I N T E G R A T E D   G E O P H Y S I C S   C O R P O R A T I O N

FOOTNOTES
ON INTERPRETATION

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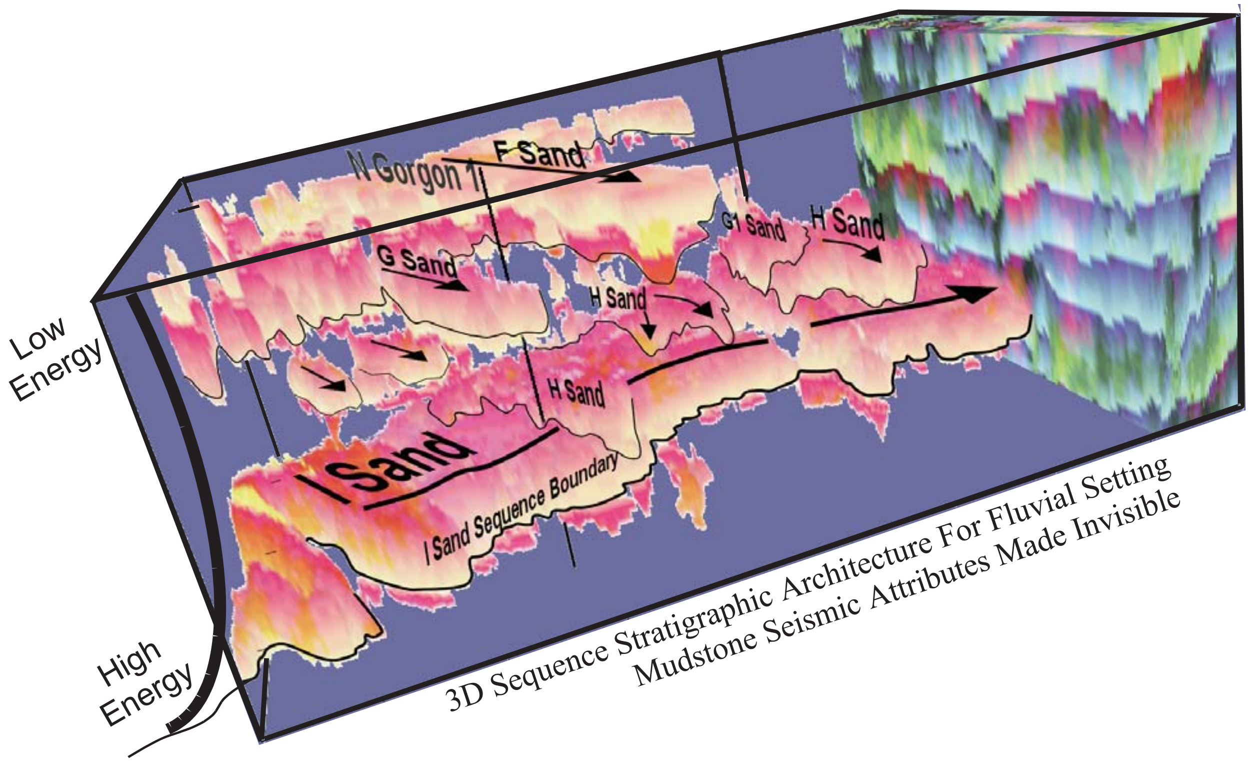
Integrated Stratigraphic Analysis For Exploration and Production

Sequence Stratigraphy Architecture as a Framework for Integration of Modern Geophysical and Geological Data



3D Sequence Stratigraphic Architecture For Fluvial Setting
Mudstone Seismic Attributes Made Invisible

Introduction

Modern sequence stratigraphy builds what is called a sequence stratigraphic architecture of a margin or basin. This can provide a great advantage to understanding the subsurface as it can clarify principals that operate on many scales, from the regional basin scale, the individual prospect scale, and the bed-to-bed scale of reservoir characterization. Thus, the study lays the foundation for integrating many kinds of data that sample the subsurface at these different scales. Seismic and well log data usually comprise the basic datasets that are required for these studies, but the modern sequence stratigraphy application utilizes geologic, geophysical, and engineering data, seismic attribute and visualization systems, and successfully integrates with structural interpreters and basin modelers.

