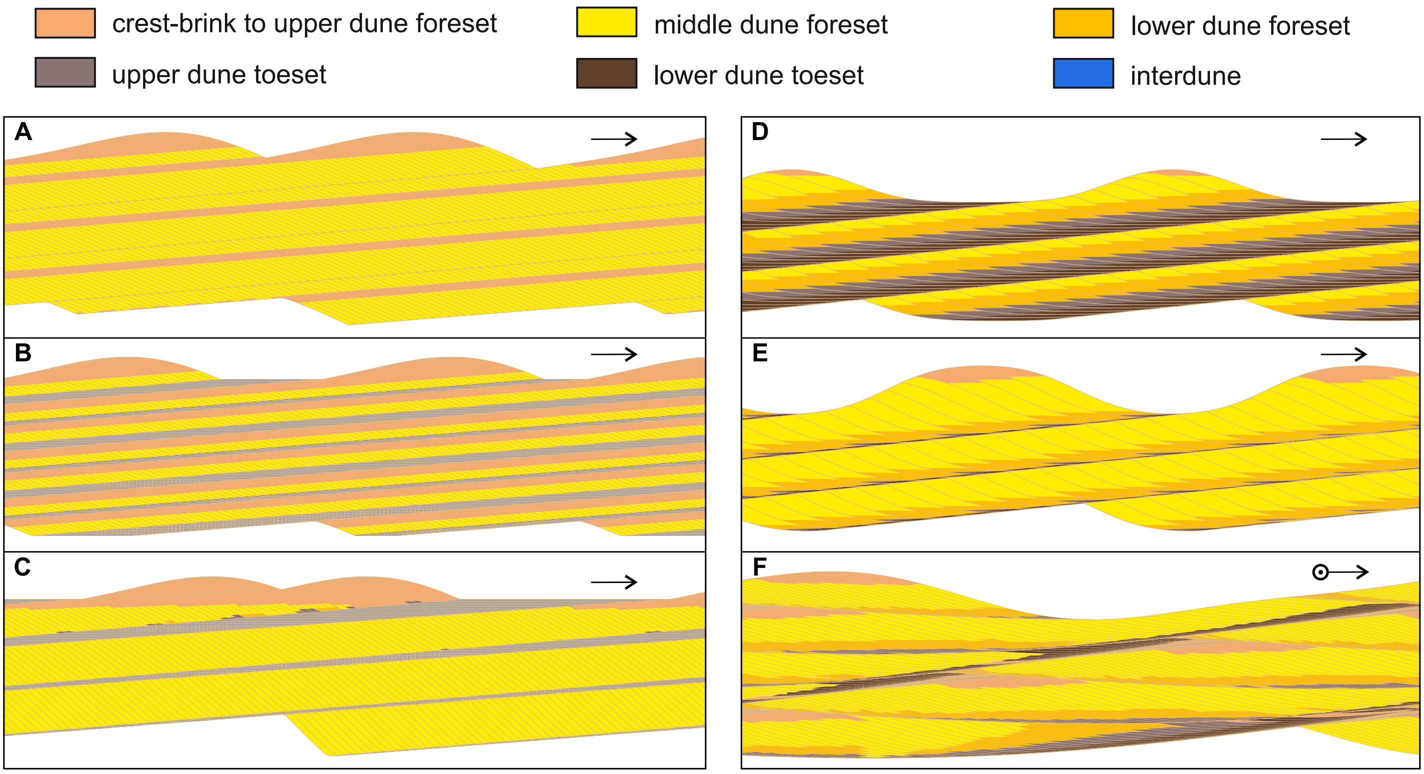
DASH can be employed to generate training-image libraries for use with MPS reservoir modelling workflows.

DASH: Approach to Modelling Dune Evolution in 3D

The Dune Architecture and Sediment Heterogeneity model (DASH) can reproduce three-dimensional sedimentary bodies, bounding surfaces and associated facies distributions formed by a wide range of dune morphologies and morphodynamic behaviours at varying temporal and spatial scales under unrestricted horizontal and vertical resolutions by virtue of its vector-based modelling technique.

