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Application of Modern and Ancient Depositional Environments to Construct Paleo-Depositional Environment Maps of the Canterbury and Great South Rift Basins

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Abstract

Predicting reservoir occurrence ahead of the bit is a challenge in areas with few wells. At the prospect and field scale, interpreters must rely on a thorough understanding of modern depositional environments to make reasonably accurate predictions of the distribution of reservoir facies. For regional studies and basin analysis, we can use modern and ancient analogues to better understand and predict the distribution of depositional environments within a basin.

There are relatively few wells drilled in the Canterbury and Great South rift basins of New Zealand. In order to assess the likelihood of finding reservoir and charge in any given prospect, it is necessary to construct regional paleo-depositional environment maps. To construct those maps, it is first necessary to understand the distribution of depositional environments in a developing rift basin. Drawing from modern and ancient analogues, we can understand the distribution of the various depositional environments of a rift basin. This, in turn, can be used to construct paleo depositional environment maps for the Canterbury and Great South Basins rift sequence.

The Triassic-aged rift basins exposed in the Khorat Plateau of Northeast Thailand provide an excellent ancient analogue. Additionally, well log and seismic evaluation for a number of basins in the Gulf of Thailand and the South China Sea (Shoup, 2007, Shoup et al, 2012) has shown that the distribution of the depositional environments in the synrift sequence of continental rift basins is very similar from basin to basin and from region to region.

Synrift Depositional Environments

The lowermost sequence in the synrift section is a conglomeratic sequence that overlies the pre-rift basement (Figure 1). The clasts are comprised of eroded pre-rift material. These are typically poorly sorted deposits and do not make good quality reservoirs.

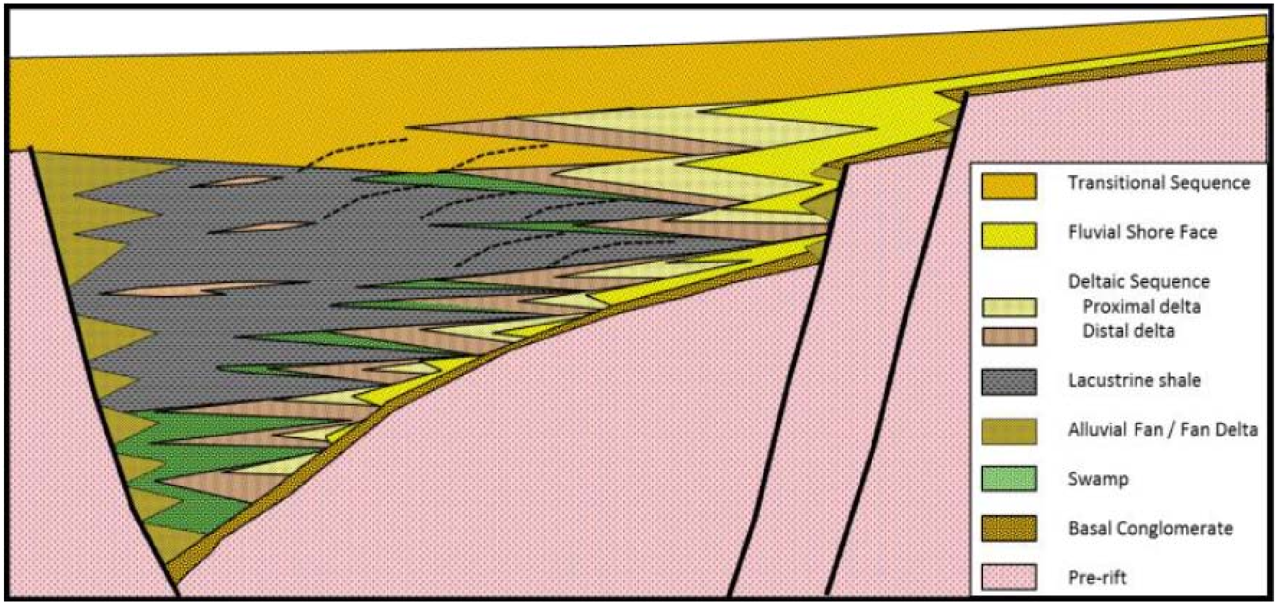

Figure 1. Generalized distribution of synrift depositional environments in a continental rift basin.