What Is A Sequence Stratigraphic Architecture?

Sequence stratigraphy analysis creates a framework for the subsurface called a sequence stratigraphic architecture. This is built from diagnostic sediment packages and key boundaries that are deposited as sea level falls, then rises. The change in sea level triggers important changes in depositional parameters like lithology and facies assemblages, depositional energy and style, and bed thicknesses. These parameters are different for clastics and carbonates, but both environments build sequence architectures. As sea level falls and rises many times, and the shorelines shift basinward and landward, the cyclic patterns of sediments in the subsurface form the sequence stratigraphic architecture. Seismic data and well logs reveal elements of this architecture (Vail and Wornardt, 1990). Examples of deep water clastic sequence architecture models are in Figure 1a & 1b, where each successive sequence progrades basinward through geologic time (Radovich, 1998). It is generally accepted that sea level is not the only factor that affects the stratigraphic architecture of an area (Perlmutter et al., 1998). Tectonic subsidence and uplift, climate, and sediment provenance and supply are other factors that may combine with sea level changes to create a complex, but predictable stratigraphic architecture. By understanding the nature of these architectures, the interpretation of modern 2D and 3D seismic data is enhanced.

Deepwater Sequence Stratigraphy Input To Basin Modeling

Detailed Horizon Maps That Define Reservoir and Scaling Units

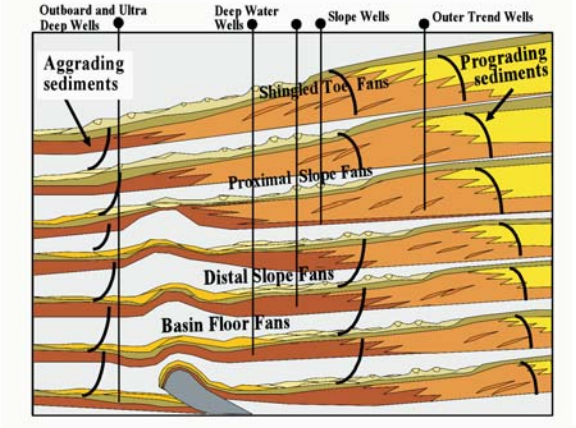


Figure 1a

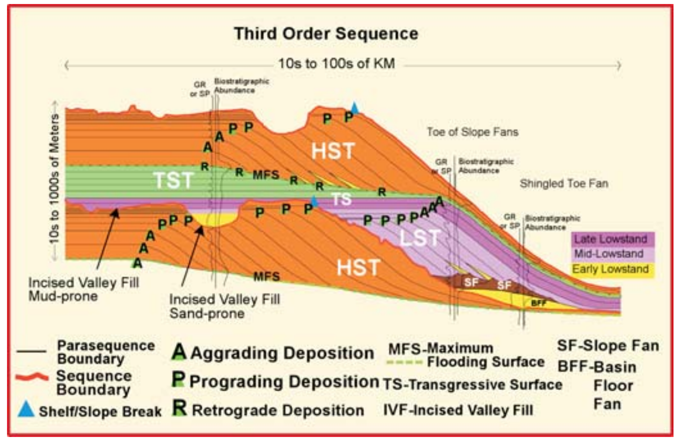


Figure 2

Sequence Stratigraphy At Regional, Prospect, and Bed-to-Bed Scales

Sequence stratigraphy studies add important parameters for evaluation at many scales of investigation required by exploration and production teams. The basic building block for sequence stratigraphic analysis is the conceptual model in Figure 2. This model often spans an entire basin, so an area of interest may be confined in only a part of the model. The stratigraphic position of an area may lie updip in the coastal plain dominated by fluvial sediments, or in the shoreline to shelf to slope break position, or in the deep water position. The stratigraphic architectures and stacking patterns of sediments are different depending on these different stratigraphic positions.