The DASH model is a geometric, rule-based forward stratigraphic model that builds upon the approach used by Rubin (1987) and Rubin and Carter (2006) to produce different hierarchies of internal architectures and bounding surfaces of aeolian deposits. However, the DASH model significantly enhances this earlier work by applying a rule-based approach to predict and model three-dimensional (3D) distributions of facies units within architectural elements for many different types of sedimentary system. DASH incorporates rules of facies organization based on observations from many natural systems. These rules can be specified based on data from geological analogues, for example using sedimentological data extracted from the FAKTS, DASA and SMAKS databases developed by FRG-ERG-SMRG.

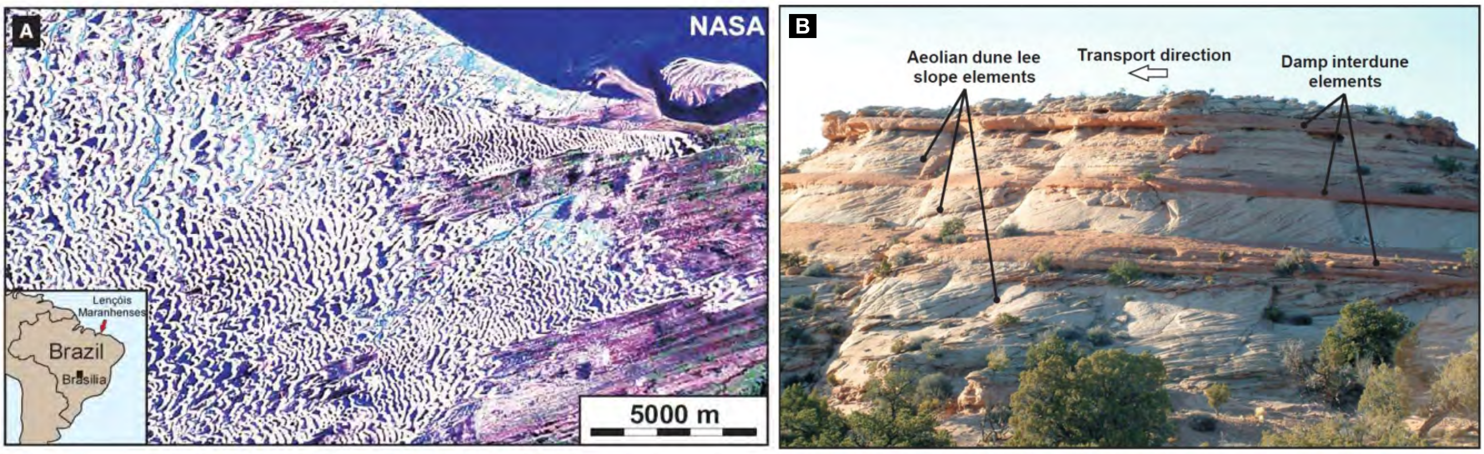
The modelling outputs enable more accurate predictions and systematic analyses of facies spatial distributions in different sedimentary systems, including for transverse dunes, linear dunes, and superimposed dunes developed upon megadunes or barforms. The modelling outputs can be further employed for predictions of petrophysical heterogeneity, for example to guide models to assess geothermal reservoir potential and to model carbon capture and storage scenarios.



