PS Optimal Gridding Selection for Field-Scale Reservoir Simulation of a Channelized Deepwater System*

Casey Meirovitz[1], Lisa Stright[2], Stephen M. Hubbard[3] and Brian W. Romans[4]

Search and Discovery Article #10934 (2017)**
Posted May 8, 2017

*Adapted from poster presentation given at AAPG 2017 Annual Convention and Exhibition, Houston, Texas, April 2-5, 2017

[1]Department of Geology and Geophysics, University of Utah, Salt Lake City, UT, USA (cdmeirovitz@gmail.com)
[2]Department of Geosciences, Colorado State University, Fort Collins, CO, US
[3]University of Calgary, Calgary, Alberta CANADA
[4]Virginia Tech Geosciences, Blacksburg, VA, USA

Abstract

Sub-seismic scale heterogeneity in channelized deepwater reservoirs can lead to significant uncertainty in reservoir connectivity and predicted performance. Though bed-scale heterogeneity can influence reservoir performance, reservoir simulation typically requires cell sizes much greater than the scale of internal channel architecture. Fine-scale sector models consisting of two stacked channel segments were used previously to quantify the influence of bed-scale heterogeneity and channel stacking on reservoir performance. Systematic upscaling and local grid-refinement are utilized here to optimize model construction for field-scale reservoir performance prediction while preserving key flow behaviors observed in fine-scale sector modeling.

Outcrop characterization of deepwater channels from the Tres Pasos Formation of the Magallanes Basin in Chile provided the framework (internal architecture and cross-sectional geometry) for each dynamic simulation. Twelve fine-scale sector models (cells 2 m x 2 m x 0.25 m) representing a range of potential offset angles and distances between two straight channel segments served as the "base-case" for upscaled model performance evaluation. Flow was induced between a single injector-producer well-pair completed 500 meters apart in opposing channel margins. Two different styles of gridding were tested for each of the 12 scenarios: (1) cartesian; and (2) conformable gridding. A range of vertical (0.25 to 2 m) and lateral (2 to 100 m) cell sizes were tested for each gridding style. Effective reservoir properties were calculated initially using flow-based averaging. History matching of upscaled and fine-scale results evaluated cumulative production, well flow rates, pressure, recovery efficiency, water breakthrough timing, and simulation runtime. Conformable gridding with cells 30 m x 30 m x 1 m most efficiently replicated high resolution simulation results for all 12 stacking scenarios. To obtain greater flexibility in defining channel fill architectures (a deterministic fill pattern was used previously), observed trends and distributions were used to geostatistically define net sand on the 30 m X 30 m x 1 m grids. Porosity and directional permeability were then assigned using the distributions of these properties and relationship to net sand taken from earlier upscaled models. Simulated results from the non-deterministic upscaled models match earlier fine-scale simulation results within 5% error. The methodology and results presented here provide the framework for future efforts to evaluate the influence of inter- and intra-channel architecture on reservoir performance prediction at the field-scale.

References Cited

Hubbard, S.M., A. Fildani, B.W. Romans, J.A. Covault, and T.R. McHargue, 2010, High-Relief Slope Clinoform Development: Insights from Outcrop, Magallanes Basin, Chile: Journal of Sedimentary Research, v. 80, p. 357-375.

Macauley, R.V., and S.M. Hubbard, 2013, Slope Channel Sedimentary Processes and Stratigraphic Stacking, Cretaceous Tres Pasos Formation Slope System, Chilean Patagonia: Marine and Petroleum Geology, v. 41, p. 146-162.

Meirovitz, C., L. Stright, B.W. Romans, and S.M. Hubbard, 2016, The Influence of Intra- and Inter-Channel Architecture in Selecting Optimal Gridding for Field-Scale Reservoir Simulation: AAPG Annual Convention & Exhibition, Calgary, Alberta, Canada, June 19-22, 2016, Search and Discovery Article #41929 (2016). Website accessed April 2017.

Meirovitz, C. L. Stright, A.A. Jackson, B.W. Romans, and S.M. Hubbard, 2016, Quantifying Inter- and Intra-Channel Architecture Controls on Reservoir Performance in a Deep-Water Slope Channel System, Tres Pasos Formation, Magallanes Basin, Chile: AAPG 2015 Annual Convention and Exhibition, Denver, Colorado, May 31 – June 3, 2015, Search and Discovery Article #10824 (2016). Website accessed April 2017.

Romans, B.W., A. Fildani, S.M. Hubbard, J.A. Covault, J.C. Fosdick, and S.A. Graham, 2011, Evolution of Deep-Water Stratigraphic Architecture, Magallanes Basin, Chile: Marine and Petroleum Geology, v. 28, p. 612-628.

Optimal Gridding Selection for Field-Scale Reservoir Simulation of a Channelized Deep-Water System, Tres Pasos Formation, Magallanes Basin, Chile

THE UNIVERSITY OF UTAH®

CHILE SLOPE SYSTEMS
University of Calgary
Virginia Tech
Colorado State University

Casey Meirovitz[1], Lisa Stright[2], Brian W. Romans[3], and Stephen M. Hubbard[4]

[1]Geology and Geophysics, University of Utah, [2]Colorado State University, [3]Geosciences, Virginia Tech, [4]Geoscience, University of Calgary

