Digital Outcrop Models - Leading to New Insights into Characterization and Modeling of Carbonate Reservoirs*

Jeroen Kenter[1], Paul (Mitch) Harris[1], Aurélien Pierre[1], Ted Playton[1], Gareth Jones[1] and Marge Levy[1]

Search and discovery Article #40455 (2009)
Posted October 15, 2009

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Denver, Colorado, June 7-10, 2009

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Abstract

Stratigraphic solutions to subsurface data sets are non-unique and, as a consequence, subsurface exploration and reservoir characterization require constant improvement of input data and geostatistical modeling concepts. Data-rich digital outcrop models of end member carbonate systems (DOMs) identify geologic heterogeneity (resolution, architecture, continuity, correlation, facies juxtaposition) and provide concepts and strategies that can be incorporated into less-constrained subsurface-based models

Lower Jurassic outcrops representing end member carbonate systems that serve as analogs in the Caspian Basin, Middle East and elsewhere were studied in the High Atlas of Morocco. They yield insight into facies and stratigraphy for 1) the platform top and steep slopes of a 34 by 6 km isolated carbonate platform (Djebel Bou Dahar) that is characterized by extensional tectonics, margin retrogradation, fracturing and tidal flat deposits and 2) facies partitioning along a 35 km mixed clastic-carbonate ramp system (Amellago) as a result of sea level, post-rift tectonic subsidence and changing depositional environments in a dip direction.

DOMs were generated by integrating traditional geology with LIDAR, RTK DGPS data, and terrestrial, airborne and/or satellite imagery which provided exact and quantitative information on properties like stratal anatomy, spatial lithofacies trends, sedimentary body shapes and facies juxtaposition rules. Lithofacies types were simulated using both static modeling (MPS/FDM) and forward modeling (Dionisos) techniques. MPS/FDM allows global conditioning to hard data and simulates both depositional and diagenetic shapes, trends and spatial associations between rock types at variable resolution scales (i.e. exploration to reservoir). Dionisos provides spectra of end-member solutions with limited conditioning but serves as a powerful tool for regional exploration, training and communication.

The “outcrop-to-subsurface” workflow yielded a digital library with morphometric data on the grand-scale and smaller (reservoir) scale in two end member carbonate settings, helped to identify the impact of data density on the preservation of geological heterogeneity and provided fundamental learnings in geostatistical modeling concepts. Future steps include generating flow models in such hydrocarbon reservoir systems and simulating diagenetic facies using MPS/FDM and Reactive Transport Modeling (RTM).

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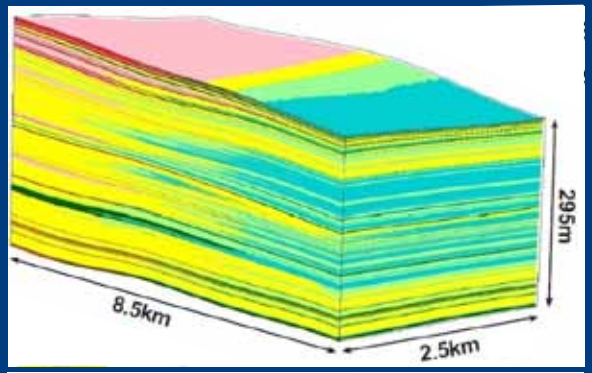
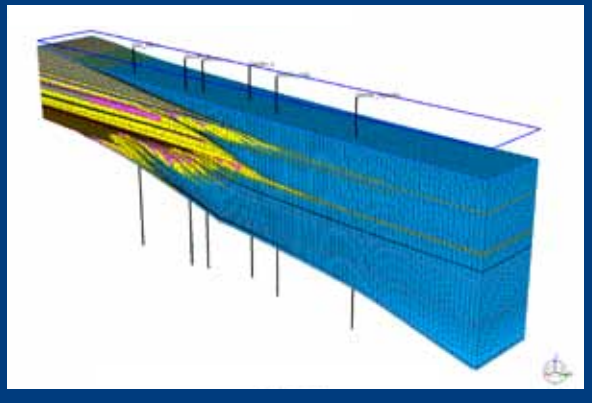




With contributions by:
Oscar Merino-Tomé, Klaas Verwer, Giovanna Della Porta, Xavier van Lanen, Franklin Rarity, Dave Hodgetts, Erwin Adams and many others

Outline

- Rationale
- Outcrop to Digital Outcrop Model and Simulation Workflow
- Djebel Bou Dahar Isolated Carbonate Platform System
- Amellago Mixed Carbonate-Clastic Ramp System
- Conclusions

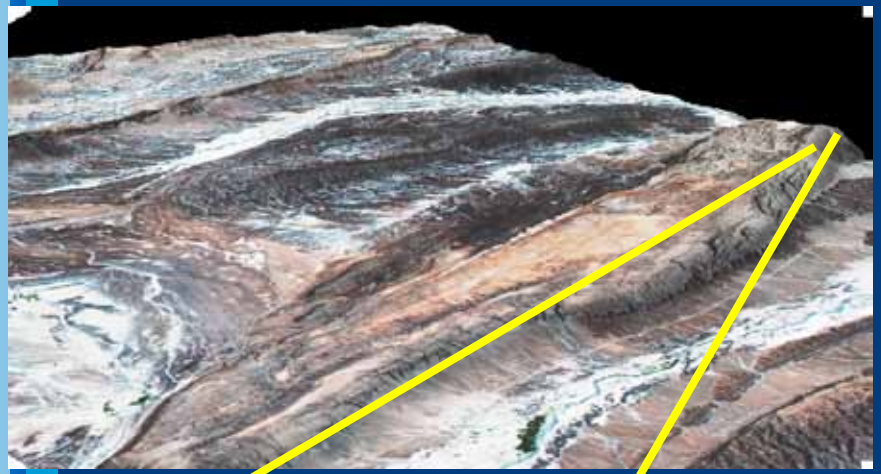
Rationale

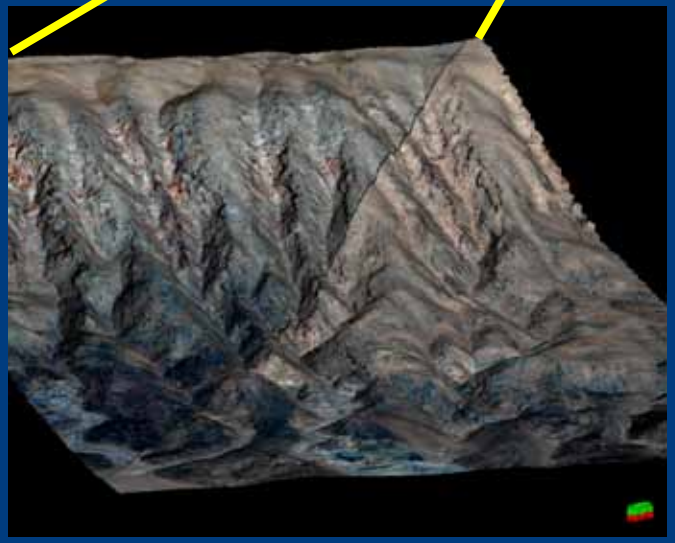
- Solutions to subsurface are non-unique - subsurface exploration and reservoir characterization require constant improvement of geostatistical modeling concepts and input data
- Outcrops provide exact and quantitative information on spatial lithofacies trends, facies proportions and 3D juxtaposition rules as well as associated stratal anatomy
- Digital models are generated by integrating traditional geology with LIDAR and RTK DGPS data and terrestrial, airborne and satellite imagery
- Forward modeling and geostatistical modeling techniques simulate spatial distribution and juxtaposition of depositional rock types
- Two systems to capture range in platform systems: isolated carbonate platform and mixed clastic-carbonate ramp, both in the Southern High Atlas, Morocco

