Multiscale Reservoir Modeling for CO_2 Storage and Enhanced Oil Recovery Using Multiple Point Statistics

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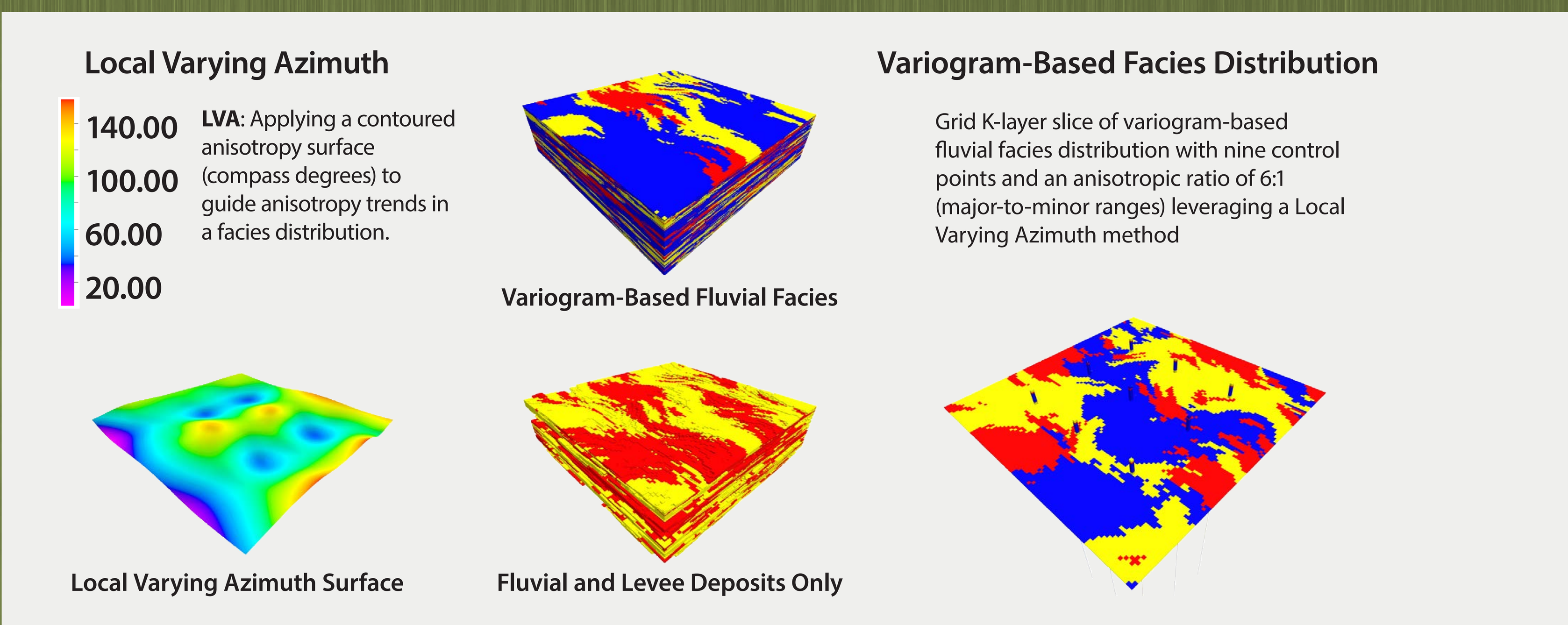
Introduction