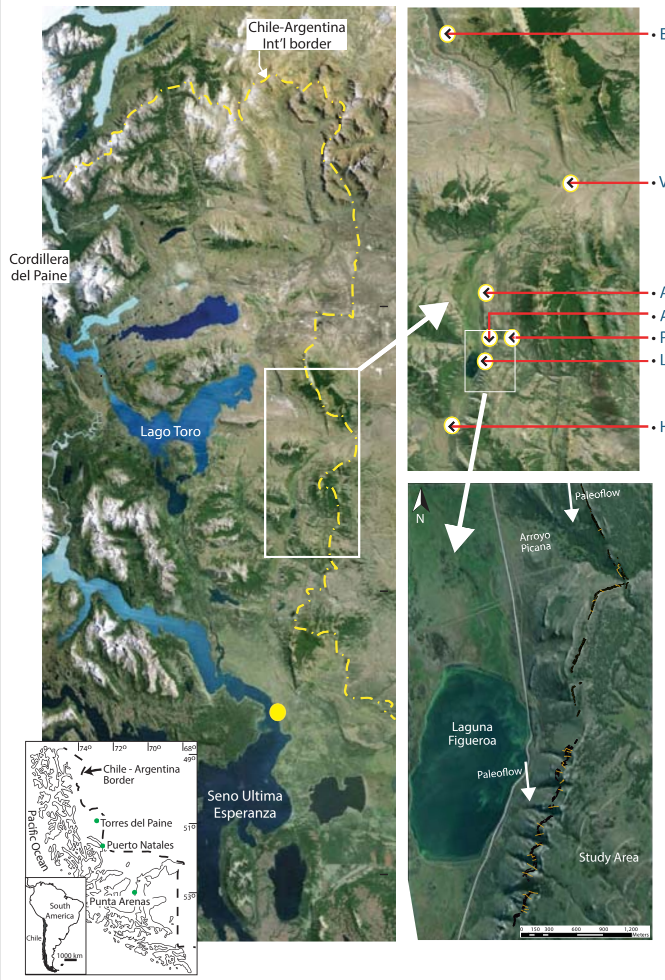
Objectives

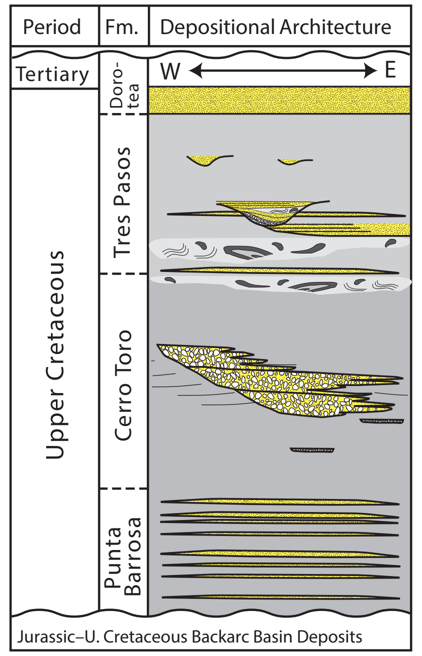
1) Systematically upscale a deep-water channelized turbidite reservoir for field-scale reservoir performance prediction while preserving key flow behaviors observed in high-resolution sector modeling.
2) Utilize detailed outcrop characterization and statistics to represent observed internal channel fill heterogeneities, facilitating future investigation of variations in fill geometries and facies proportions.
3) Quantitatively assess error introduced through upscaling methods.
4) Create and test a field-scale dynamic model of the Lower Laguna Figueroa channel complex set.

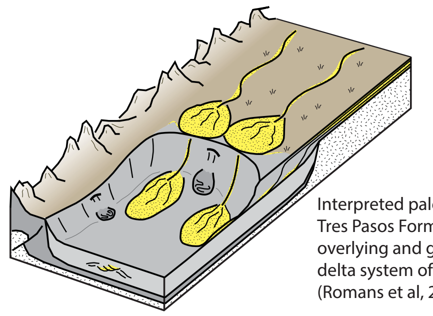
Geologic Background and Study Area

The Late Cretaceous Tres Pasos Formation consists of a turbidite-dominated succession that records the terminal phase of deep-water deposition in the Magallanes foreland basin, southern Chile. Slope channel deposits accumulated along a high-relief margin (>1 km relief) along a depositional profile >40 km long (Hubbard et al., 2010). This study focuses on a 120 m thick and 2.5 km long sandstone-rich succession of slope channel strata located adjacent to Laguna Figueroa. 3D exposures along a depositional-dip oriented transect enables well-constrained mapping of channel architecture.

GoogleEarth images of the Ultima Esperanza District with CSS JIP study areas highlighted. Inset map at lower left shows location of study area with respect to southern South America (compare locations of the Torres del Paine and Puerto Natales).

