



SEQUENCE STRATIGRAPHY OF THE LATE PALEOCENE-PLIO- PLEISTOCENE DEPOSITS, CENTRAL TARANAKI BASIN, NEW ZEALAND

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ABSTRACT

A sequence stratigraphic study was carried out on late Paleocene -Pleistocene age sedimentary rocks within northern Graben of the north of Taranaki basin, west of Taranaki Peninsula. Geologically, the study area contains an anticline cut by few faults in the southeast. The purpose of this study was to identify the sequence stratigraphic parameters such as system tracts and seismic facies within the sequences by seismic sections and well data. Eleven 2D seismic lines covering an area of approximately 217.km² with three wells were used in this study. The seismic line was interpreted to estimate the system tracts, seismic facies, and sequence boundaries by petrel 2009 and Kingdom 8.8 software. Types of seismic facies such as parallel; sub-parallel, continuous, sub-continuous, wavy, free reflection, chaotic, high amplitude high frequency and high amplitude low frequency were defined in the seismic section. Based on reflection terminations, seismic facies, and well logs, eight sequence boundaries were determined in the study area. These main horizons were confirmed by generating the synthetic seismogram of the well witiora-1 and correlated with the seismic section for locating the sequence boundaries. A new horizon was detected between the upper and lower Giant formation as characterized by onlapping feature indicating a period of seawater encroachment. The sea level changes resulting to different system tracts such as LST, TST, and HST were also determined in the seismic sections and gamma ray log.

Keywords: Taranaki basin, sequence stratigraphy, chronostratigraphy, seismic facies, system tracts.

1. INTRODUCTION

Sequence stratigraphy is considered as the study of sediments and sedimentary rocks in order to understand the facies of connected strata geometry (Vail and Mitchum, 1977). A sequence stratigraphic analysis was carried out on late Paleocene -Pleistocene age of central Taranaki basin deposits located in the west of Taranaki Peninsula. The study area is about 217 km² and geologically consisting of a big anticline with some faults striking towards the southeast of the study area. The Taranaki Basin lies on the western boundary of New Zealand offshore occupying an area of about 100 000 km² and is located along the west coast of New Zealand's North Island (King and Thrasher, 1996). Several later tectonic events have deformed the latest deposits of the basin as seen in the seismic sections (Kamp *et al.* 2004). Taranaki Basin is considered as the main and the only basin in New Zealand used for hydrocarbons productions (Tripathi and Kamp, 2008). It is approximately separated into two structural regions namely the Western Steady Platform and the Eastern Movable Belt. The Western Steady Platform is Tectonically stable since Cretaceous times and is categorized by progradation deposition sea floor (Hansen and Kamp, 2006). On the other hand, the Eastern Movable Belt shows a complex morphology due to the Neogene Kaikoura Orogeny tectonic (Hansen and Kamp, 2004). Sedimentation during late Paleocene to Pleistocene involved deposition or slope to basin clastic type's categorized as slope fan, floor fan, and channel incision. All these depositions have been variously

affected by sediment fluctuation, basin structure, local subsidence, and sea level change, giving rise to a variation of slope sub topography and deeper water depositional elements. (Hansen and Kamp, 2006). Geologically, the study area also consists of eight lithostrata units divided into Kapuni group, Moa group, Mokau group, Urenui formation, Giant lower formation, Giant middle formation, Giant upper formation and Surficial formation (King *et al.* (1999) and Cooper (2004)). Based on some seismic sections, the central and northern basin was faulted due to tectonic activity in late Quaternary. All faults are normal and the largest fault in the study area is Cape Egmont fault which is oriented NE-SW passing through the Taranaki Peninsula and extended into the north graben. This fault has an average rate of horizontal extension along the Cape Egmont Fault of about 0.1-0.2 mm/ yr. (Nodder, 1993). The study area is essentially located between the folded North and central (Figure-1).

By sequence stratigraphic analysis, a chronostratigraphic framework was developed for understanding the relationship between rocks and stratigraphic evaluation (Pomar *et al.* 2005). Seismic reflections were divided into packages of different system tracts and seismic sequences. According to the (NZPM), the Witiora-1 well penetrated Late Paleocene to Pleistocene sedimentary sequence (Croacker, 1991) through potential reservoirs of Miocene Mokau formation and the basal tertiary-upper cretaceous deposits. Shallow gas shows were encountered between 750m and 900 m depths.