Outcrop to Digital Model

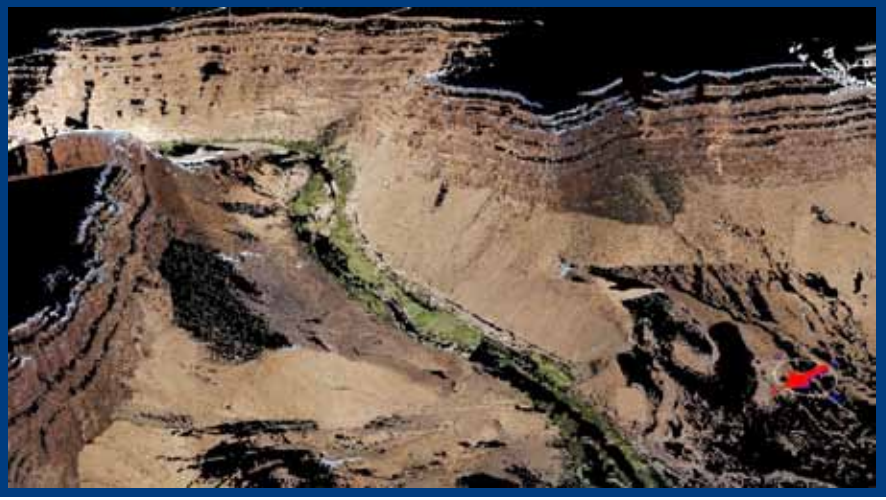
- Digital tools allow quantification of geologic features in space
- Resulting digital outcrop models (DOMs) capture such spatial data at the intersection of the outcrop morphology with the underlying geology
- DOMs are pseudo 2D representations of “hard” data
- Complemented by adding “soft” data like depositional surfaces, information from measured sections and mapped rock type zones using, lidar and/or hyperspectral imaging attributes, i.e. VRGS (University of Manchester)
- Next transfer of the data set into a cellular domain – so-called “sgrid” - for static modeling (like in GoCad or Petrel) or forward modeling (i.e. Dionisos)

Carbonate Systems from Outcrops

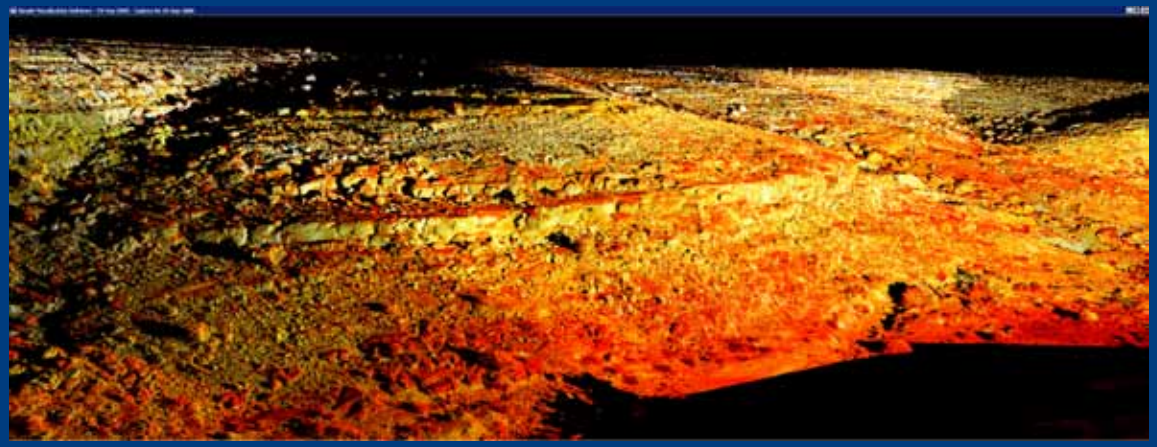


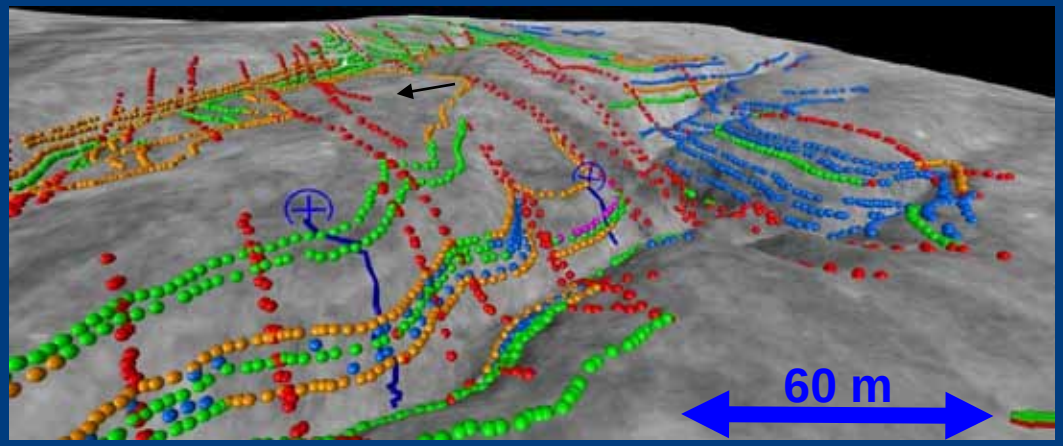


Outcrops imaged using aerial photography, satellite imagery draped on DEM



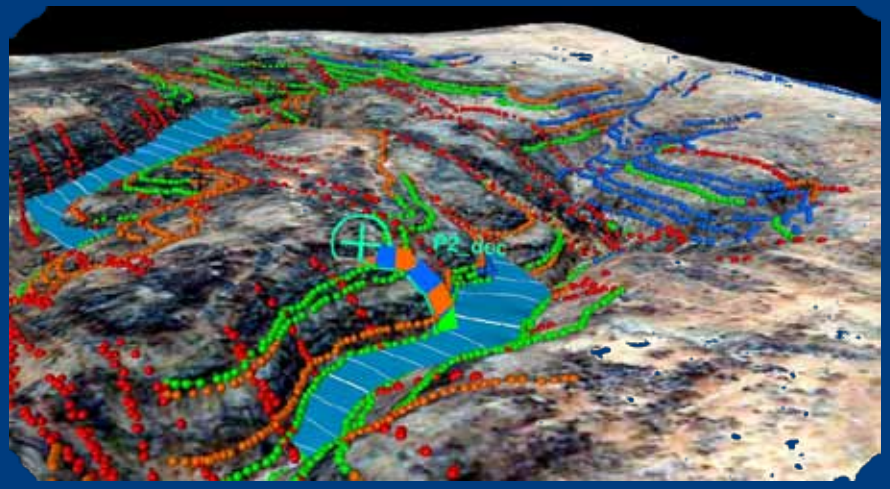
LIDAR and RTK DGPS “hard” data acquisition