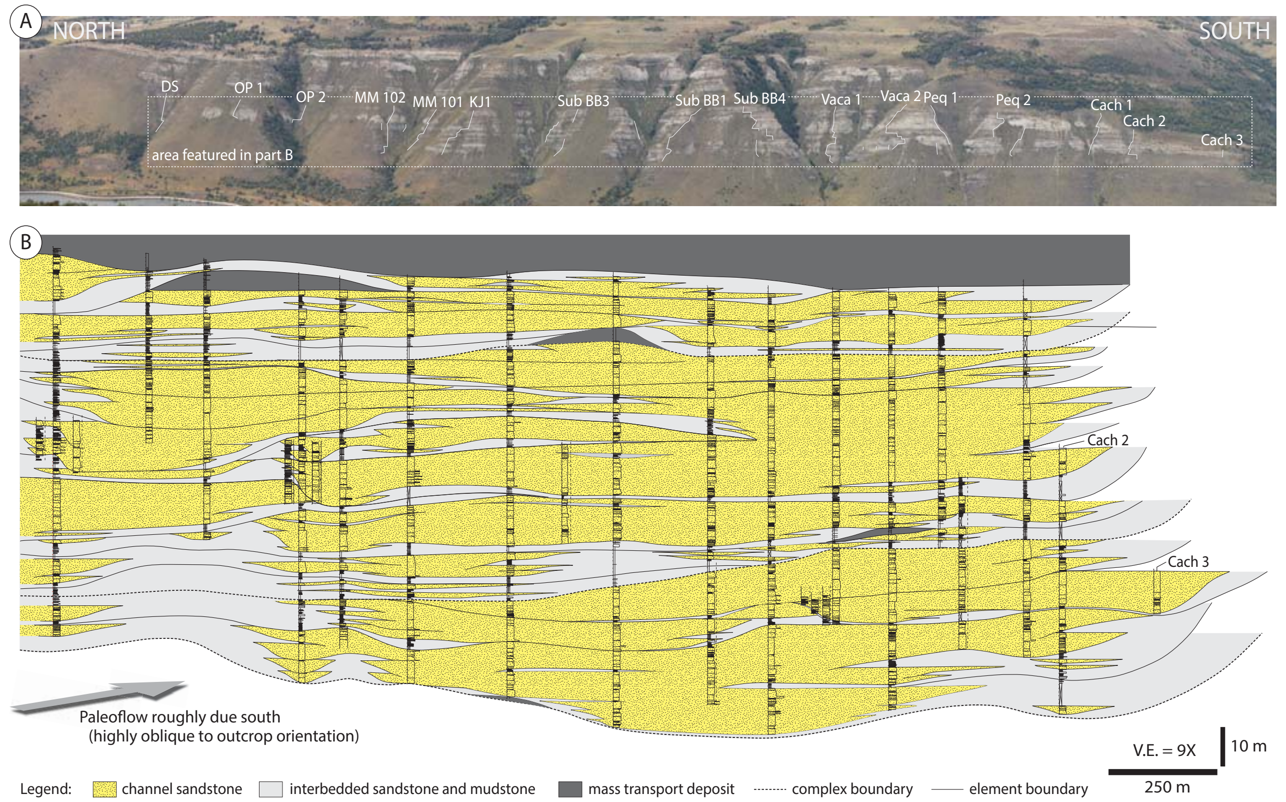






Interpreted paleogeographic setting for the Tres Pasos Formation slope system, and overlying and genetically linked shelf-edge delta system of the Dorotea Formation (Romans et al, 2011).

Tres Pasos Formation, Lower Laguna Figueroa Section



The Lower Laguna Figueroa Outcrop Belt is a large-scale (>120m thick), composite channel complex set delineated in the Laguna Figueroa area. This complex set is comparable to channelized slope systems explored off numerous continental margins (Macauley and Hubbard, 2013).

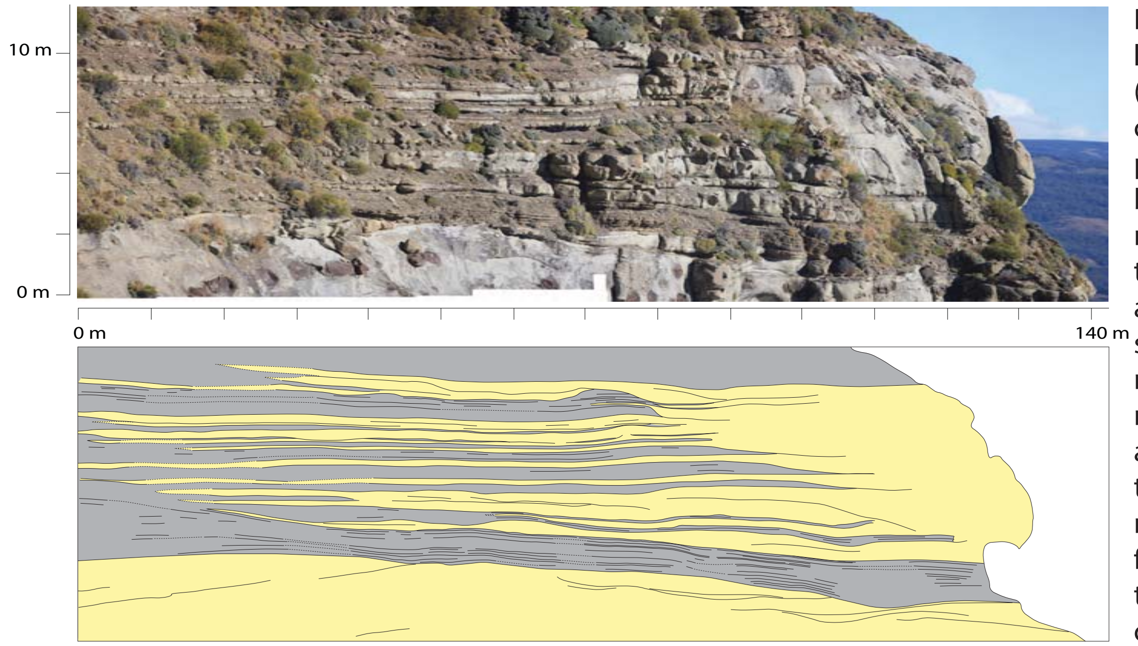
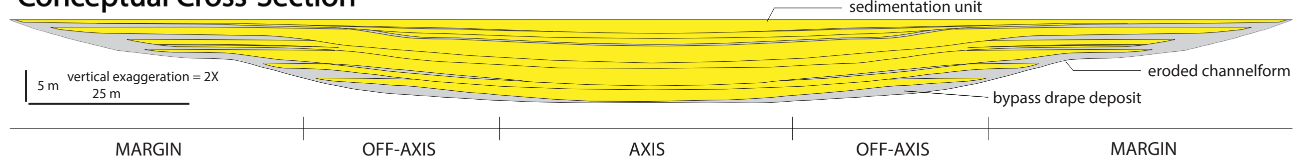


Photo (top) and line-drawing trace (below) of a channel, the primary building block for modeling. Note the more axial amalgamated sandstone (at right) transitions to non-amalgamated and finer facies to the left. This relationship is further depicted in the conceptual cross-section below (bottom).