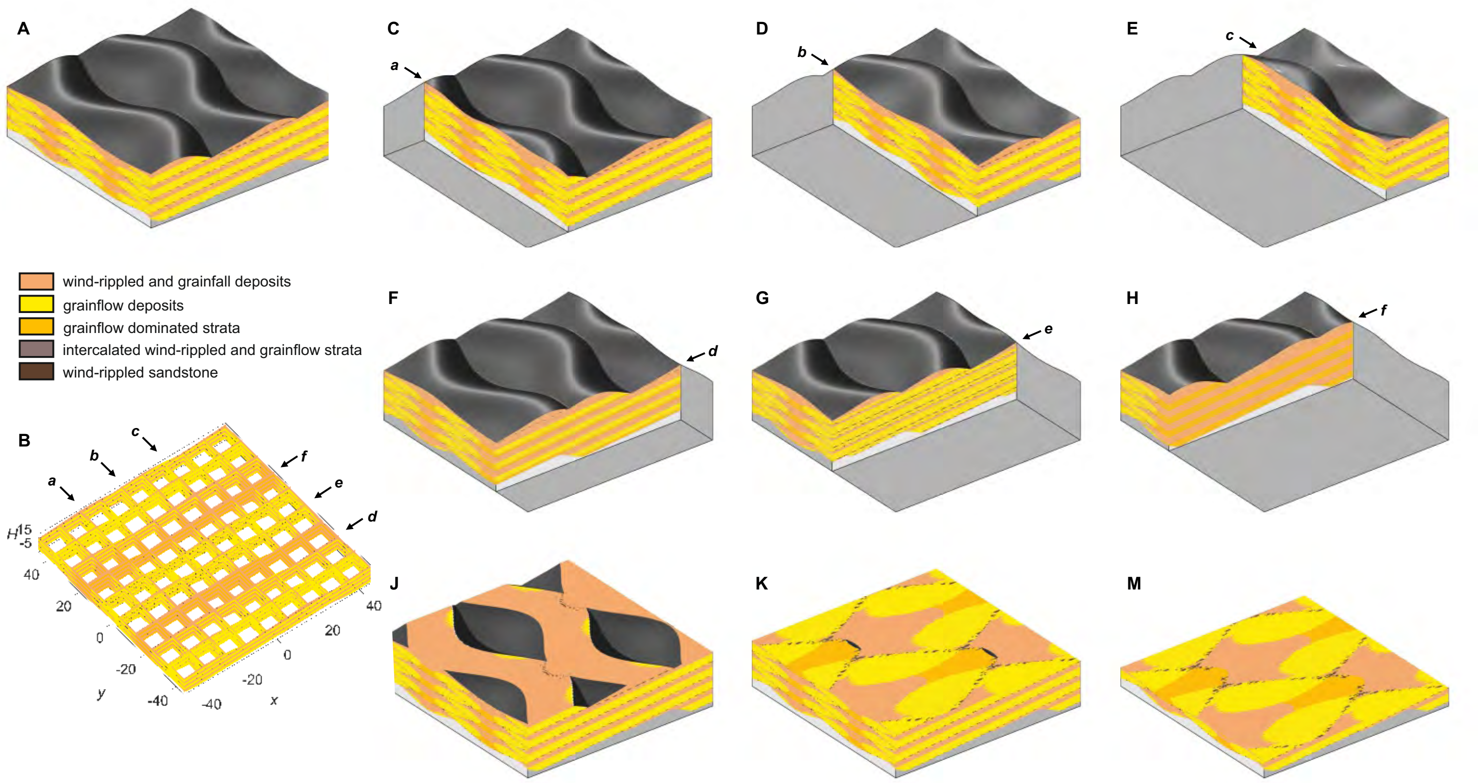
Above. Examples of modelled cross sections by DASH. Black arrows show dominant bedform migration directions. The cases from A to E are dominantly controlled by unidirectional sediment transport, whereas the case F is controlled by two dominant sediment transport directions that are perpendicular to each other, i.e., to the right and out of the page. (A) Cross section of the stratigraphy produced by transverse dunes without interdune flat. (B) Cross section of the stratigraphy produced by transverse dunes with interdune flat. Dunes maintain the same size while migrating . (C) Cross section of the stratigraphy produced by transverse dunes with interdune flat. Dunes decrease in height while migrating. A-C are generated by the migration of dunes that possessed out-of-phase sinuous crestlines in plan view. (D). Cross section of the stratigraphy produced by linear dunes close to the apex of sinuous crestlines. (E) Cross section of the stratigraphy produced by linear dunes away from the apex of sinuous crestlines. D and E are generated by perfectly longitudinal bedforms with along-crest migrating sinuosity. (F) Cross section of the stratigraphy produced by more complicated bedforms with along-crest migrating superimposed bedforms.