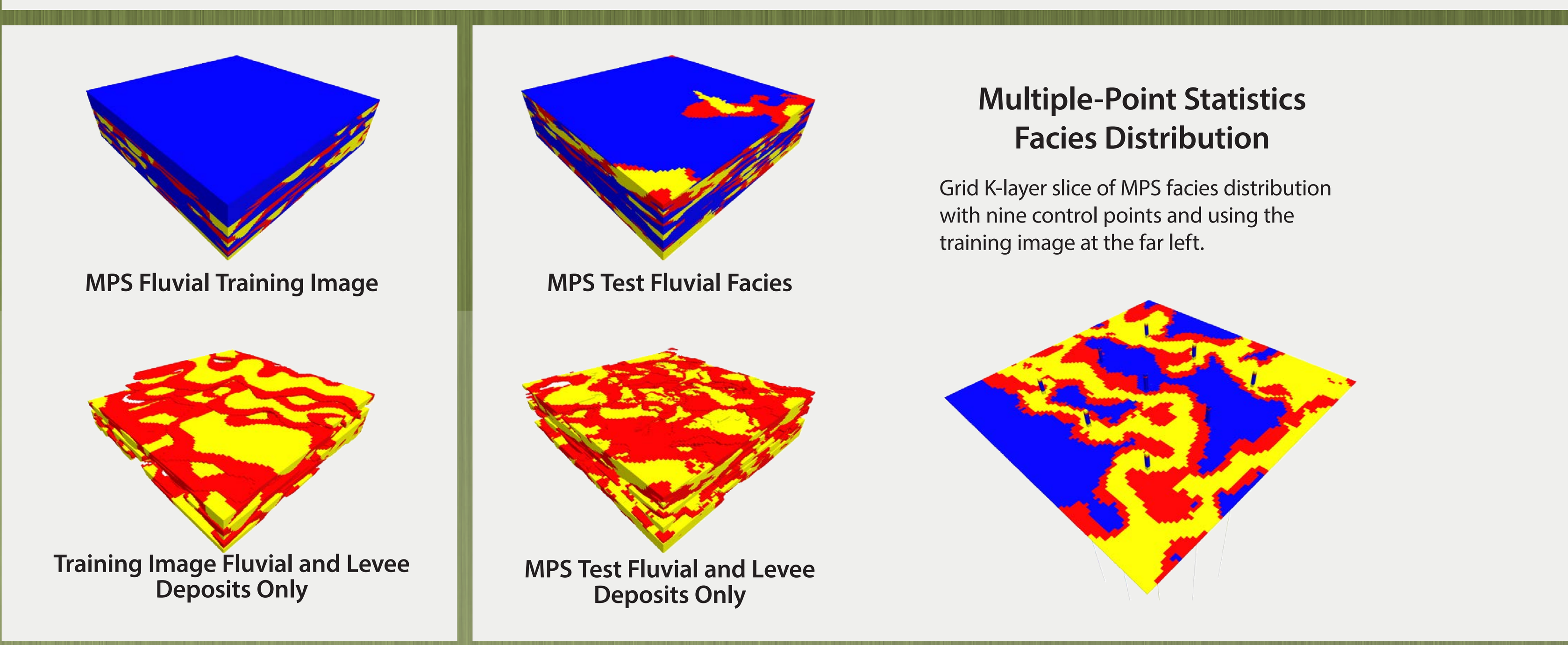
New applications are being developed in the field of reservoir modeling to answer questions about CO_2 storage and CO_2 enhanced oil recovery (EOR). The Energy & Environmental Research Center (EERC) and the Plains CO_2 Reduction Partnership Program, in collaboration with the U.S. Department of Energy, have been constructing 3-D geocellular models for the purposes of studying CO_2 storage and CO_2 EOR. These efforts are gaining importance as we continue to investigate methods in climate change mitigation and greenhouse gas reduction.

Targets for potential geologic storage of CO_2 may consist of a variety of reservoir types, comprising heterogeneous lithologies from numerous depositional environments. Each depositional environment contains its own reservoir and nonreservoir rock based on 1) the presence of economically viable petrophysical properties (porosity and permeability); 2) the existence of temperature and pressure conditions effective in keeping injected CO_2 in the supercritical phase; and 3) the presence of a competent cap rock or seal to limit vertical mobility of sequestered CO_2. An understanding of reservoir hydrodynamics (where injected fluids may migrate or accumulate) is necessary to accurately model and monitor CO_2 injection. An additional consideration for realistic scenarios is the proximity to CO_2 sources for economic viability of CO_2 storage.