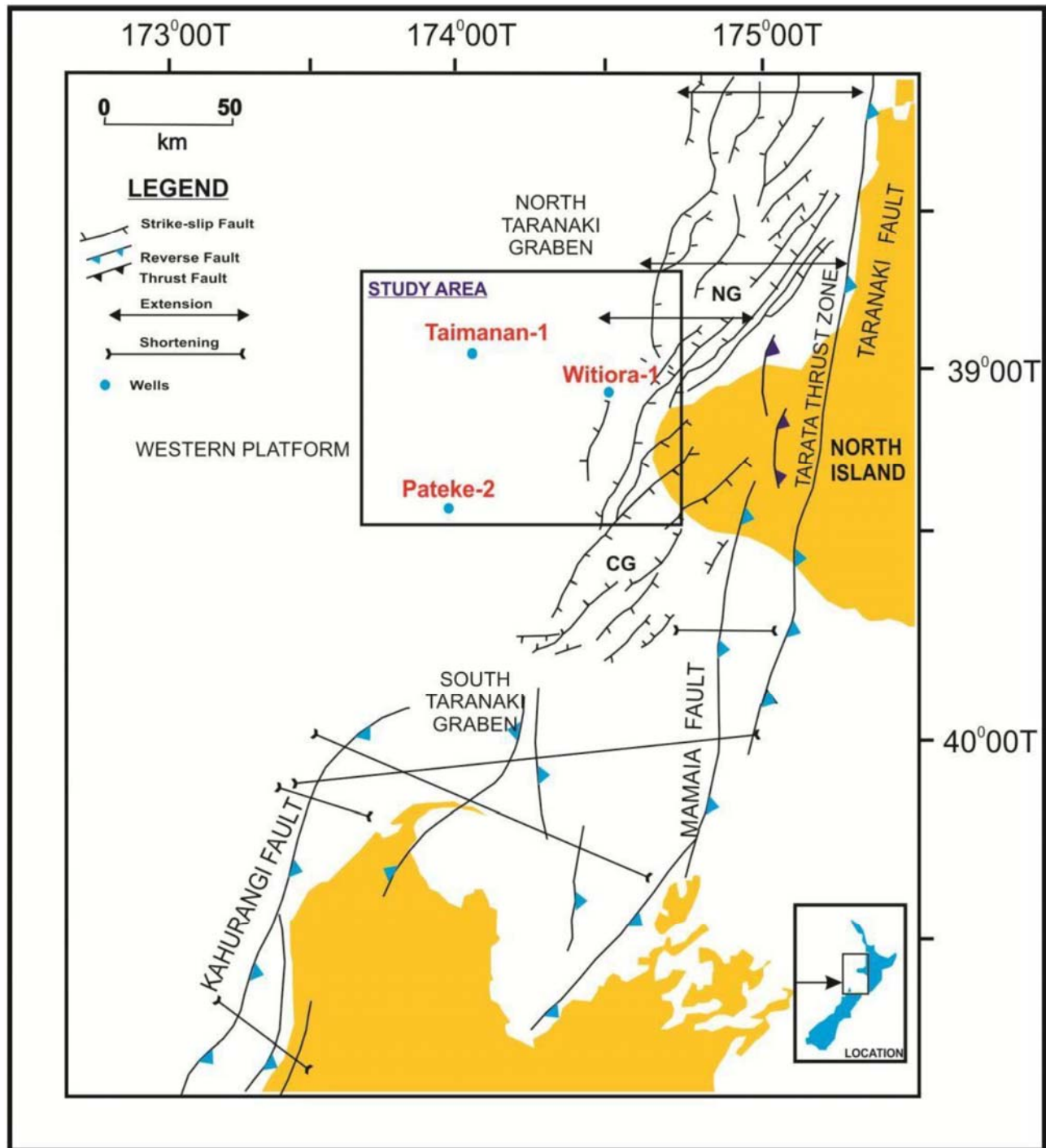


Figure-1. Map showing major structural elements of the Taranaki Basin indicating major faults and location of study area (King and Thrasher, 1996).

Sequence boundaries of the sedimentary units in the seismic sections are identified by reflection terminations such as downlap, onlap, toplap and truncation due to sea level changes through the geological ages (Vail

et al (1997), and Mitchum *et al.* (1977). The surface that covered the seismic sequence defined the genetic reflection packages, mostly represent unconformity surfaces.