Deepwater Sequence, Lowstand Aggradation Cycle

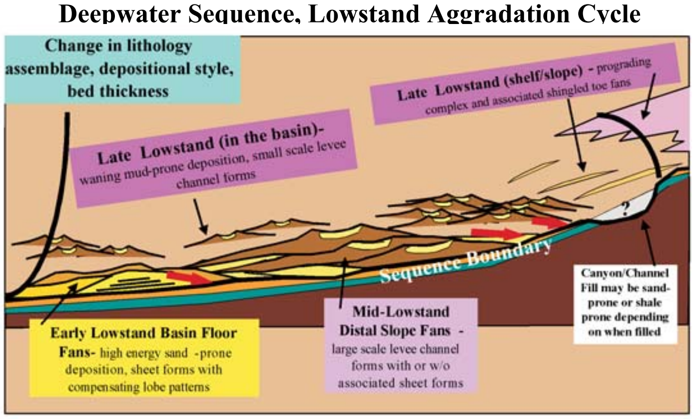


Figure 1b

Regional Scale

The sequence analysis begins with regional seismic and log data to determine the positions of the coastal plain, shelf margins, and basin in relation to the areas of interest. A portion of a seismic sequence stratigraphic interpretation for the Gulf of Mexico is in Figure 3 (Radovich et al., 1991). Well ties to seismic greatly enhance the sequence analysis, but for regional analysis, wells are not required. Sequence boundaries and stacking patterns are interpreted on the seismic and available well log data and integrated with structural interpretations. The analysis is integrated with a variety of geologic and geophysical datasets from biostratigraphic studies, to gravity and magnetic interpretation, to sonic logs from known discoveries. Regional play evaluation is based within this framework and includes assessments of where preferred reservoir/seal couplets develop within clastic and carbonate facies, delineation of possible hydrocarbon source facies, clarification of stratigraphic and structural elements and structural timing, and input to basin hydrocarbon modeling. The reservoir and sealing facies units form the plumbing system for the area. These facies packages are especially important to integrate with regional or local subsidence or uplift events that push the hydrocarbon source layers through the oil and gas generation windows. Integrated analysis can ensure that reservoir units properly 'tap' the most likely oil and gas migration pathways (Figures 4a & 4b).

Sequence Stratigraphic Architecture in Offshore Gulf of Mexico - Shelf to Slope

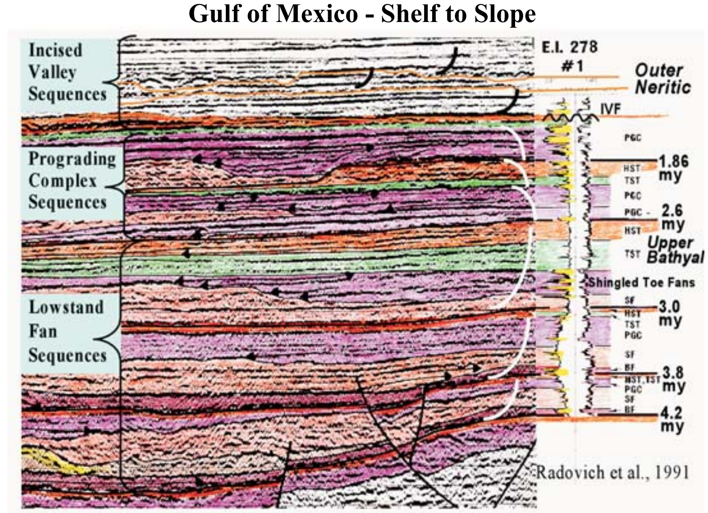


Figure 3

Seismic Sequence Stratigraphy Input to Basin Modeling -
Detailed Horizon Maps That Define Reservoir and Scaling Units