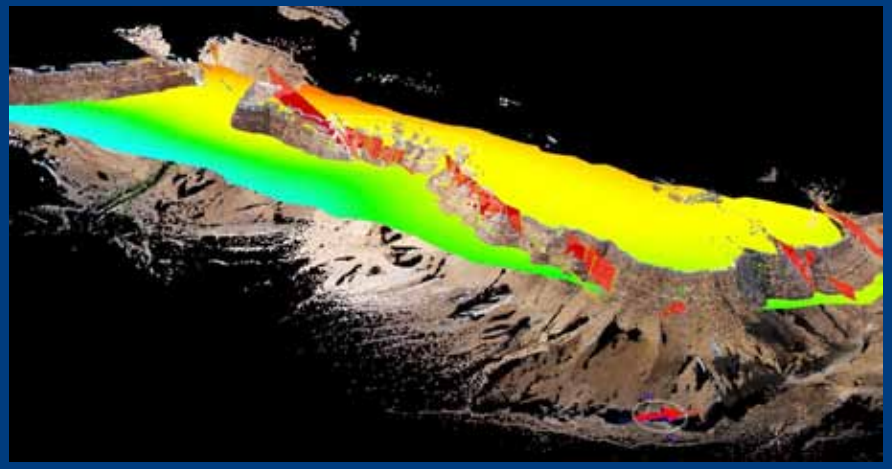


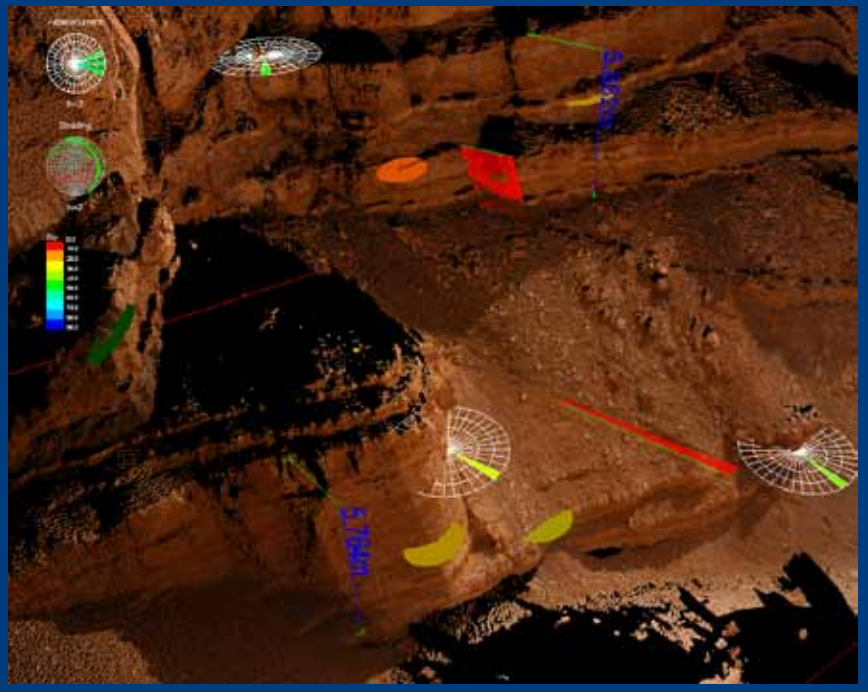


Acquisition of field data and generation of Digital Outcrop Models (DOMs)

DOMs and capturing additional “soft” (interpreted) data





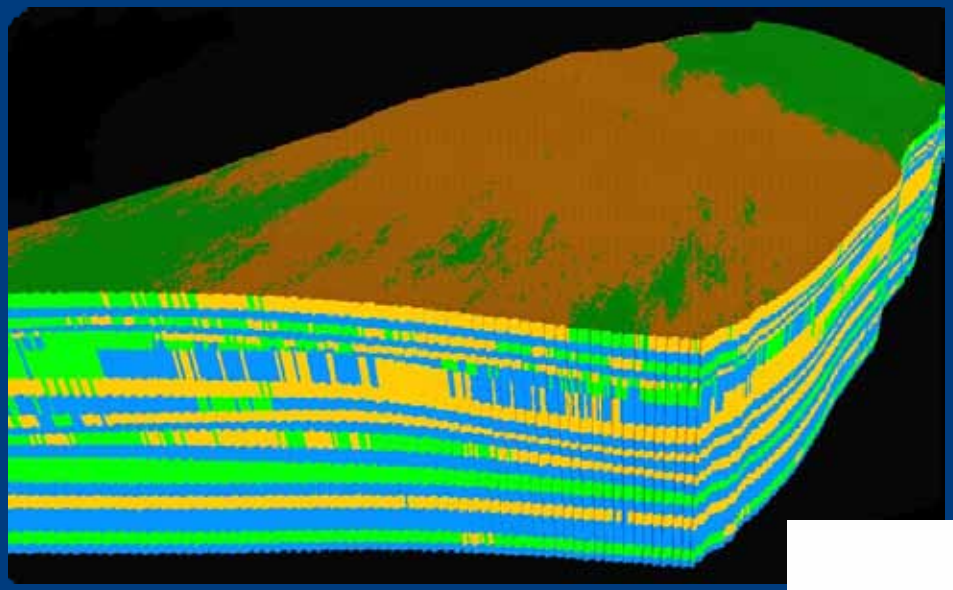


Capturing “soft” data using Petrel or VRGS

Digital Model to Simulation Workflow

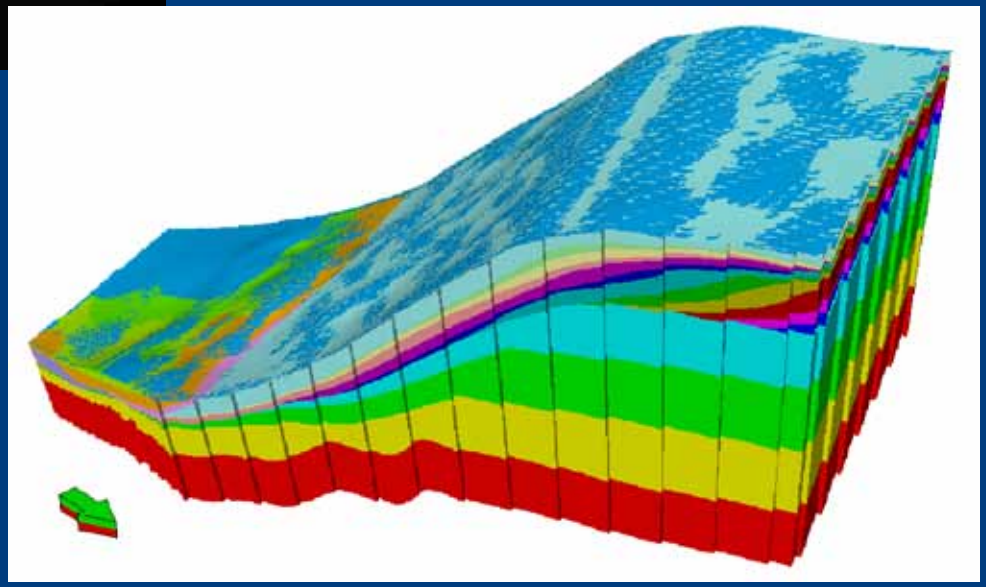
- Utilize geostatistical tools to distribute the rock types in 3D away from the hard data areas
- Common tools for simulating rock types are stochastic techniques or multiple point statistics (MPS/FDM)
- The first use variograms but inability to simulate sedimentary trends or bodies and can not be conditioned to global rock proportions
- MPS/FDM allows such conditioning and is capable of simulating both depositional and diagenetic shapes, trends and spatial associations between rock types

Stochastic SIS models using variograms and object-based techniques



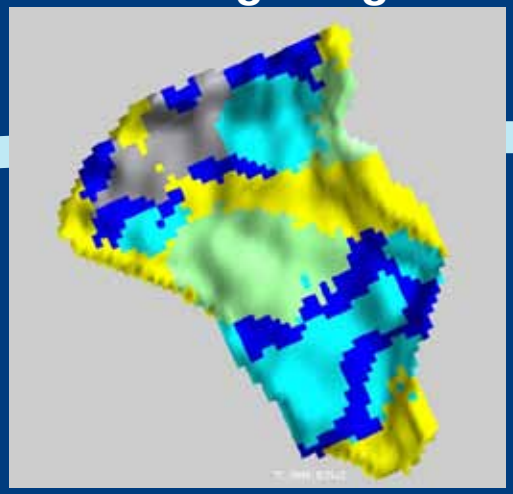
Platform interior – variograms only

Retrogradational slope – variograms and object-based

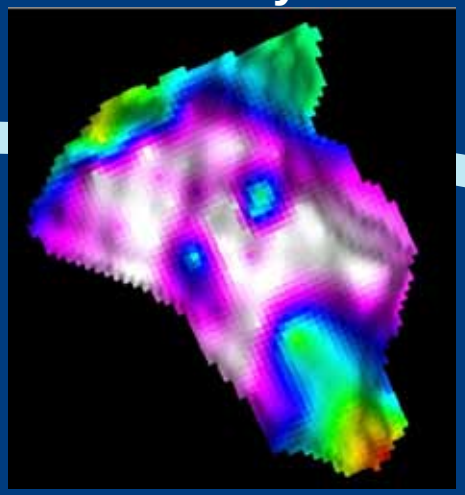


Multiple Point Statistics and Facies Distribution Modeling (MPS/FDM)