Application 1: Modelling Dune Morphodynamics & Internal Lithofacies

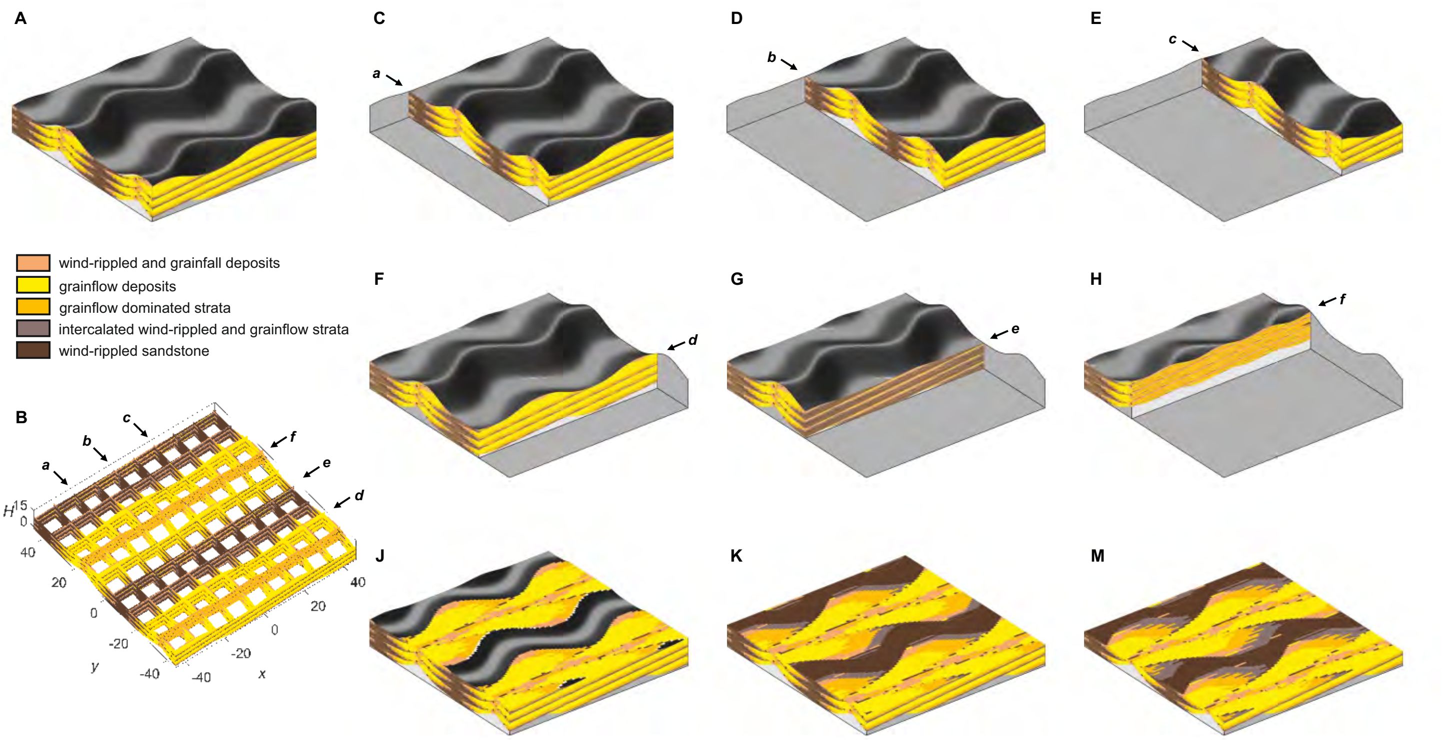
DASH is able to model the internal distributions of domains with distinct facies characteristics within larger-scale dune and interdune architectural elements. Facies domains are modelled in 3D using a series of rule sets that consider the geometry, distribution and topology of fundamental lithological types within the model. Principal amongst these rules are (i) the inclination of the local surface slope, and (ii) the position along the depositional profile of a dune or interdune. In combination, these variables are closely associated with different facies types observed in nature. These rules are established in a way that reflects our understanding of the distributions of sediments and smaller-scale bedforms on modern dunes, and the corresponding distributions of lithofacies in ancient successions.



