Title: Integrated reservoir modeling of stratigraphically complex tidally influenced estuarine systems : A case study from Lakshmi Field, Gulf of Cambay, India

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ABSTRACT

The Gulf of Cambay, West coast of India, contains several prolific fields with stacked reservoirs present in Oligo-Miocene tidally influenced estuarine deposits. The Miocene Lower Tarkeshwar Formation of the Lakshmi Field is one such complex hydrocarbon reservoir at the South-Eastern mouth of the Gulf of Cambay. As this field matures, there is an increasing requirement for a calibrated, geocellular model to predict the reservoir connectivity and continuity and assess the potential for further development, including secondary recovery. Such modeling is made difficult due to the poor seismic resolution of the reservoirs which is unable to image sand-body architecture with confidence and the availability of only limited core and production data to calibrate the model. In these geologically complex settings with relatively limited data a highly integrated, cross-disciplinary approach is required to construct these predictive models.

The first step in the modeling approach was to establish a conceptual sequence stratigraphic framework of the Miocene estuarine deposits and identify the probable architectural elements present in the stratigraphic section. Log motif-based recognition of flooding surfaces and sequence boundaries, integrated with core-derived facies from near-by wells and studies of depositional analogues from the modern Gulf of Cambay, was then used to define both the field-wide correlation of reservoir units, facies types and facies distribution. Correlation using flooding surfaces reveals that the stratigraphy of the Miocene Lower Tarkeshwar Formation comprises two large erosion and fill cycles, with the lowermost estuarine fill including three para-sequences. Each of these para-sequences contains a variety of depositional elements including tidal bar, tidal channel, inter-bar channels, tidal flat/estuarine mud flat and salt marsh, bay-head deltas, and marine muds.

Once the depositional framework was established, the key flooding surfaces and sequence boundaries were seismically mapped in detail and tied to the corresponding well markers. These surfaces provided the broad framework to populate the facies distribution. Horizon slicing from seismic attributes, including normalized RMS amplitude and instantaneous frequency, seismic

coherency, spectral decomposition and continuous wavelet transformation (CWT), revealed geomorphic features that are consistent with the interpreted depositional system. Facies distribution maps were created from these attribute slices at key stratigraphic levels of interest. These maps were used to represent the probability of occurrence of individual facies and their inter-relationships within a specific geologic interval. Pressure gradient analysis in conjunction with production data revealed possible compartmentalization within the broader estuarine complex which guided the connectivity framework within the depositional model. The vertical probability distribution of facies from wells, combined with geo-morphometrics from seismic attribute analysis were used to define the spatial distribution of facies and to populate facies away from areas of well control.

These geo-spatial relationships were used to create a 3D geocellular model of the Miocene Lower Tarkeshwar Formation of the Lakshmi Field. In the model, the major fairways of deposition trend approximately parallel to the long axis of the main structure, but skirt the flanks of the Lakshmi Field structure. These fairways are considered to represent large estuarine distributary channel systems, filled with a variety of stacked and variably connected tidally influenced channel bars and inter-bar channels. Major fairways are separated by tidal flat "interfluves".

Multiple realizations of the facies architecture effectively captured the ranges in uncertainty of the reservoir connectivity, continuity and distribution. Since the underlying depositional framework is based on established sequence stratigraphic concepts, the geocellular model is useful in predicting paleo depo-centres and provides upside opportunities in newer stratigraphic plays. The distribution of petrophysical properties, including porosity, permeability and water saturation are guided by the facies framework within the geocellular model. This geocellular model forms the basis of dynamic modeling which will be used to evaluate further development options, including secondary recovery. The model is also being used to better understand the distribution and behavior of the aquifer leg of the reservoir, a vital part of any future water injection planning.