Conceptual Cross-Section

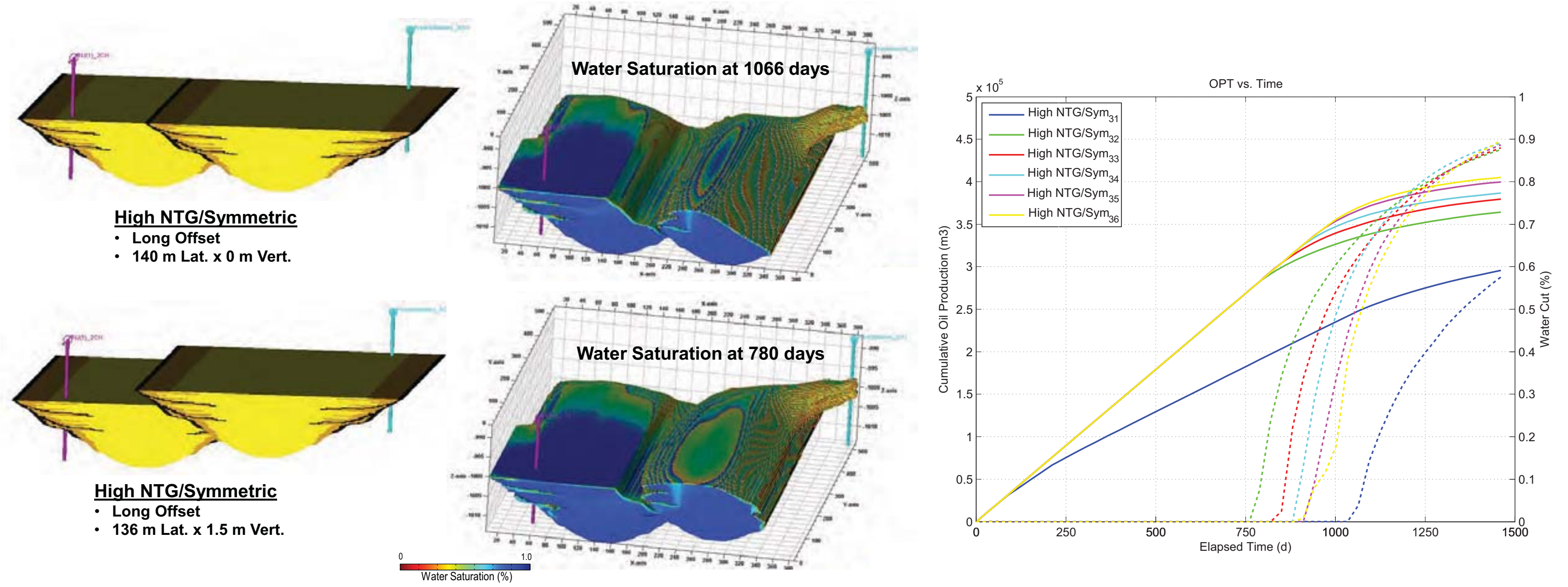


Macauley and Hubbard, 2013

"Fine-Scale" Geologic Heterogeneity and Reservoir Performance Prediction

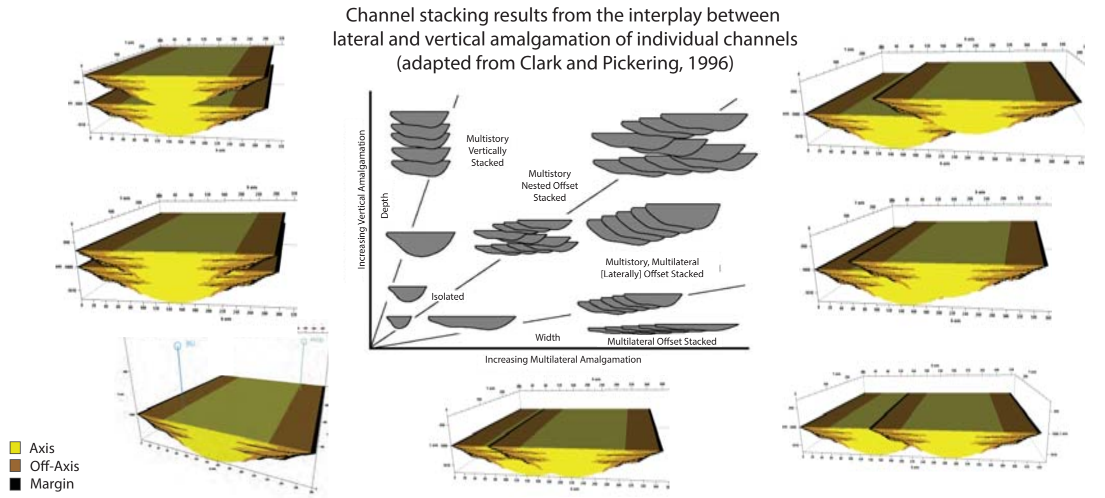
Outcrop images from Lower Laguna Figueroa channels demonstrating the nature of off-axis and marginal facies assemblages (A) Despite reduced overall Net:Gross, off-axis interbedded sands appear laterally connected to amalgamated axial sands. (B) Shale drapes associated with the margin facies can significantly reduce connectivity between stacked channels.