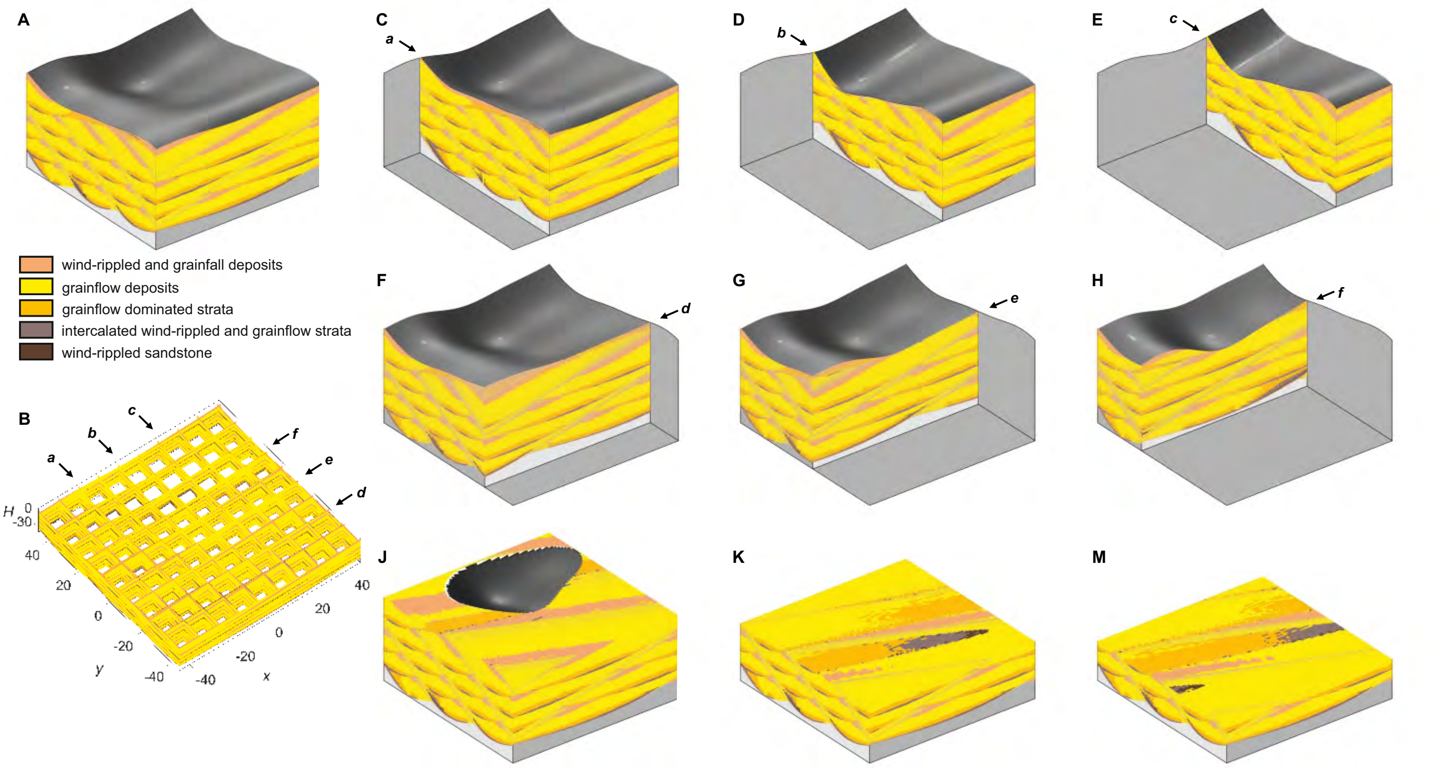
Above. Dunes and interdunes in modern systems and ancient preserved successions. (A) Flooded coastal aeolian transverse dune field in north-east Brazil. (B) Aeolian succession from part of the Jurassic Navajo Sandstone, Utah (Mountney, 2002).



Above. Three-dimensional geomorphology and sedimentary architecture and lithofacies distributions of typical transverse bedforms with sinuous, out-of-phase crestlines. Facies are modelled based on the local true dip magnitude of strata. The default settings include eight types that effectively represent facies types and complexity observed in nature.



Above. Three-dimensional geomorphology and sedimentary architecture and lithofacies distributions of idealised longitudinal bedforms without net lateral migration.



Above. Three-dimensional geomorphology and sedimentary architecture and lithofacies distributions of superimposed bedforms with along-crest migration.

