Sequence Stratigraphy and Facies Architecture of Deep-Water Reservoirs: New Data, Tools and Concepts

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Current understanding of deep-water siliciclastics arrived relatively late on the stage of sedimentary geology. Sedimentary processes active at bathyal to abyssal depths did not lend themselves to empirical analog study so important to the early advancements achieved in other depositional settings. As a result, understanding the stratigraphy and facies architecture of deep-water reservoirs has been historically linked to and dependent on technology development. Because direct observations of deep-ocean turbidity currents and debris flows was, until recently, impossible, conceptual understanding of how these sediments were transported and deposited had to await the development of new remote sensing tools and technologies. For example, the first indirect indications of large-scale, naturally occurring sediment gravity flows followed the development and distribution of sea-floor communications cables in the late 1800s and early 1900s. Periodic cable breakages demonstrated the existence of turbidity currents and allowed early researchers to estimate their power and velocity. Later, the development of experimental flumes led to better understanding of the flow mechanisms associated with graded beds common to ‘‘flysch’’ deposits, now known to be dominantly turbidites.

In the 1970s and early 1980s, several nearly identical models for submarine fans were developed, based largely on outcrop studies. These models described an inner (or upper) channelized fan, a lobe dominated mid fan and an extensive thin-bedded, fine-grained sheet deposit comprising the outer fan. Submarine fan models have evolved dramatically with the advent of high-resolution 3-D seismic, side-scan sonar and other water-bottom imaging tools developed in the 1980s and 1990s. Extensive channel networks are now known to be persistent in deep-water systems and channelized flow more prevalent and important to the development of reservoir-grade sand deposits relative to unconfined flow. Channels play an important role in moving sands to even the most distal reaches of many submarine fans, whereas low-density silts and muds are commonly stripped off the upper part of turbidity currents and deposited as overbank in more proximal to medial areas dominated by slope channels. This flow stripping process often results in an overall proximal to distal increase in the sand:mud ratio, the inverse of sediment distribution patterns depicted in the classic fan models.

The development of seismic stratigraphy and later sequence stratigraphy concepts in the 1970s and 1980s was based largely on observations made on multichannel 2-D seismic, well, and outcrop data from passive-margin settings around the world. Based on principles of accommodation, sequence stratigraphy has provided a conceptual framework to better understand and predict the stratigraphic occurrence, distribution, and facies variability of deep-water reservoirs. Improved imaging using modern 3-D seismic, and the deep-water drilling activities of the 1990s has confirmed the fundamental principles of sequence stratigraphy and allowed the concepts to be applied to deep-water reservoir interpretation and prediction at increasingly higher levels of resolution. These data show that a lowstand cycle of sediment flux may generate early slope failure, slump and slide deposits associated with falling sea level. Early slope failure deposits are often overlain by coarser grained distributary channel sands, which are primary reservoir targets. These sand-rich units are mostly deposited during peak lowstand times when sediment flux and shelf bypass are at a maximum. Late-stage deposition of progressively finer grained, levee-associated turbidites is a common product of waning coarse sediment supply to the upper slope as shelf accommodation increases during early transgression. This idealized sequence stacking pattern is predictive, but not always observed at every location along the depositional profile—because sites of deposition tend to shift both laterally and first basinward than landward through time. In addition, a complete depositional stacking pattern is more typical where the grain-size input to the system is broadly distributed; i.e., mixed sand and mud systems. Coarse-grained sand-dominated systems typically lack well-developed levees whereas mud dominated systems display well-expressed levees and less voluminous distributary elements.

Many of the recent advancements in the data, tools, and concepts applied to deep-water siliciclastics have been driven by the need to explore for and develop hydrocarbon reservoirs in the high-cost deep-water environment. For example, recent improvements in 3-D–visualization technology have significantly enhanced our understanding of deep-water channel architecture. Previously unimagined, the complex vertical and lateral facies variations associated with temporally evolving and laterally migrating sinuous deep-water channel systems can now be imaged in great detail. This detailed understanding of channel architecture enables improved predictions of reservoir facies and net:gross, more accurate placement of reservoir properties into 3-D geologic models and more precise positioning of exploration and development wells. With its vast technological resources, extensive global databases and exploration and development focus on deep-water reservoirs, the petroleum industry, in effective partnership with academic research, has contributed greatly to the improved understanding of the stratigraphy and facies architecture of deep-water reservoirs we now enjoy.