Reservoir performance is strongly impacted by heterogenous marginal facies, especially when channels are laterally stacked. Upscaling tends to under-represent marginal facies resulting in overprediction of reservoir volumes and intra-channel dynamic connectivity.



High-resolution sector modeling (Meirovitz et al., 2016) shows oil production and water breakthrough are slowed by the baffling effect of marginal facies. Introducing 1.5 meters of vertical offset increases the average production rate by 20%, also resulting in water breakthrough 284 days earlier. Upscaling of the simulation grid and reservoir properties must be designed to capture these effects.

High Resolution Sector Models As "Base Case" for Upscaling



High-resolution (2m X 2m X 0.25 m cell size) sector model realizations used to analyze potential impacts to reservoir performance due to inter- and intra-channel architecture provide the "base case" for evaluation of upscaling procedures.

Sector models capture twelve stacking patterns designed to represent a range of possible channel migration behaviors. Offset angle varies from 0° (lateral) to 90° (vertical). Offset distance is either short (1/4 channel width) or long (1/2 channel width).

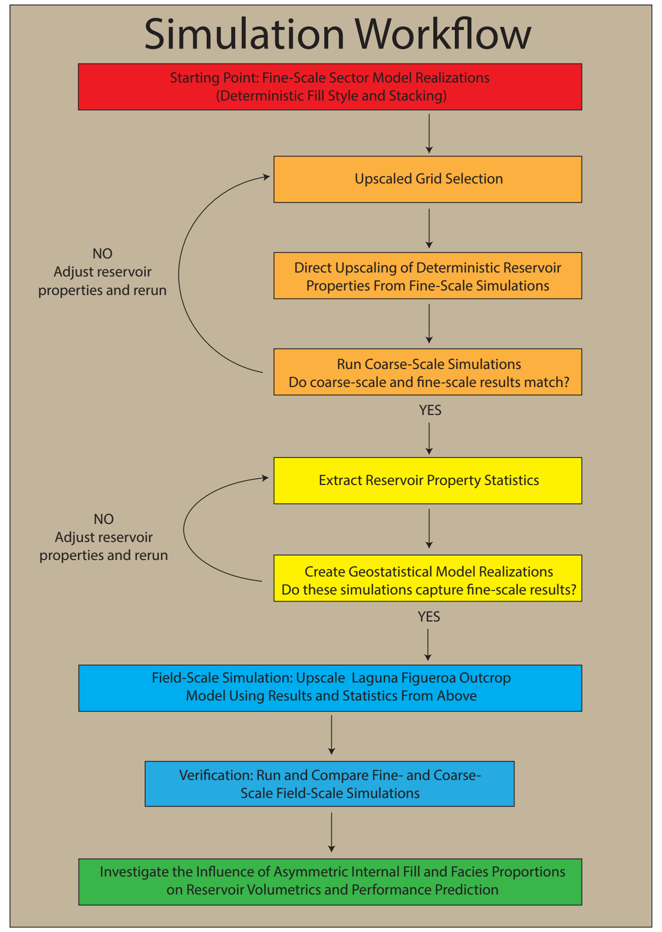
Optimal Gridding Selection for Field-Scale Reservoir Simulation of a Channelized Deep-Water System, Tres Pasos Formation, Magallanes Basin, Chile

THE UNIVERSITY OF UTAH®

CHILE SLOPE SYSTEMS
University of Calgary
Virginia Tech
Colorado State University

Casey Meirovitz[1], Lisa Stright[2], Brian W. Romans[3], and Stephen M. Hubbard[4]
[1]Geology and Geophysics, University of Utah, [2]Colorado State University, [3]Geosciences, Virginia Tech, [4]Geoscience, University of Calgary

Modeling Approach



Multiple options for grid upscaling were investigated before arriving on an "optimal" grid design.

Reservoir properties are upscaled to the new grid using "flow-based upscaling" and arithmetic averaging.

All 12 sector models are treated as a single case with adjustments to reservoir properties applied across all 12 realizations.

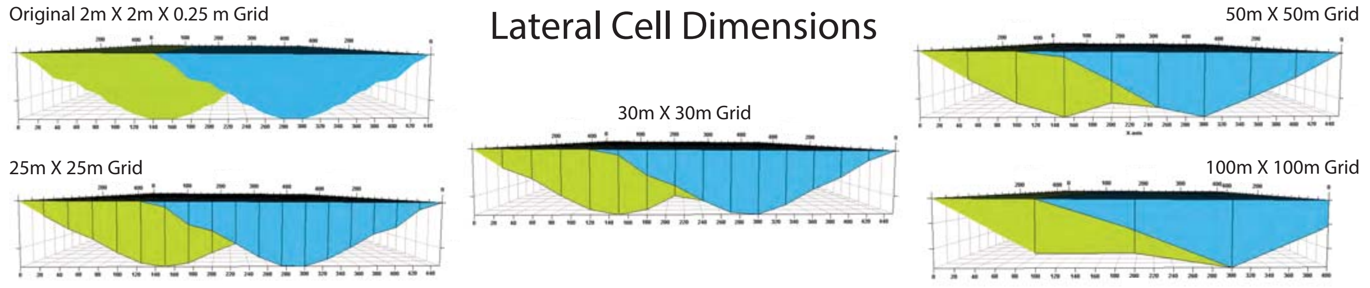
Geostatistical realizations of internal channel architecture are created using geometric trends and property distributions/relationships extracted from the upscaled deterministic models.