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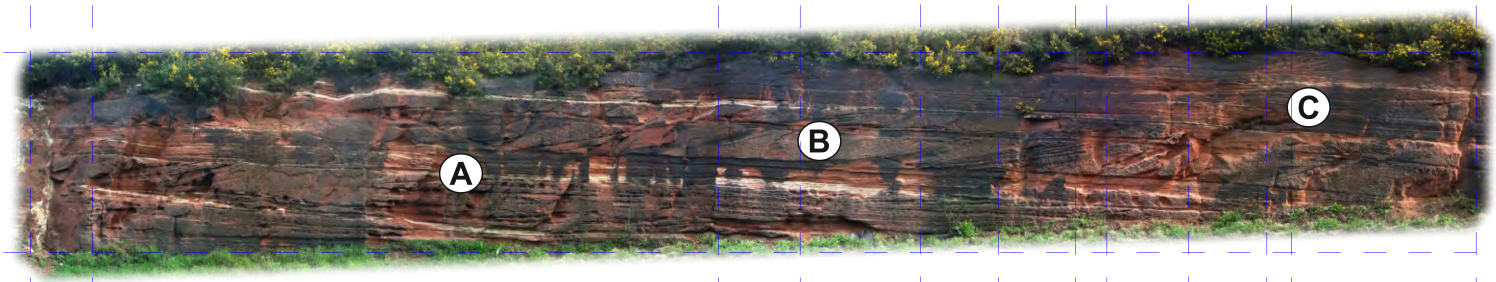
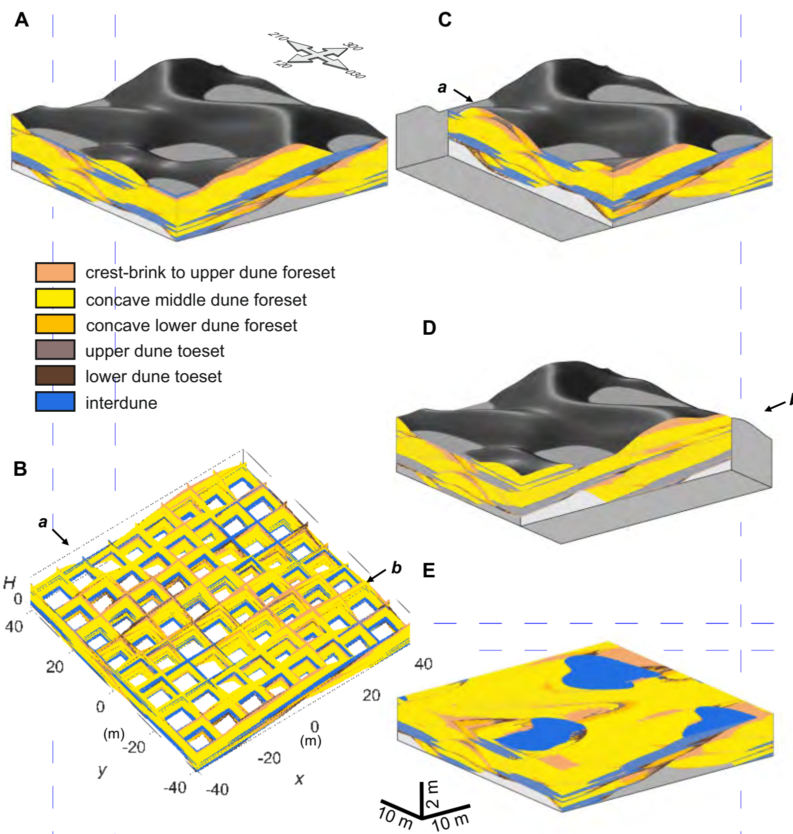
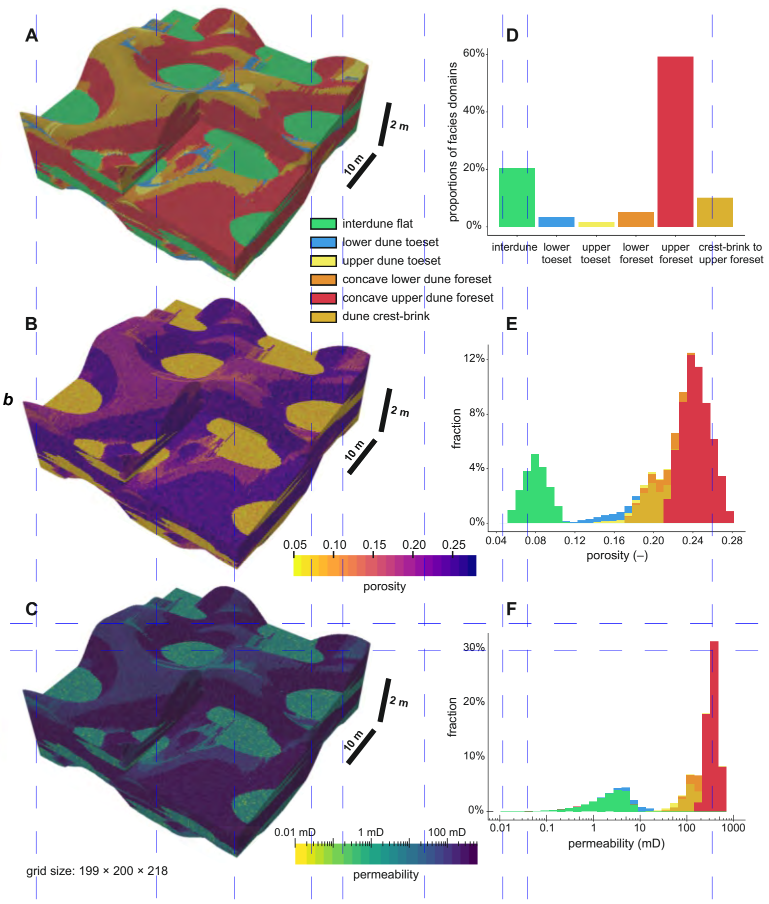
Application 2: Modelling Petrophysical Properties of Sedimentary Succesions