The characterization and assessment of geologic targets for potential CO_2 storage are achieved through the construction and simulation of a reservoir model. The geologic modeling workflow includes 1) data acquisition; 2) structural modeling; 3) data upscaling and property modeling utilizing advanced geostatistical methods; 4) uncertainty analysis and history-matching; and 5) predictive simulations of CO_2 injection, pressure response, fluid saturation, and migration.

Several geostatistical approaches are available to assist in reducing uncertainty with various data sets. If the depositional environment is well understood, an optimized facies model can be constructed by using a unique method called multiple-point statistics (MPS). Unlike variogram-based algorithms, MPS uses a training image to determine facies associations between control points in the 3-D grid (Strebelle and Journel, 2002; Caers and Zhang, 2004).





MPS Facies Modeling: Training Images and Control Points

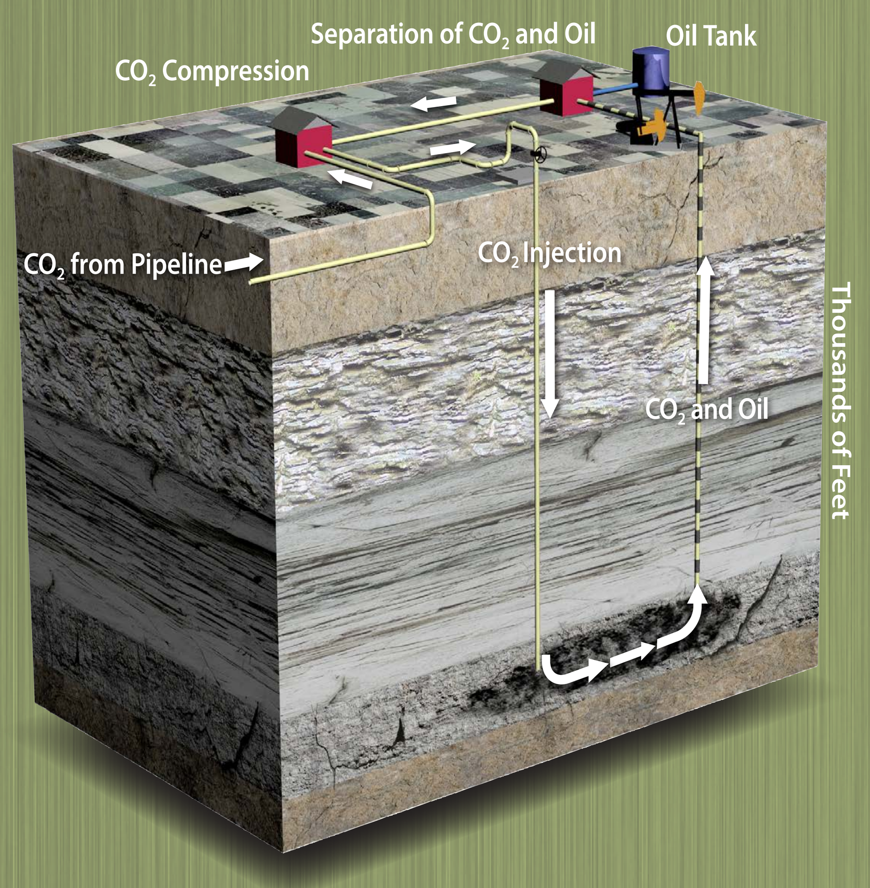
Training Image: Idealized reservoir volume containing pattern information (facies, facies stacking, lateral facies associations, and facies proportions) in a format that can be measured by modeling software.

Control Point: Hard data (known conditions at a particular location) which is used to guide an MPS distribution.