Porosity, permeability, and Net:Gross sand distributions are adjusted to match simulated results to the "base-case" simulations.

Upscaling methods and statistics are applied to the 600M cell field-scale geologic model and results verified. This upscaled model provides the basis for ongoing investigation.

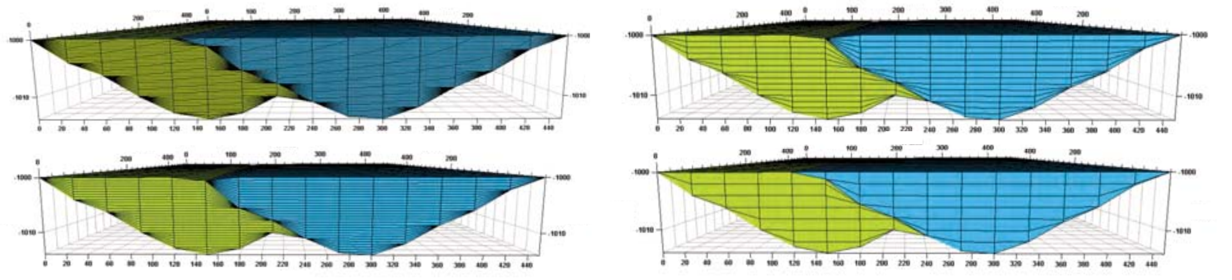
Grid Selection

Lateral Cell Dimensions



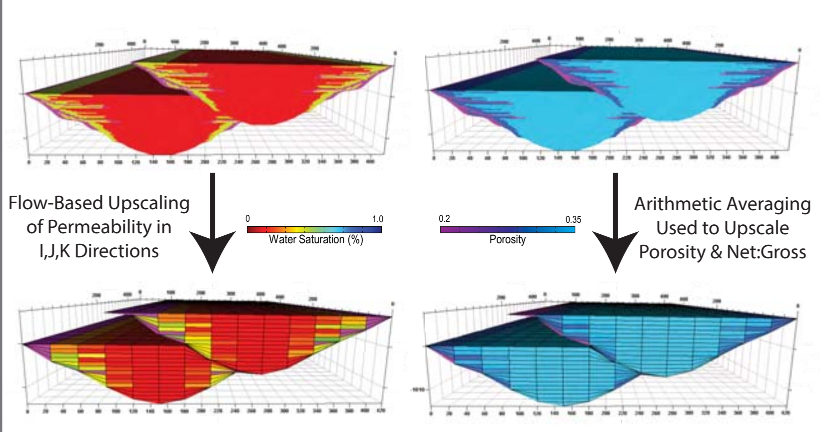
Multiple grid options are shown for a single model realization. A combination of qualitative criteria (preservation of channel form geometry/internal fill architecture) and flow simulation results were employed in selecting an "optimal" lateral cell size. A conformable grid with 30m X 30m cell sizes best met these criteria considering all 12 stacking patterns.

Layering



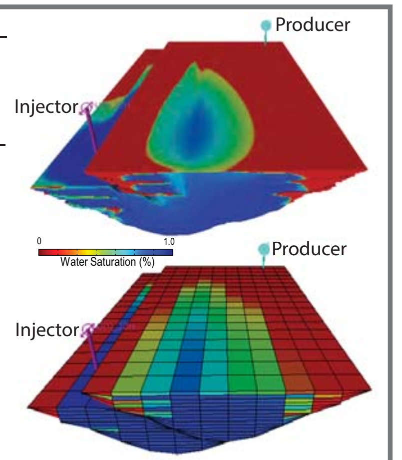
A range of cell thicknesses (0.25 to 2 m) were explored using the same selection criteria as above. Ultimately a 1 m cell thickness was selected. Upscaling to a 30m X 30m X 1m grid reduces the total number of cells by a factor of 900.

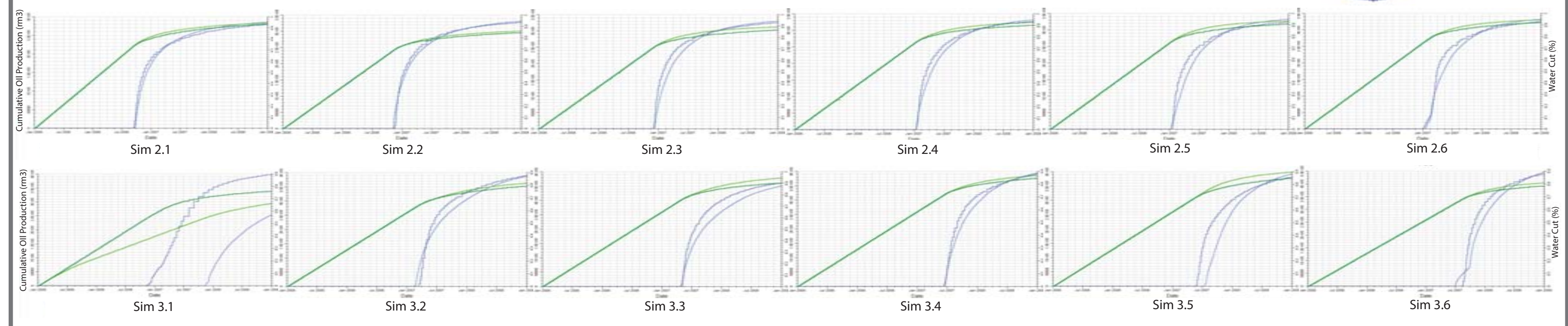
Direct Upscaling of Deterministic Fills and Simulation Results



Left: Flow-based upscaling and arithmetic averaging used to assign reservoir properties to upscaled models. Upscaled porosity was increased by the average difference in pore volumes between all 12 model realizations (1.6%).