Above. Wilmslow and Helsby Sandstone formations, Triassic Sherwood Sandstone Group, Cheshire, UK. (A) Wavy-laminated damp interdune strata. (B) Aeolian dune cross-bedded sets. (C) Wind-rippled dune-plinth strata.





Upper Left. Three-dimensional geomorphology and sedimentary architecture and lithofacies distributions of a succession that embodies the architecture and facies distribution of the Triassic Helsby Sandstone Formation, Cheshire Basin, UK. Based on data from Mountney and Thompson (2002). **Upper Right.** Outputs of static geocellular modelling aided by DASH, for a succession that embodies the stratal architecture of the Helsby Sandstone Formation. (A) Geocellular model of DASH facies domains, with their proportions charted in (B). Facies-domain proportions reflect in part the full preservation of modelled bedforms on the top surface: the proportion of crest-brink to upper foreset and interdune domains are ca. 5% and 26% in the part of grid underlying the top surface, as opposed to ca. 10% and 20%, respectively, in the entire grid. (C) Realization of a Sequential Gaussian Simulation of porosity values modelled in the facies domains shown in (A); distributions of porosity values vary across the facies domains as shown in (D). (E) Realization of a Sequential Gaussian Simulation of permeability values modelled in the facies domains shown in (A); distributions of porosity values vary across the facies domains as shown in (F). Note that in the preserved Triassic Helsby Sandstone Formation, the original dune topography and the facies associated with it are not preserved. Here we reconstruct the original dune morphology and its associated facies distribution for the purpose of interpreting the palaeoenvironment of deposition.

