Production- to Exploration-Scale Analogs from Quaternary Systems: A Source-to-Sink Perspective

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Abstract

Quaternary systems and experiments provide opportunities to develop analogs for hydrocarbon exploration and production that are semi-quantitative and predictive, and conform to physically base understanding of sediment-dispersal systems from source-to-sink.

For exploration, scaling relationships between different segments of modern source-to-sink systems indicate that, at the first-order, the scales and properties of one part of a system can be predicted from the scales and properties of another. For example, in modern systems, the length scales and volumes of basin-floor fan systems scale to characteristics of fluvial feeder systems, for example drainage-basin lengths, and the depths of flow in fluvial channels. Hence, retrodiction of drainage basin lengths and paleoflow depths can be used to predict absolute scale of basin-floor fans in immature exploration settings, or position within basin-floor fans for mature settings, such that facies properties away from core or well-log data can be more reliably predicted. A recent test case with the data-rich Gulf of Mexico Cenomanian and Paleocene-Eocene used detrital-zircon analyses to estimate drainage-basin lengths, and well logs to estimate point-bar thicknesses as a proxy for paleoflow depths, then predicted basin-floor fans dimensions. Empirical analyses of basin-floor systems from a large database illustrates that fan dimensions scale to drainage basins and point-bar thicknesses within a fairly narrow range, indicating this modern-analog based approach can be exported to other basins that are data poor.

For development and production, many commonly used analogs are based on specific case studies, modern and ancient, that may or may not be appropriate in terms of scales and/or properties. Here again, scaling relationships, coupled with natural transformations in scales and properties with downdip transport, provide important insights that can be used to populate geological models, or raise important questions about existing interpretations. For the Lower Cretaceous McMurray Formation, within the Alberta Oil Sands region, an understanding of system scale from detrital zircon signatures and analyses of point-bar thicknesses indicates the McMurray represents a continental-scale river system that was routed through the backbulge of the foreland-basin system to the Boreal Sea. Most existing interpretations of McMurray environments of deposition stress brackish conditions based on ichnofacies, and tidal influences based on silt drapes that commonly occur on large-scale inclined strata. However, high-resolution 3d seismic data consistently shows signatures that are consistent with highly migratory point bars, with numerous neck cutoffs, and lateral amalgamation of channel belts with high width-thickness ratios (100-300:1). In modern systems, this style of channel belt occurs within the uppermost limits of, and above, backwater controls on river processes: backwater lengths scale to flow depth divided by slope, such that in large river systems like those of the McMurray, with inherently deep channels and low slopes, backwater lengths are typically >3-500 km. Most interestingly, in river systems of this scale, brackish influences are typically several hundred kilometers downstream from backwater limits, and tidal influences may extend that far, but have limited influence on flow and sediment transport.

Channel belts within the backwater reach have, by contrast, low width:thickness ratios (20-50:1), and are non-amalgamated, typically cutting through delta topset facies. In this case, modern analogs provide alternatives for McMurray interpretations that are inconsistent with other data, and need to be reconciled.