Right: Example water saturation distributions at water breakthrough. Upscaled reservoir properties generally capture flow behaviors observed in high-resolution simulations.

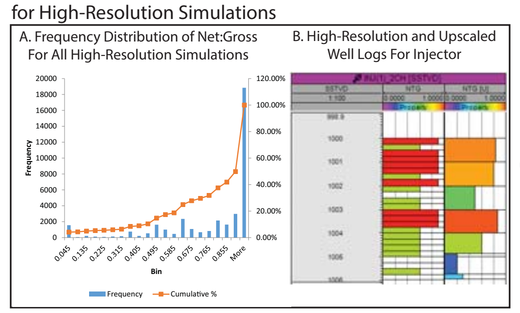




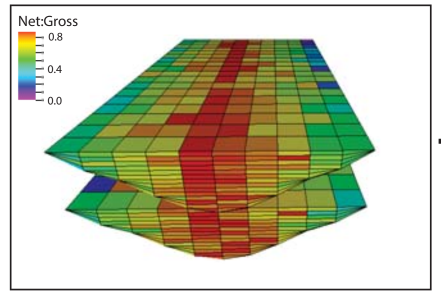
Above: Time series plots of cum. oil production (green) and producer water cut (blue) comparing original and upscaled model results. Offset angle and distance increase from left to right and top to bottom, respectively. Final production volumes match within 2-4%. Water breakthrough matches within 30 days or less. Simulation 3-1 is an important exception, highlighting a limitation in the ability of upscaled models to fully capture flow through highly heterogeneous marginal facies in an extreme case.

Development of Geostatistical (Non-Deterministic) Realizations

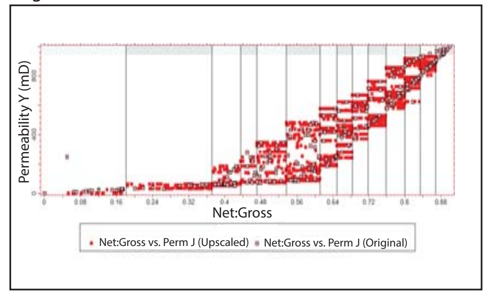
1) Calculate Frequency Distribution and Upscale Well Logs for High-Resolution Simulations



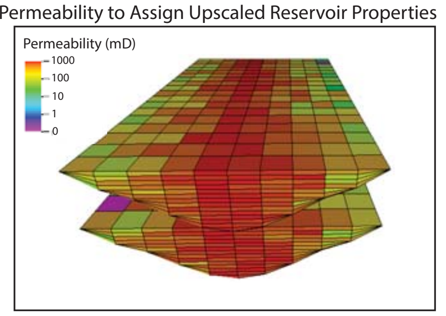
2) Combine Net:Gross Statistics, Upscaled Well Logs, and Trends in SGS to Create Distributed Net:Gross



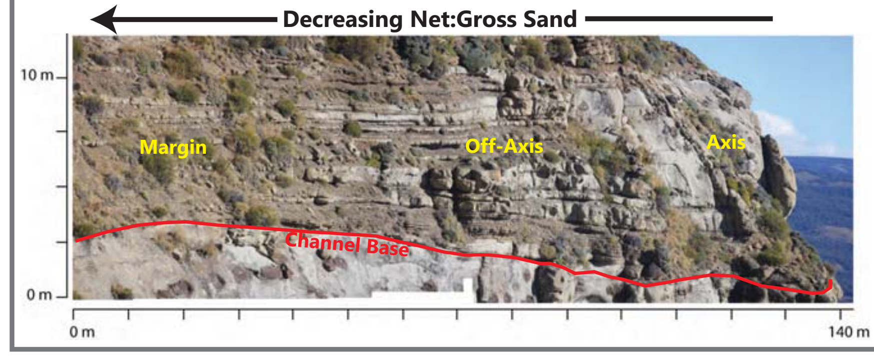
3) Relate Net:Gross to Porosity/Permeability from High-Resolution Models



4) Utilize Relationship Between Net:Gross and Porosity/Permeability to Assign Upscaled Reservoir Properties