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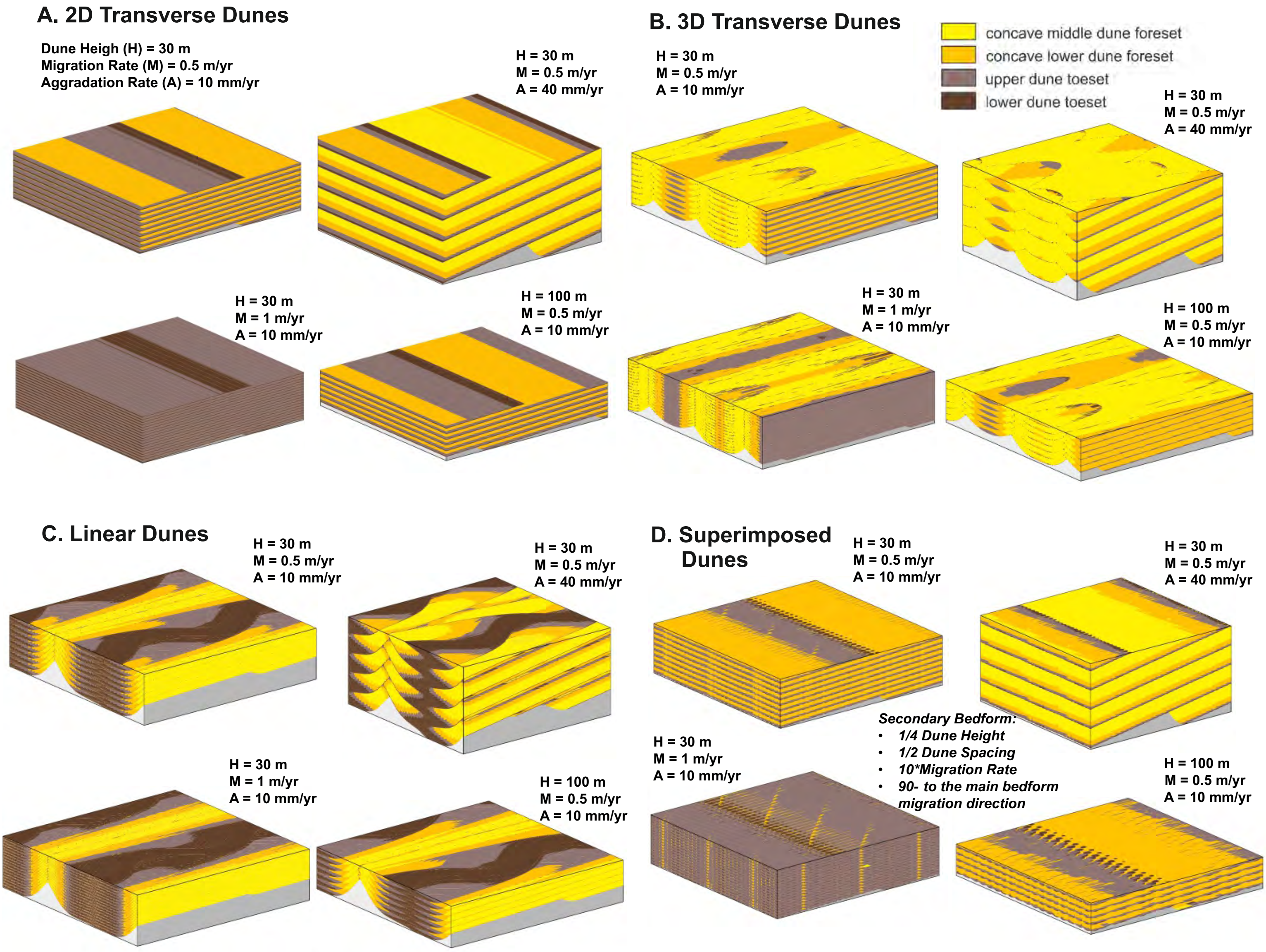
Application 3: Quantify Controls on Facies Heterogeneity of Dune Deposits

Dune-domianted sedimentary systems record past climate changes due to their sensitivity to environmental variables, such as changing rates of sediment supply, climate and palaeoflow, the action of physical, chemical and biogenic stabilising agents, and also interactions with other coeval sedimentary systems. Due to the interplay of allogenic and autogenic controls, the preserved sedimentary record of dune systems is highly complex and exhibits a variety of sedimentary architectures and spatial heterogeneities in facies distributions. DASH can be used to investigate the variations in facies heterogeneity across different types of dunes, taking into account their sizes, migration rates, and aggradation rates over a broad spectrum of temporal scales. The modelling outputs enable more accurate predictions and systematic analyses of facies spatial distributions in different sedimentary systems, including those hosting transverse dunes, linear dunes, and superimposed dunes. The modelling outputs can further be employed for predictions of petrophysical heterogeneity, for example, to guide models to assess geothermal reservoir potential and to model carbon capture and storage scenarios.



Above. Modelling outputs illustrating examples of (A) 2D transverse dunes (B) 3D transverse dunes (C) linear/longtitudial dunes and (D) superimposed dunes, encompassing a range of dune heights, migration rates and aggradation rates. These results highlight the significant variability in internal facies heterogeneity. DASH is capable of generating 3D models constrained by integrated datasets, including well data, outcrop observations, seismic imagery, and published literature.