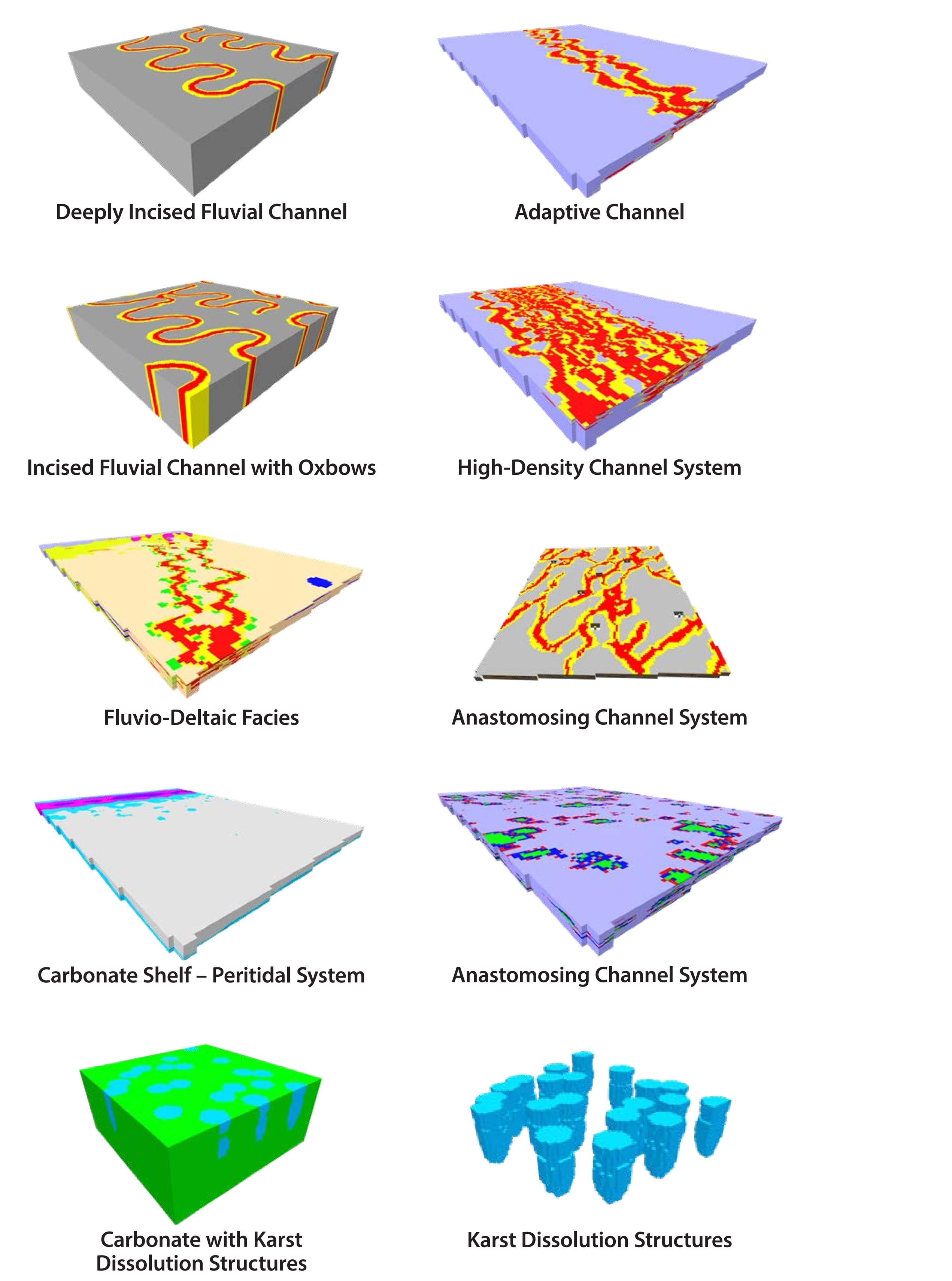
The actual facies distribution process is well discussed by Caers and Zhang (2004) and is achieved by 1) specification of a seed value (starting point within the 3-D grid) and definition of a random path; 2) searching for the nearest control points or previously simulated cells; 3) construction of a probability model based upon proximal control points and the relationships measured from the training image; 4) assignment of the most probable value to the unknown cell; and 5) moving to the next unknown cell, following the predefined random path, to repeat the process until all cells have been visited.