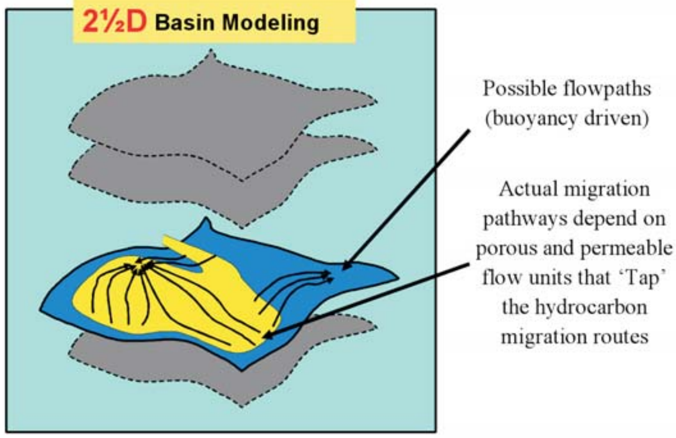


Figure 4a

Seismic Sequence Stratigraphy -
Well Logs Tied to 3D Seismic Data

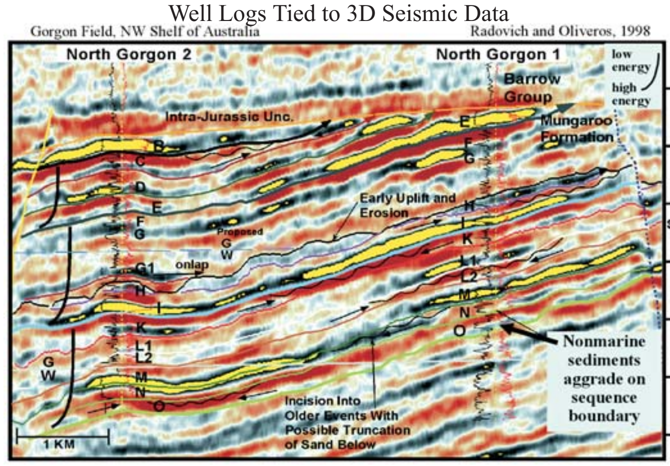


Figure 5

Prospect Scale

Seismic sequence interpretation is refined for prospect analysis and can provide important parameters for drilling plans like target locations and depths, predicted facies, lateral continuity of reservoirs, and possible thicknesses. This phase of a project often continues with interpretation on a variety of 3D seismic amplitude and attribute volumes. Figure 5 shows a detailed 3D seismic interpretation that was done before the drilling of the second well. Seismic 3D volume visualization tools have enhanced the interpretation of processed data volumes including impedance, AVO, instantaneous phase, frequency and other attribute volumes. Reservoir targets are further delineated into sets of depositional events that may require the input of more detailed horizons and maps. This data is input to reserve estimation procedures. The regional sequence architecture leads to an understanding of how to risk targets at the prospect level. For example, some sequences when viewed regionally may show more favorable reservoir sand grain sizes than others and can achieve lower risks.