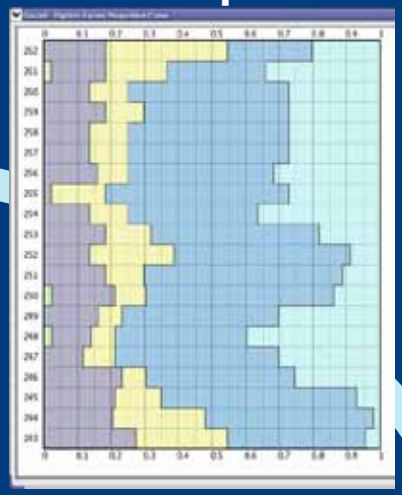
Training Image



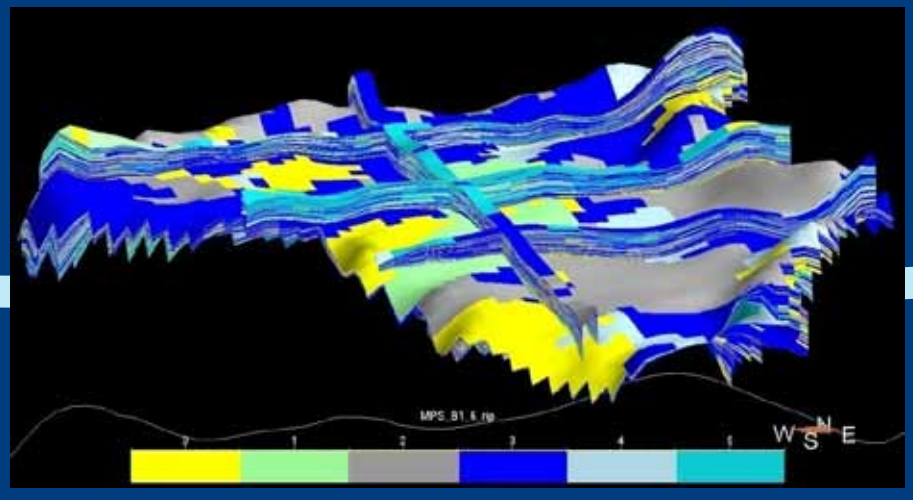
Probability Cube



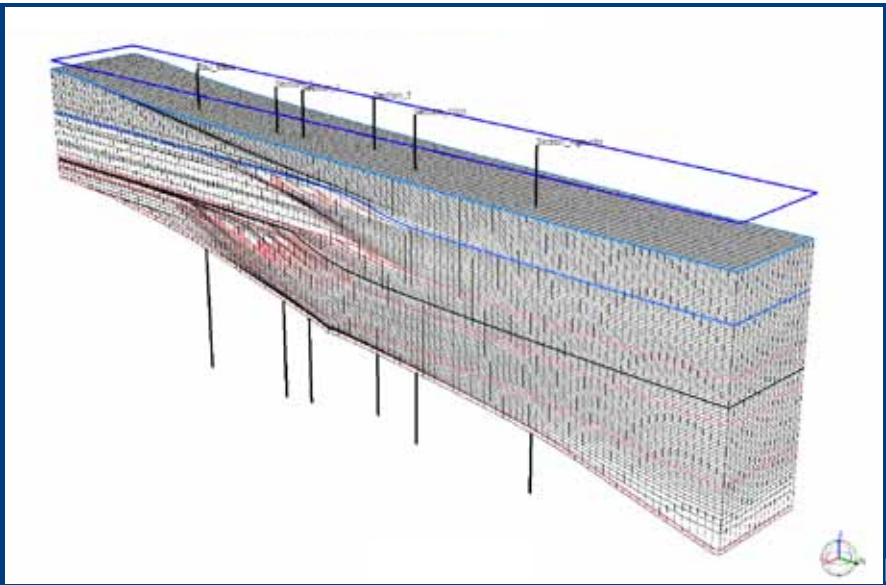
Facies Proportion Curve



MPS Simulation

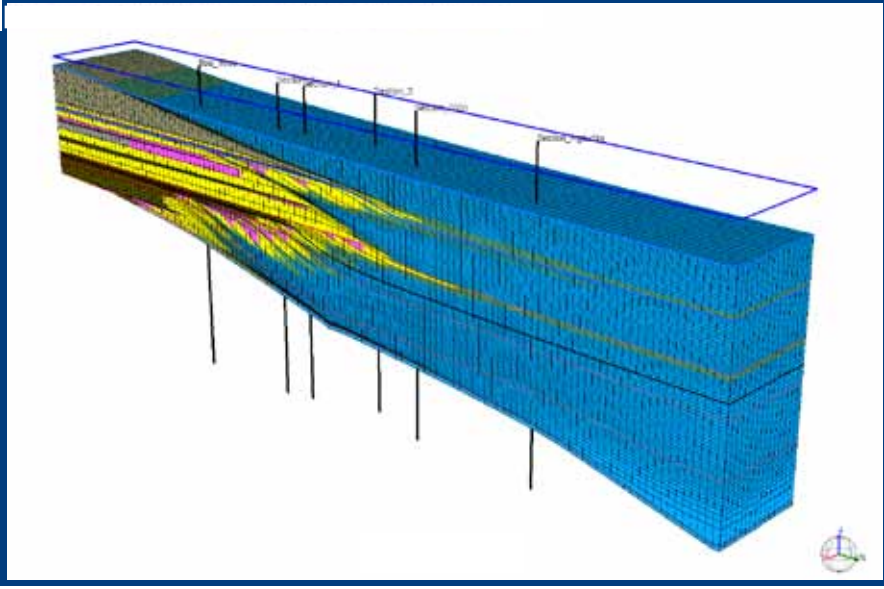


Forward Modeling (Dionisos)