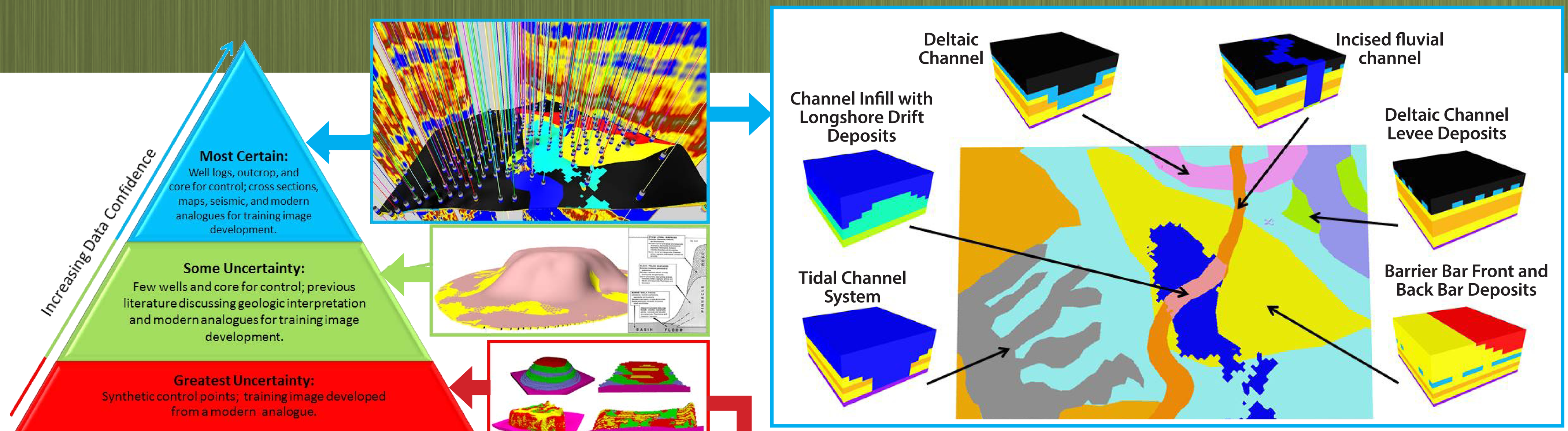
The ability to apply geologic understanding of a depositional model to estimate conditions in unsampled locations is a strength not available in variogram-based methods and may result in more realistic results (an example being the knowledge that fluvial facies are likely to exhibit high connectivity rather than a widely scattered distribution of fluvial facies). Variogram-based statistical methods are perhaps better suited for the distribution of petrophysical properties within each facies, needing only to apply a general understanding of anisotropic trends.

It should be noted that even with a valid training image, the results will likely not be geologically sound without accurate control points to guide the distribution. Without using control points, the resulting facies distribution will be statistically viable in comparison with the training image, but it is unlikely that a realistic result will be achieved. The EERC has begun construction of an MPS training image "library" created to house and archive training images used to develop reservoir facies models for use in future investigations.