For basins that are subsiding at a rate greater than the rate that clastics are entering the basin, swamps or lakes form in the deeper portions of the rift basin. The earliest sequences are typically swamps that may or may not develop into an open water lake over time. Therefore, we often observe swamp facies in the lowermost sequence in the deepest part of the rift basin. Swamps also typically form along the margins of the sloping side of a half-graben rift basin (Figure 1). The nature and extent of the swamp are a function of climatic influences and the rate of sediment input into the basin. The sequence is typically source-prone, with source rocks comprised of coals and coaly shale and/or algal-rich source rocks.

Alluvial fan sequences will form along the faulted margins of the rift basin where there are pronounced basement highs (Figure 1). If lacustrine or marine conditions have developed within the rift basin, then we see the development of fan deltas, which are alluvial fan complexes that form in a body of standing water. In that fan delta sequences are often interbedded with source-prone lacustrine shale they make good exploration targets. For there to be sufficient fan delta reservoirs to be deposited, the highland needs to have a large enough exposed surface area for it to develop drainage. This only needs to be a few 10s of square kilometers. Since these deposits are typically poorly sorted, reservoir quality may be a concern.

In continental rift basins in wet climatic regions, the swamp facies usually grades upward to a lacustrine sequence (Figure 1). The lacustrine sequences are generally found in the deeper areas of the rift basin. The nature and extent of the lacustrine sequence is a function of climatic influences and the rate of sediment input into the basin. The wetter the climate, the more likely there will be a well-developed lacustrine sequence. The sequence is typically source-prone, with source rocks comprised of algal-rich shale.

In rift basins where the lakes were deep, lacustrine turbidites may have formed (Figure 1). They are typically found in the deepest portion of the rift basin, which is typically near steep-sided basement highs. These will generally be good quality reservoirs interbedded with sealing source-prone shale. Since their occurrence in the section is not predictable, exploration for these targets require risk-mitigation methods such as seismic attributes.

Fluvial – shoreface sequences are found on the gently sloping side of asymmetric half-grabens. In the early stages of rifting, the fluvial sequence typically consists of braided rivers. As the rate of sediment input wanes during the later stages of the rift basin development, the fluvial sequence may change to meandering or anastomosing. The shoreface sands represent fluvial and deltaic sands being re-worked into a belt of sand-rich sediments that rim the lake. These are reworked by the process of lake level fluctuation. In areas where there are seasonal lake level fluctuations, such as Ton Le Sap Cambodia, these shoreface deposits can be extensive.

Lacustrine delta sequences will form where rivers are entering the rift basin on the gently sloping side of asymmetric half-grabens. As with all deltaic sequences, as we move basinward from the basin margin, the deltaic deposition is more characterized by shale than sandstone. Syn-depositional growth faults, also common in deltaic sequences may have formed in the deltaic depocenters. The synrift deltaic sequences are often the most prolific producing reservoirs in the synrift section. They are preferentially located in the migration pathway for hydrocarbons generated in the synrift swamp or lacustrine shale. The trapping mechanisms for these reservoirs can be rift-related faults, syndepositional growth faults, or stratigraphic onlap to basement.

The transitional sequence is deposited during the transition from synrift to post-rift. Transitional sediments will be deposited over basement highs, but will still exhibit wedge geometry with thickening into the basin center. In basins dominated by continental deposition, this is typically a redbed sequence. In rift basins with a marine access, this sequence is often characterized by a transgressive sequence.

Stratigraphic Framework, Canterbury and Great South Basins

We evaluated the stratigraphic framework of the two basins by examining the facies relationships between wells as observed in a number of cross sections constructed for both basins, and one cross section extending from the Canterbury Basin through the Great South basin (Figure 2). This cross section extends from the Resolution well in the Canterbury Basin to the Hoiho well in the Great South Basin. The Takapu well, drilled on a basement involved thrust fault, represents the structural high between the two basins.