Cellular Model

Simulation

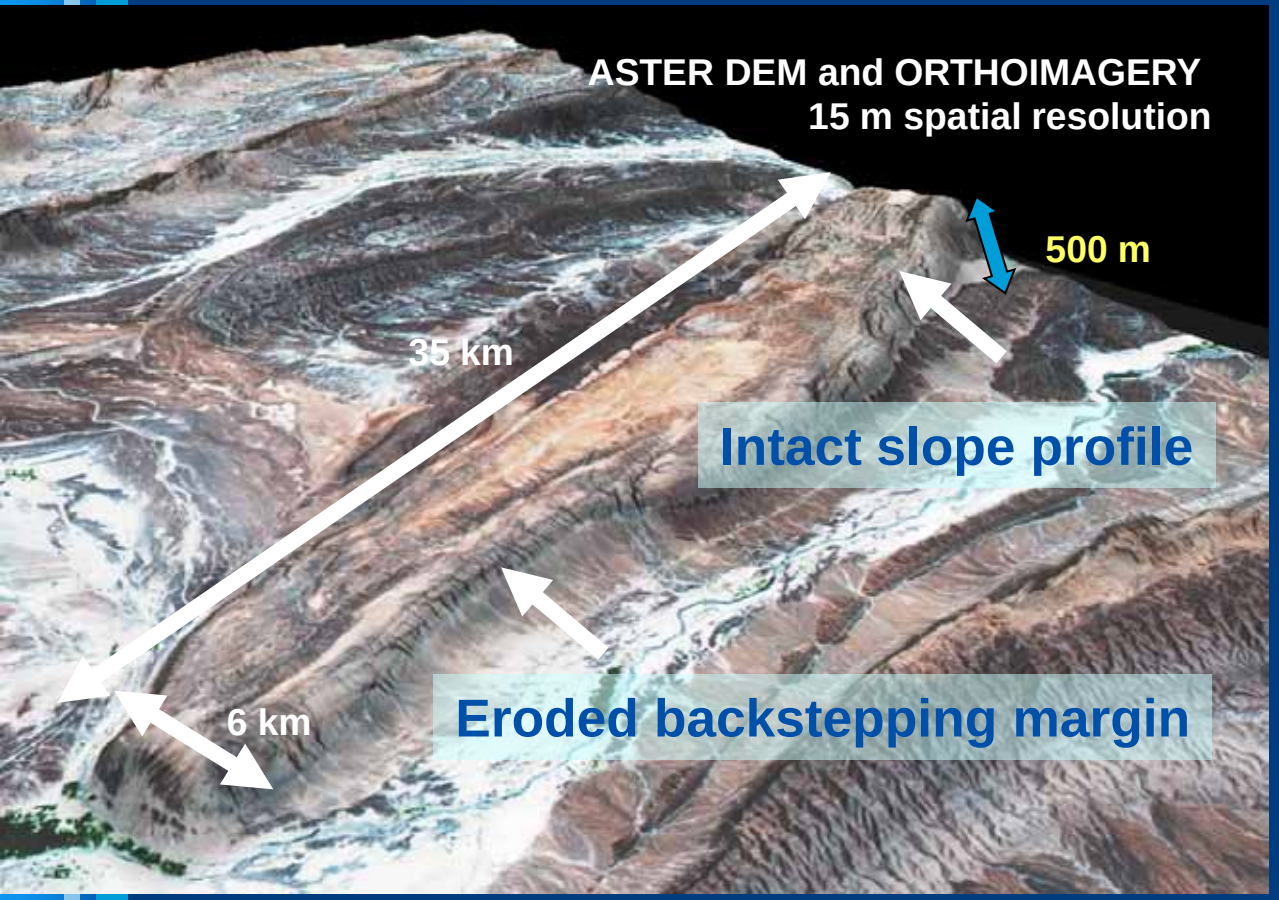


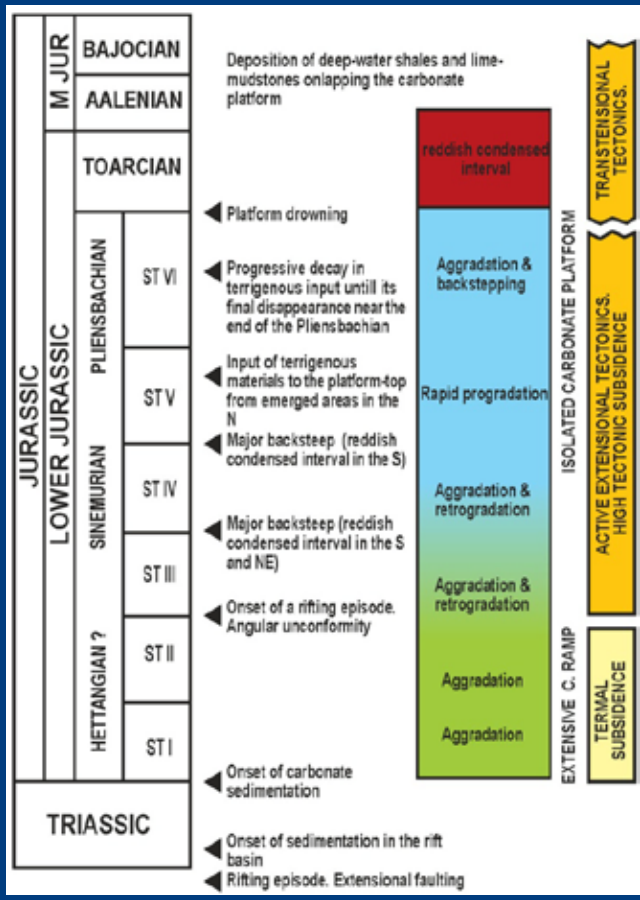
Process based simulations of rock type distribution with limited conditioning; for end member models, proportions and SSF

Djebel Bou Dahar Isolated Carbonate Platform

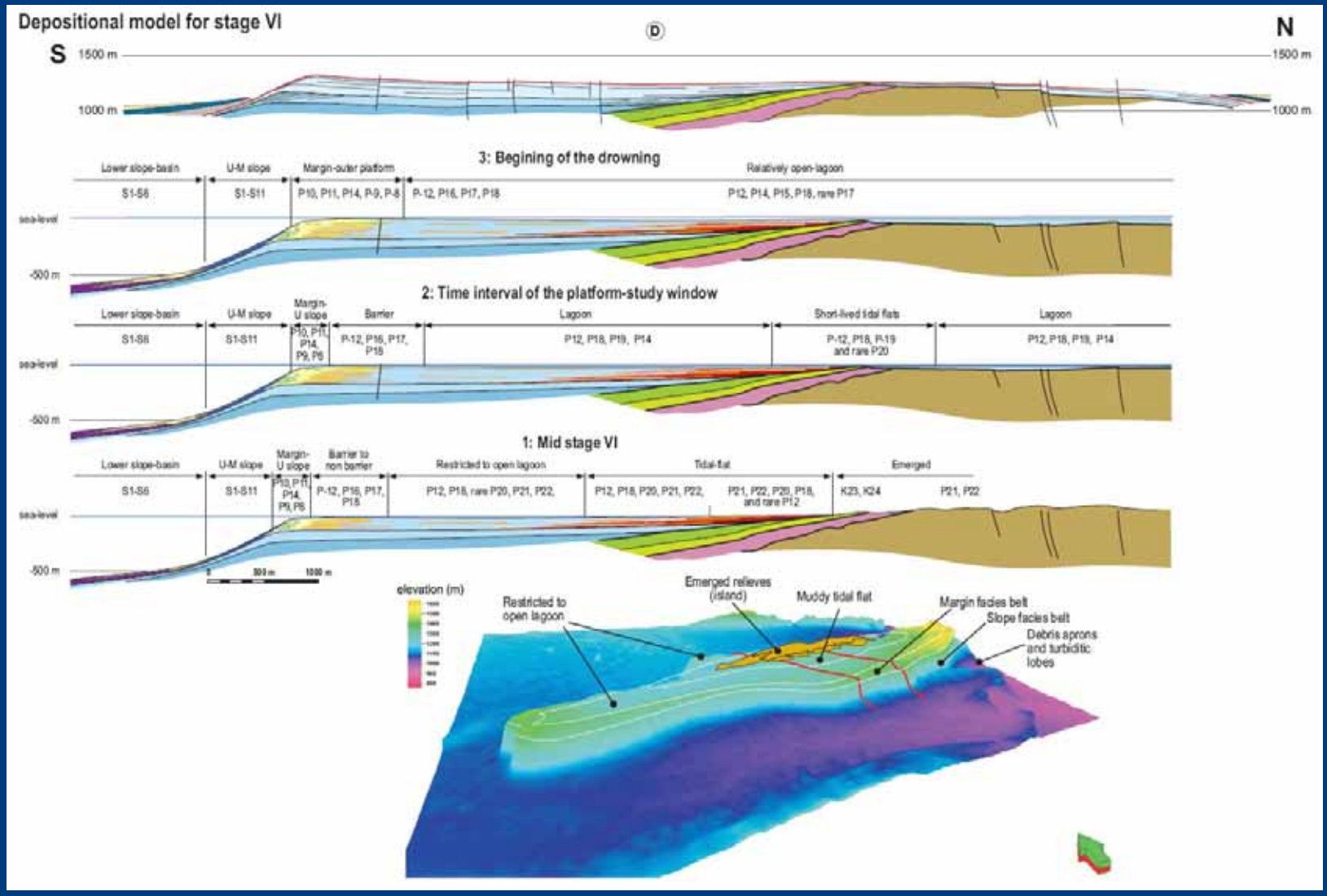
- Simulate facies and stratigraphy for platform top and steep slopes of an isolated carbonate platform, 35 by 7 km
- Themes: extensional tectonics, eustacy, tidal flats, ramp to flat topped platform and retrograding margin, extensive syndepositional fracturing
- Analog for reservoirs in the Caspian Basin, Black Sea, Turkmenistan and elsewhere
- “Hard” geological data captured by RTK DGPS, LIDAR and stored in a DOM
- MPS/FDM simulation for each of the six sequences scheduled end 2009