Sequence Stratigraphy Inputs the 'Plumbing System' for Basin Modeling

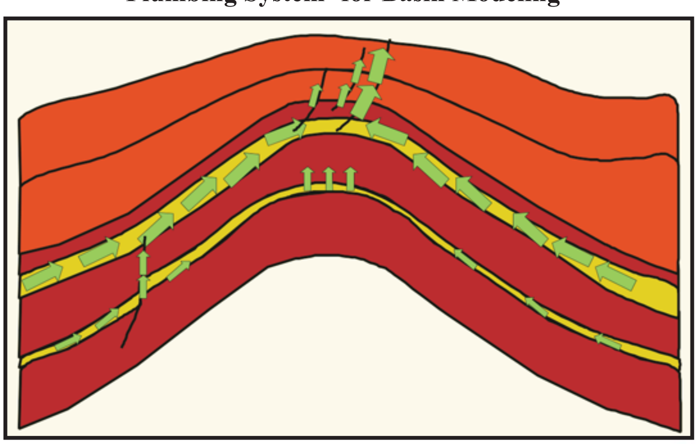


Figure 4b

Bed-to-Bed Scale

Sequence interpretation on the reservoir modeling scales require rigorous well log to seismic sequence stratigraphy investigation. The detailed well log sequence stratigraphy study will include defining a hierarchy of depositional events and tying this to seismic data. These smaller scale depositional events stack to form larger scale events as shown in Figure 6 (Radovich and Oliveros, 1996). The seismic data, porosity to permeability cross plots, facies designations, and reservoir engineering data are studied and integrated within this framework. Important pressure differences may exist across these sequence stratigraphic boundaries. In addition, it is key to understand where the available well logs have sampled the lithofacies at each producing level. Well logs used for stochastic schemes may not sample the sweet spots of the reservoir as predicted by seismic amplitude and attribute data. An example of this is shown in the Figure 7. This figure shows an attribute map of a producing horizon. The two available wells that are input to calibration may not sample the seismically defined 'sweet spot' along the fluvial axis of deposition. Pseudowells or other adjustments must be made to result in an accurate reservoir model.

Sequence Stratigraphy -
Well Log Crosssection and the Hierarchy of Depositional Events

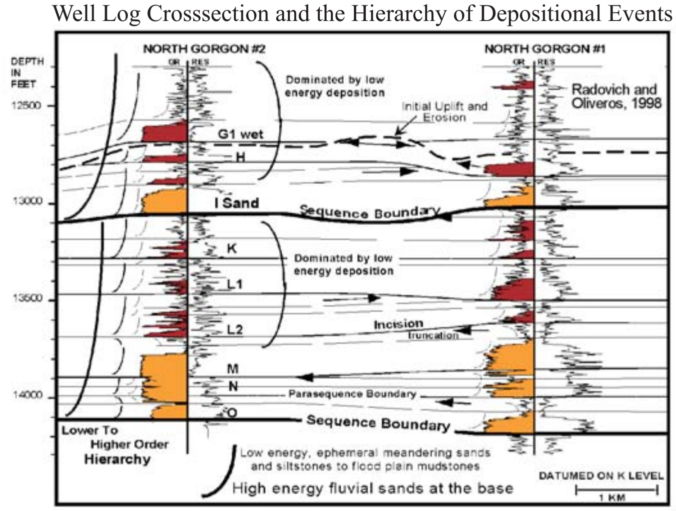
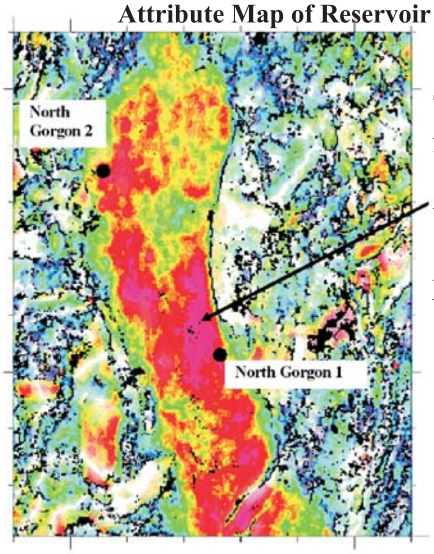


Figure 6

Attribute Map of Reservoir Facies



These wells do not drill the 'sweet spot' of this reservoir, shown in the hot pink colors.

Figure 7

Modern Sequence Stratigraphy

The conceptual models for sequence stratigraphy interpretation have advanced since the introduction of the technique in 1977. Extensive criteria and models are available for carbonates (Loucks and Sarg, 1993), for nonmarine environments of deposition (Van Wagoner et al., 1995), and in coastal plain to shelf settings (Van Wagoner et al., 1990). Deep water environments have received special attention in the last decade (Mitchum, 1985) and the understanding of fan types and their sandy lithofacies development has resulted in discoveries in many deep water settings (Weimer and Link, 1991). Recent studies also incorporate outcrop analog comparisons as well as physical models where sediments that are dropped into flumes and square boxes are examined for sedimentary structures and morphologies.

Sequence stratigraphy concepts provide the conceptual models that greatly aid the interpreter utilizing 3D visualization tools with many 3D seismic amplitude and attribute volumes (Radovich and Oliveros, 1998), and (Radovich and Henry, 2001). The sequence stratigraphic interpreter can utilize the full sophistication of these systems because they have conceptual models to guide them through the immense quantity of data now routinely available to the interpreter.

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