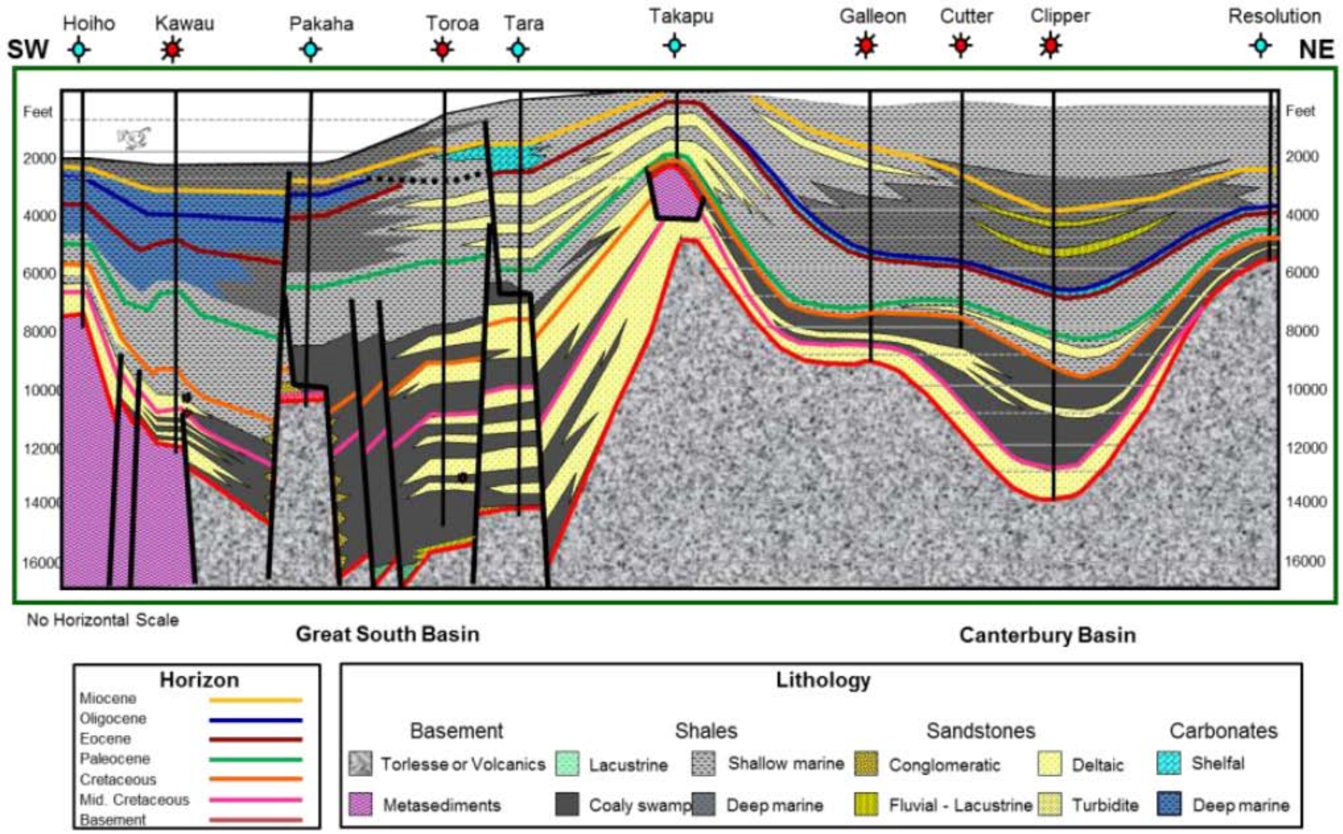

Figure 2: Cross-section illustrating the stratigraphic framework of the Canterbury and Great South basins. We can see from the cross section that rifting is imitated in the GSB during the Early Cretaceous and in the Middle Cretaceous in the Canterbury Basin. The transition from synrift to post-rift appears to be in the latest Cretaceous to Paleocene for both basins.

Structural Framework, Canterbury and Great South Basins

The principal control of the distribution of synrift depositional environments is the depth to the base of the synrift sequence, which for the Canterbury and Great South Basins is the Early Cretaceous volcanics or the older Torlesse metamorphics. The depth structure map for basement, as well as the other horizons, was compiled from multiple publications, proprietary reports, and from personal seismic interpretations. The maps were hand-contoured with a 500-metre contour interval. The maximum depth to basement for both basins is between 6500 and 7000 metres (purple, Figure 3)).