DBD - Overview

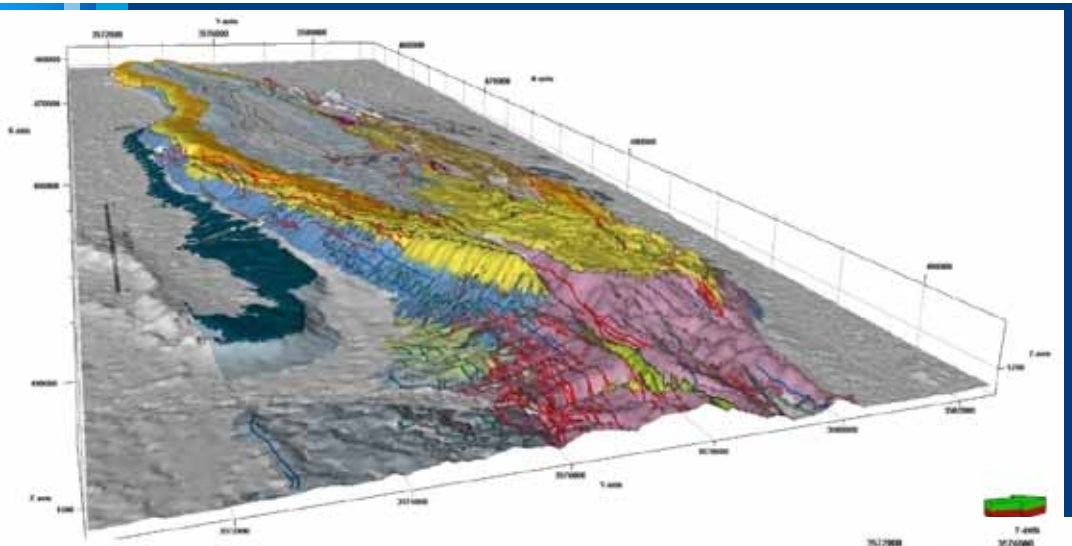




DBD – Traditional Geological Analyses

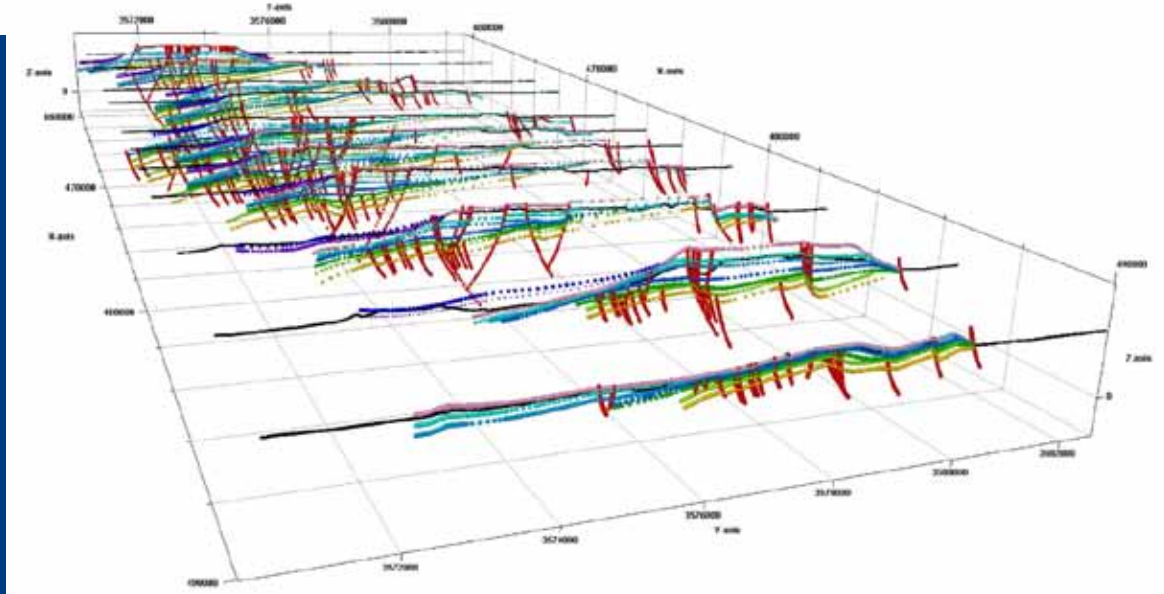


DBD – Painting Facies and Balancing Cross Sections



Facies captured from outcrop painted on DOM

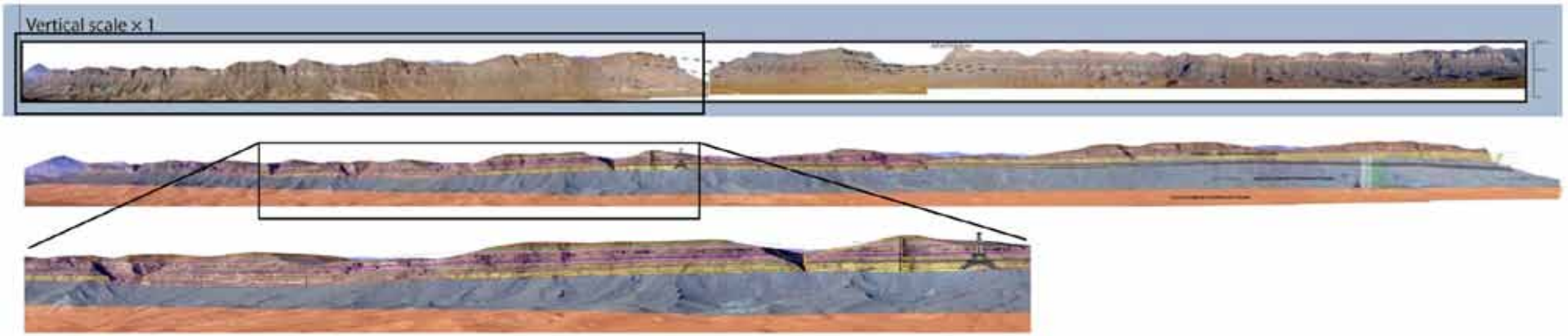
Cross sections reconstructing stage boundaries in DOM