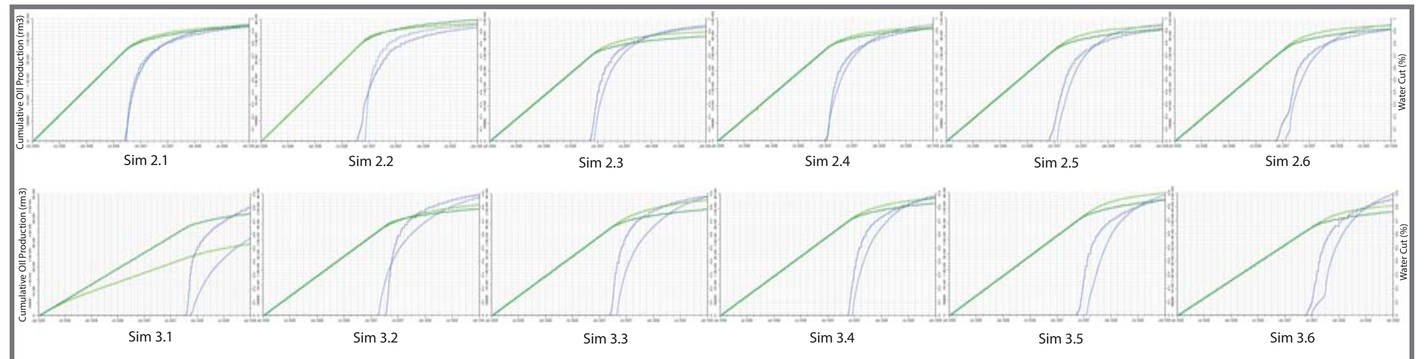


Above and Right: Flow chart outlining process for developing geostatistical, non-deterministic upscaled simulations consistent with original high-resolution sector models. A non-deterministic representation of observed internal channel architecture is required for future field-scale simulations designed to capture channel fill asymmetry and variations in Net:Gross sand.



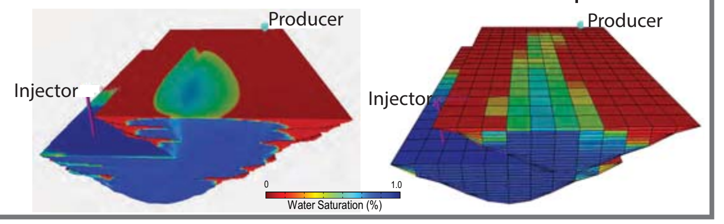
Left: Decreasing Net:Gross sand from channel axis to margin is clearly observed in outcrop and provides an important link between outcrop characterization and flow simulations.

Geostatistical Sector Model Simulation Results

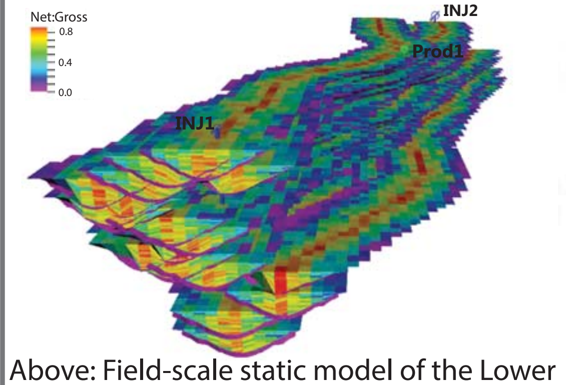


Above: Time series plots of cum. oil production (green) and producer water cut (blue) comparing original and upscaled model results. Dynamic results from geostatistical flow simulations generally capture high-resolution behavior and performance within 5% error. Discrepancies between simulations are most sensitive to pore volume matching (i.e, porosity property).

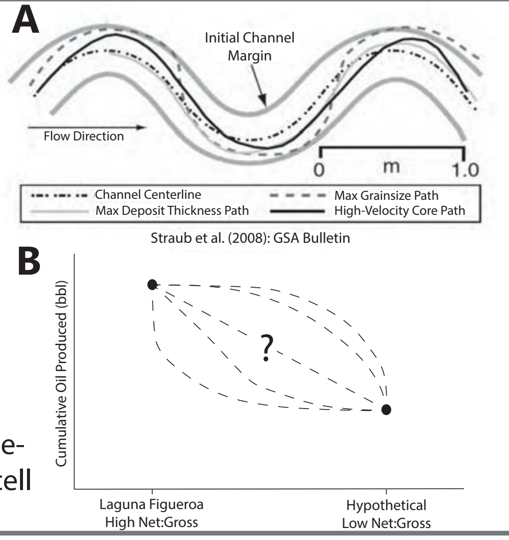
Right: Example water saturations at water breakthrough. Coarse models generally capture high-resolution flow behavior. In this case (3.4), water breakthrough is just slightly earlier than the base case.



Application of Upscaling Methods to Field-Scale Simulation



Above: Field-scale static model of the Lower Laguna Figueroa outcrop. Non-deterministic Net:Gross colorshade shown. Upscaling procedures as developed here reduce the overall cell count from >600M to ~1.6M cells.



Middle: The 3D field-scale model will be adapted to: A) Quantify the influence of facies asymmetry in deep-water channelized deposits on predicted reservoir volumes and performance; and B) Identify potential threshold behaviors relating channel-scale Net:Gross sand and cumulative oil production (dynamic connectivity).

Conclusions and Next Steps

1) A process of systematic upscaling has been demonstrated which makes possible field-scale reservoir modeling of the Laguna Figueroa outcrop while preserving simulated fine-scale reservoir behaviors.

2) Process derived statistics make possible stochastic representation of internal fill architecture, facilitating future efforts to quantify the influence of asymmetric channel fill and variable channel-scale Net:Gross sand on 3D reservoir volumetrics/performance prediction.

3) The ability to fully capture the baffling effect of marginal facies in purely laterally offset channel elements remains elusive and is a topic for future research.

4) Ongoing efforts to extract facies geostatistics/trends from the Laguna Figueroa outcrop (Tres Pasos Fm.) promises to provide improved outcrop-based detail for future modeling.

A Special Thanks To Our Sponsors: Chevron, Repsol, Shell, nexen, Statoil, bhpbilliton, ConocoPhillips, HESS, Schlumberger