MPS Training Image Library

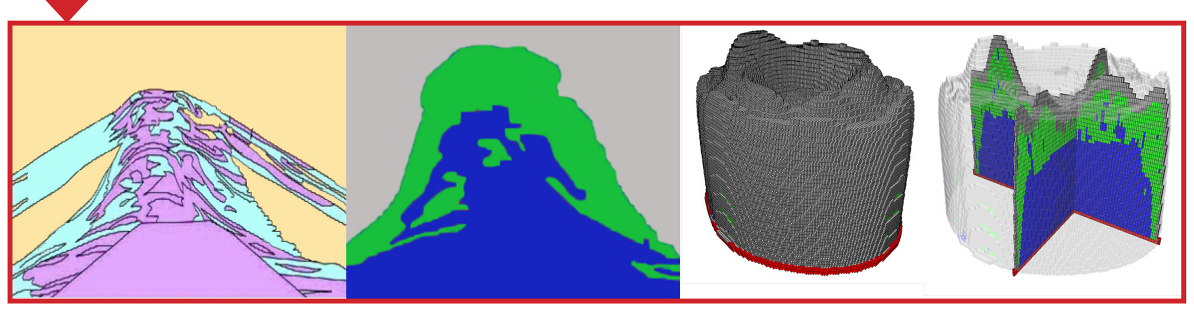




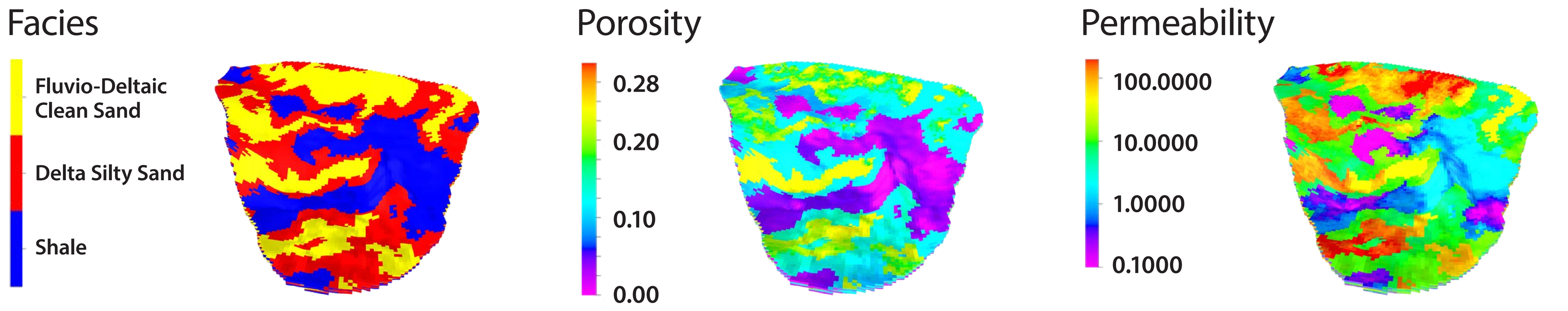
Field-scale: complex sandstone reservoir with different geobody regions, each having an individual training image and resulting facies distribution.

EERC Case Studies

The EERC has developed several reservoir models to further investigations of potential CO_2 storage and EOR using MPS methods, including small-/local-scale models (pinnacle reefs, multiple reef complexes, and carbonate mound accumulations 2–30 km in diameter), oil field-scale, and basin-scale clastic and carbonate models. The facies models constructed in these efforts have been used to constrain petrophysical property distributions (porosity, permeability) which are necessary for numerical simulations of fluid flow and pressure effects to better understand the fate of injected CO_2.



Local strucure: reef MPS facies model example (from left to right): geologic interpretation of facies associations, training image, full facies distribution, and facies cross sections to show internal structure.



Basin-scale: fluvio-deltaic MPS facies realization used to constrain successive porosity and permeability models.

Summary

MPS is a tool incorporated within high-performance reservoir modeling software capable of 3-D geocellular model construction, such as Schlumberger's Petrel Software, and is proving effective in estimating reservoir facies in unsampled locations. The MPS method allows the user to incorporate a preexisting knowledge of the spatial relations and proportions of geologic constituents in the creation of a more realistic facies model. The variogram-based statistical methods do not allow the user to apply such knowledge of reservoir facies and may produce questionable results in some scenarios. Variogram-based statistical methods are better suited for the distribution of petrophysical properties within each facies, needing only to apply a general understanding of porosity and permeability anisotropic trends.

Reservoir models constructed for the applications of CO_2 storage and EOR at the EERC have used MPS to capture realistic geologic heterogeneity. Geologic heterogeneity controls porosity and permeability distributions, which, in turn, control preferential fluid flow, pressure response and, ultimately, CO_2 storage efficiency and capacity.

Acknowledgments

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