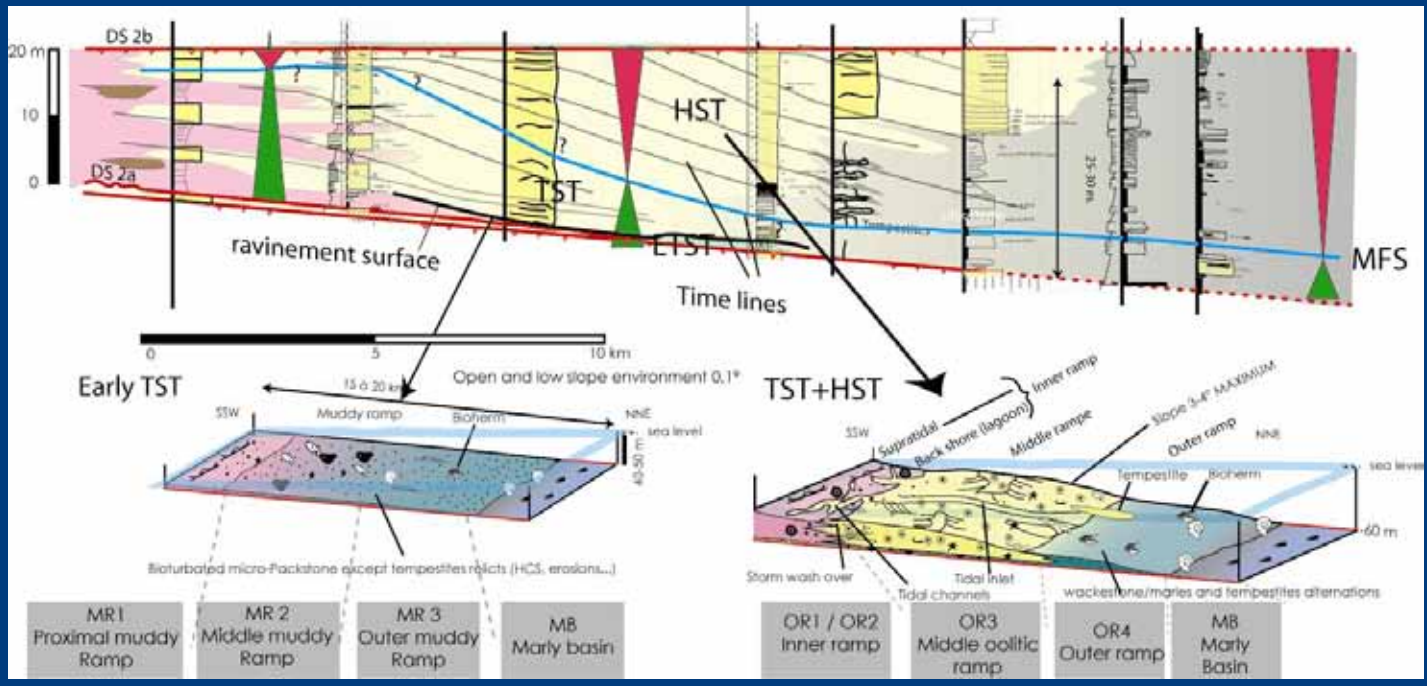
Amellago Ramp System

- Simulate facies and stratigraphy of early Jurassic mixed carbonate-clastic ramp system (35 km in dip direction)
- Themes: alternating ooid (HST) – and mud (TST) intervals; interfingering with basinal clastics
- Analog for Mesozoic to Tertiary carbonate ramp reservoirs like in Middle East
- Virtual Reality Geology Software (VRGS) facilitated identification and registration of key surfaces, measured sections and facies transitions
- Completed Dionisos models and trial (partial) MPS/FDM simulations; full field model expected end this year

Amellago Ramp – Traditional Geological Analyses

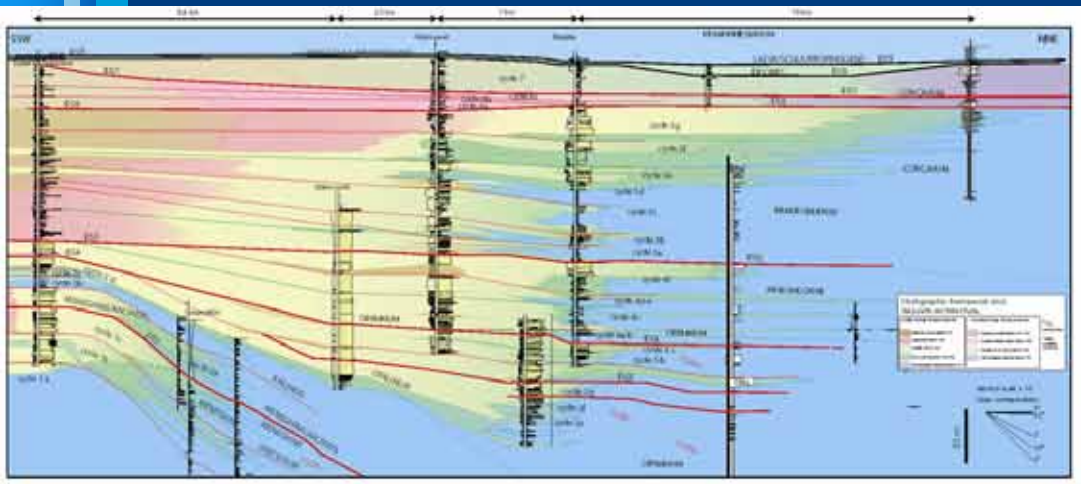


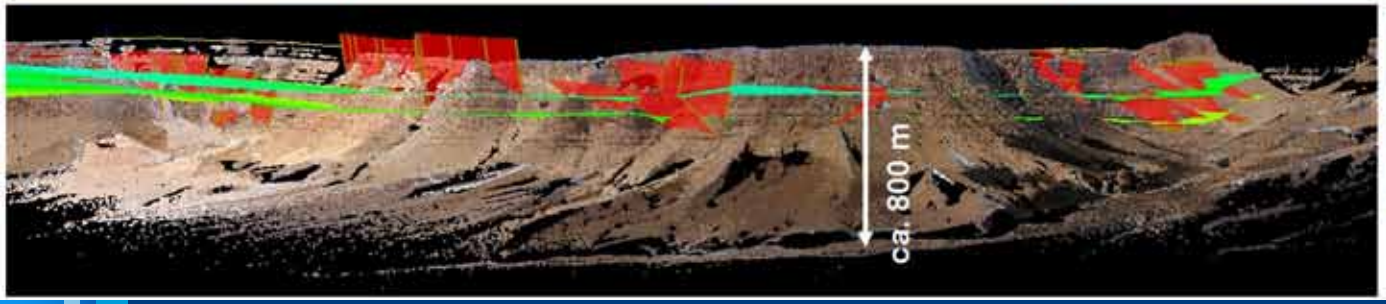
Traditional photo pans and depositional concepts

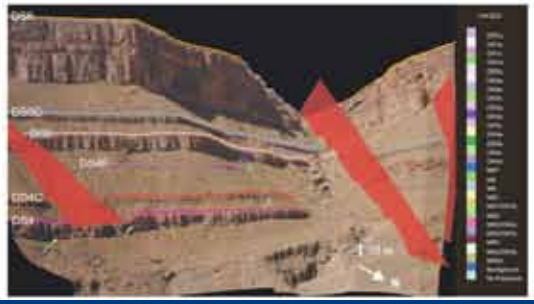


Amellago Ramp – Generation of DOM using Lidar and satellite imagery

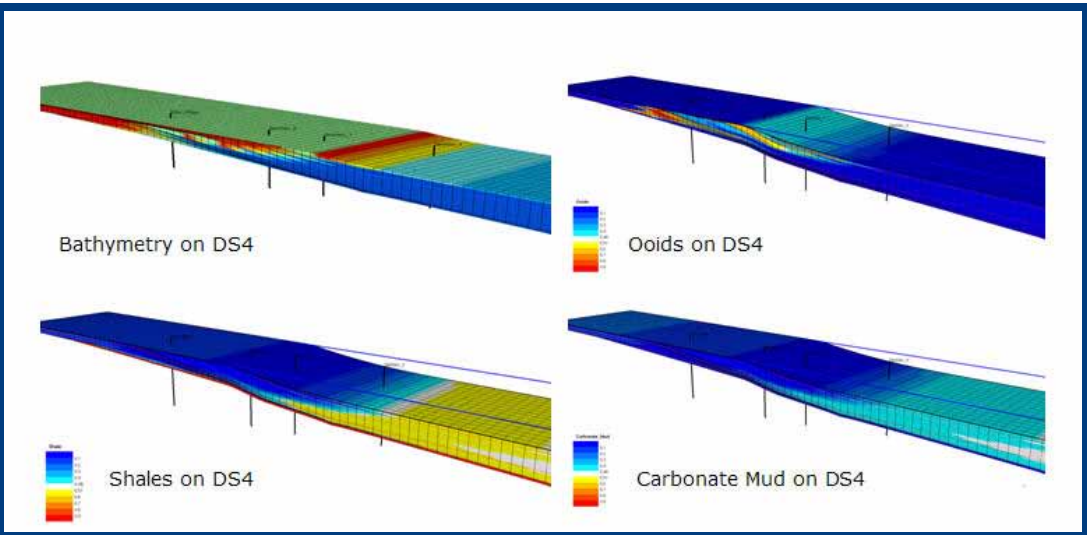
High resolution LIDAR foundation for capturing spatial “hard” data (top right) and VRGS assisted extracting additional “soft” data like SSF surfaces, faults, facies boundaries, etc.