The maximum depth to the top Middle Cretaceous is slightly less than 5000 metres in the Great South Basin, and slightly less than 6000 metres in the Canterbury Basin. The maximum depth to the top Cretaceous is slightly more than 4000 metres in both basins., and the maximum depth to the Paleocene is slightly more than 2500 metres in the Great South Basin, and slightly more than 3000 metres in the Canterbury Basin (Figure 3).

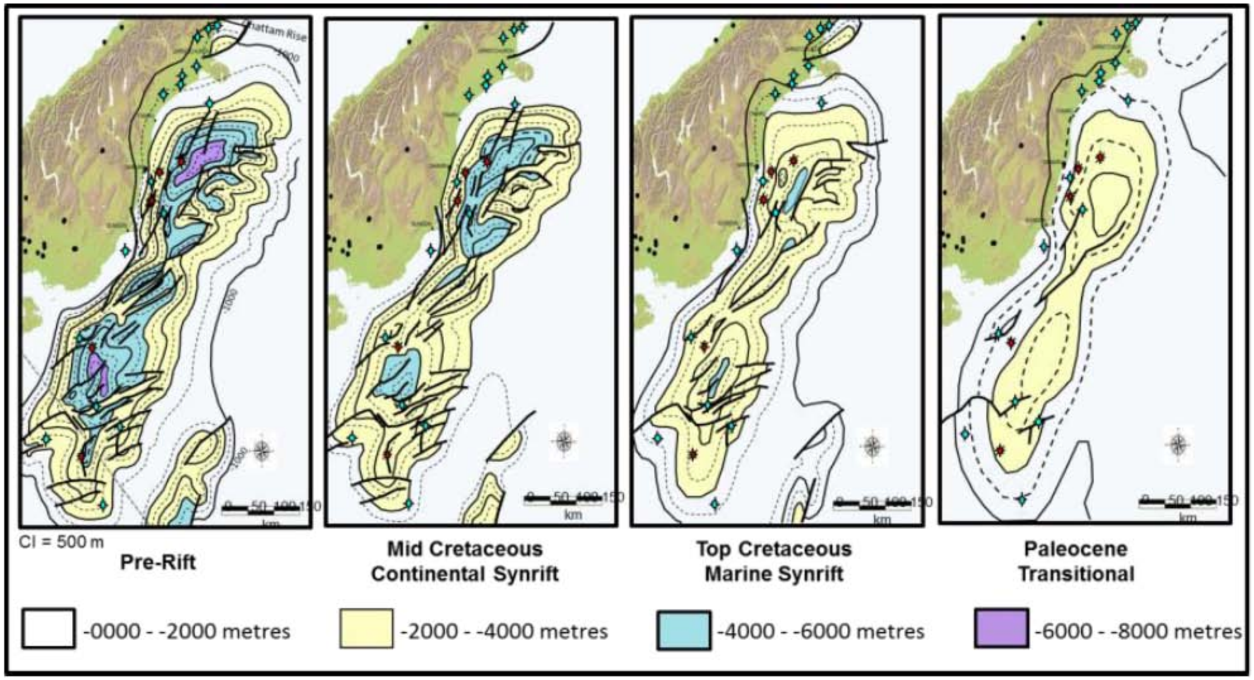

Figure 3. Depth Structure Maps for the Pre-rift, Mid and Top Cretaceous, and the Top Paleocene.

Synrift Depositional Environments, Canterbury and Great South Basins

Before reconstructing the paleo depositional environments, we first need to construct the gross interval isochore map for the sequence. The depositional environment maps were then constructed with the isochore maps as the base (Figure 4).

In the early stages of rifting during the Middle Cretaceous, both the eastern and western margins of the basins will be characterized by highlands. The flanks of the basin are characterized by fluvial to shoreface deposits, which have been confirmed by several well penetrations. The deeper portions of the basin are very likely dominated by swamps, but may also be characterized by open lakes. The preponderance of coals encountered in the GSB penetrations suggests a more swamp-like environment. However, we do postulate open lakes, and most likely deep lakes in the deepest portions of the basin (Figure 4a).