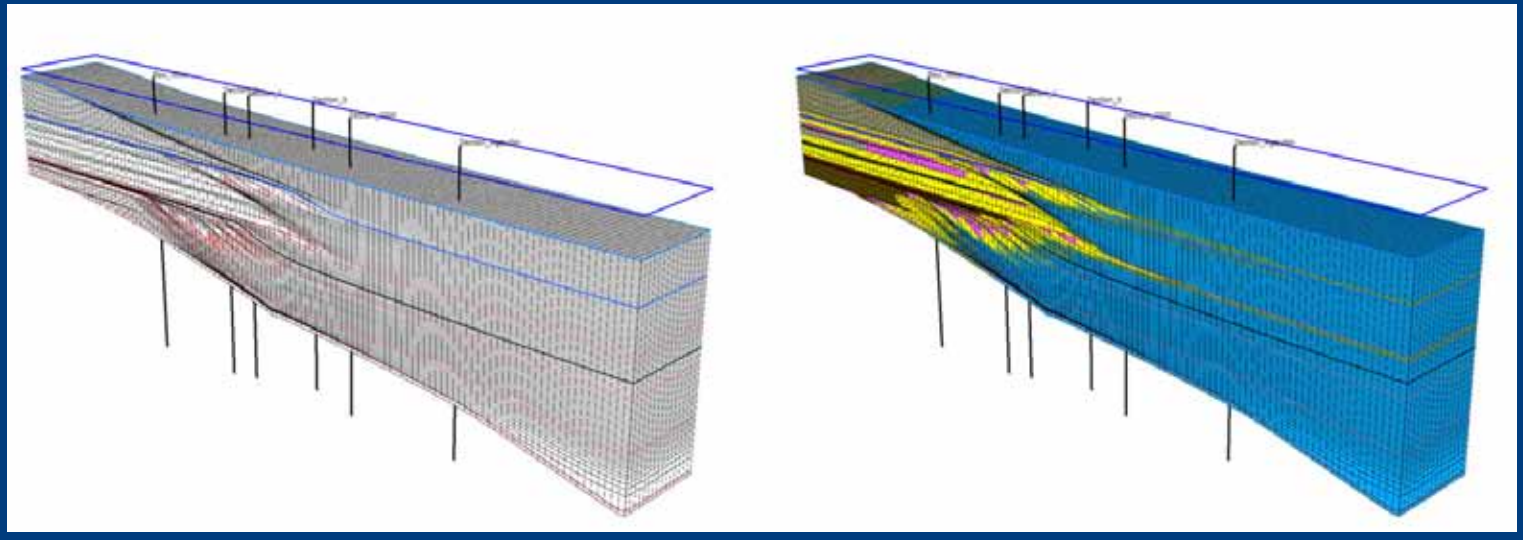




Amellago Ramp – Forward Modeling (Dionisos)

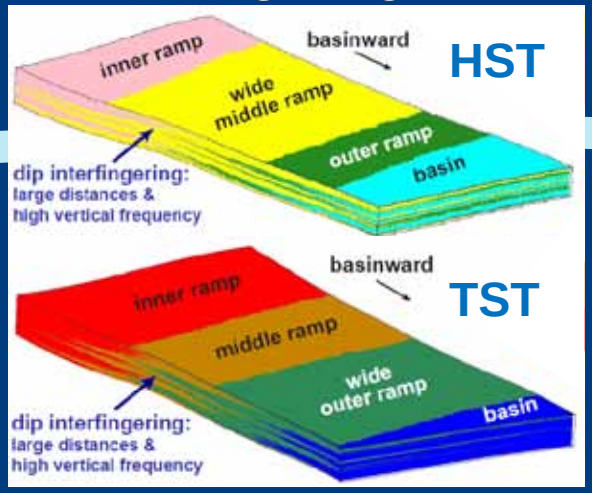


Forward modeling of facies distribution but limited hard data conditioning

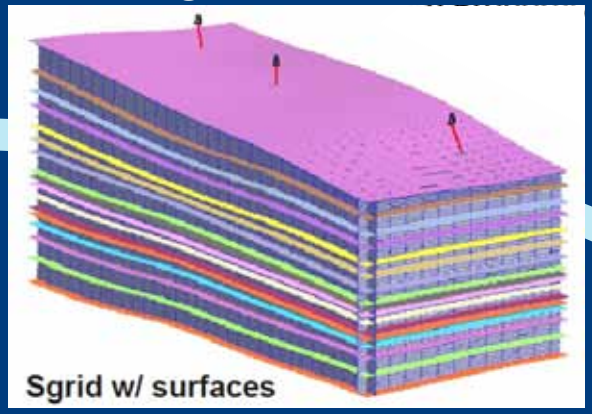


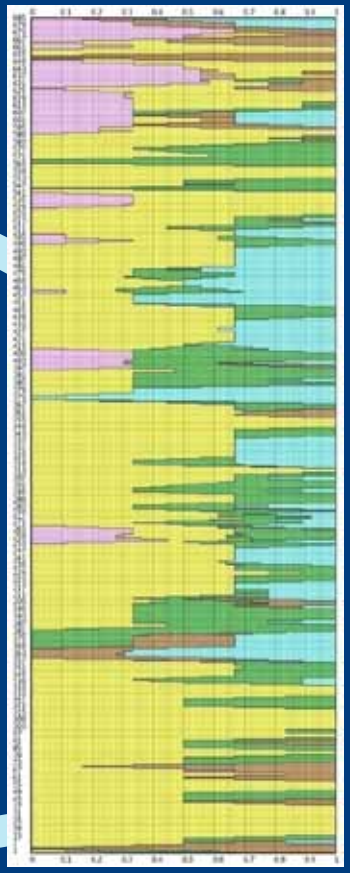
Multiple Point Statistics and Facies Distribution Modeling (MPS/FDM): Amellago ramp system

Training Image



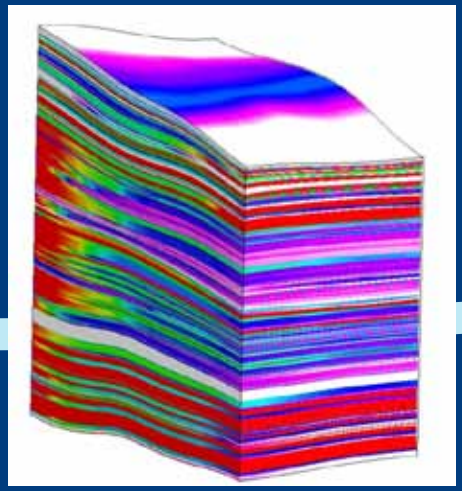
Sgrid and SSF



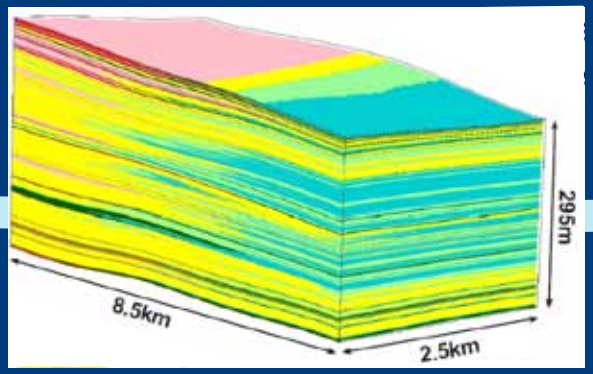


Facies Probability Curve

Facies Probability Cube



MPS Simulation



Summary and conclusions

- Outcrops provide exact and quantitative information on spatial lithofacies trends, facies proportions and 3D juxtaposition rules as well as associated stratal anatomy
- Product: digital catalog with spatial data on grand-scale and reservoir scale, lithofacies elements, juxtaposition rules, facies proportions and stratal anatomy of two key carbonate platform settings
- Models can be queried and contrasted/compared with subsurface carbonate reservoirs to provide solutions and/or alternatives
- Next steps:
  - Generating flow models for hydrocarbon reservoirs
  - Simulating diagenetic facies using MPS/FDM and Reactive Transport Modeling (RTM)