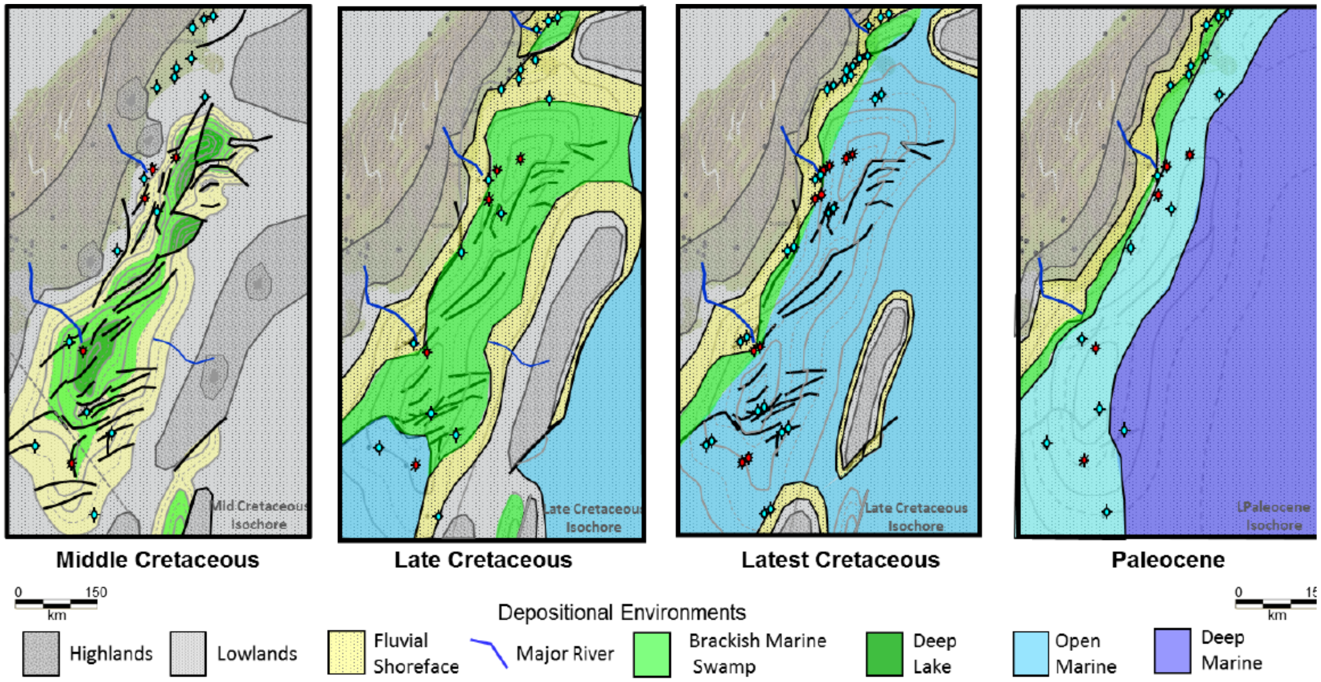

Figure 4. Depositional Environments of the Synrift Section, Canterbury and Great South Basins.

During the Late Cretaceous, the highlands on both the eastern and western margins of the basins will have been somewhat eroded, but still relatively high. It appears that the highlands on the eastern margin of the basins is eroding, or subsiding, at a greater rate than those on the western margin. We see two large delta systems entering from the west, one near the Cutter – Galleon wells in the Canterbury Basin, and another near the Tara and Taroa wells in the GSB (Figure 4). The deltaic sands appear to have also been reworked into a shoreface sequence along the basin margins.

We are also beginning to see the influx of marine waters at this time. In the southern portion of the GSB, this interpretation is based on well penetrations (Figure 2). The marine transgression from the east is based on reconstructions from GNS and Robertson Research. Because of this marine influx, the central portion of the rift basin normally dominated by lacustrine facies is dominated instead by coal swamps (Figure 4b) which either are brackish water swamps with occasional marine influx during sea level high stands, or were deposited in an extensive tidal estuary.

In the uppermost part of the Late Cretaceous, we see open marine conditions prevail across most of the basin. Coal swamps are still present, but are now confined to the coastal margin on the western flank of the basin (Figure 4c).

During the Paleocene, the basins are beginning to see the incursion of deep marine conditions, with transgression coming from east to west (Figure 4d). The coastal shoreface, deltaic and swamp environments are now updip of all but the westernmost wells

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