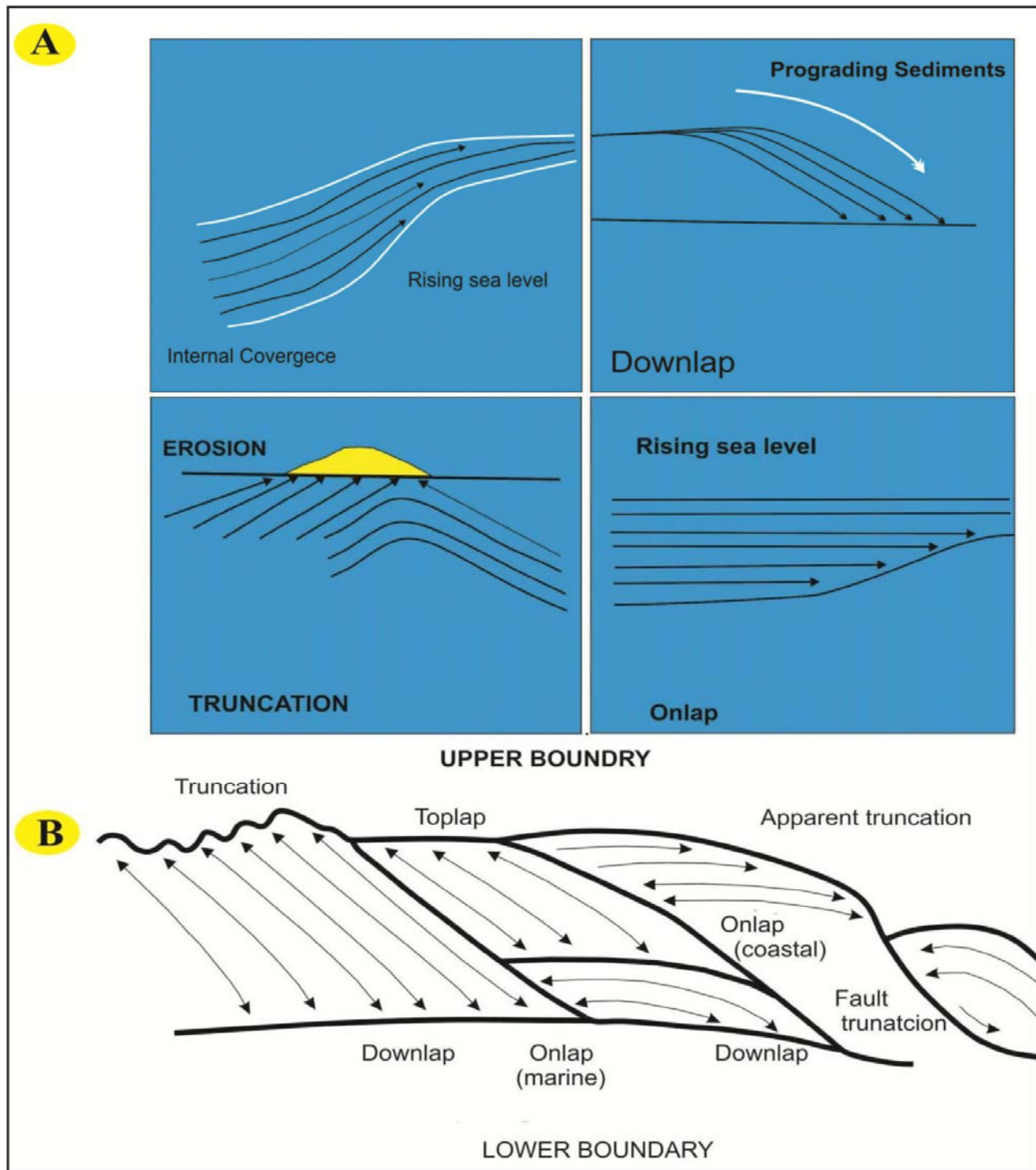


Figure-2. (A) Delineation reflection terminations types. (B) The example illustrated the reflection terminations at lower and an upper boundary. Emery and Myers (1996).

Seismic facies analysis means analysis of reflection configuration and other seismic parameters within the depositional seismic sequence and also by interpreting the well and the patterns appeared on the seismic sections according to the principles of seismic sequence stratigraphy (Vail and Mitchum 1977). The term

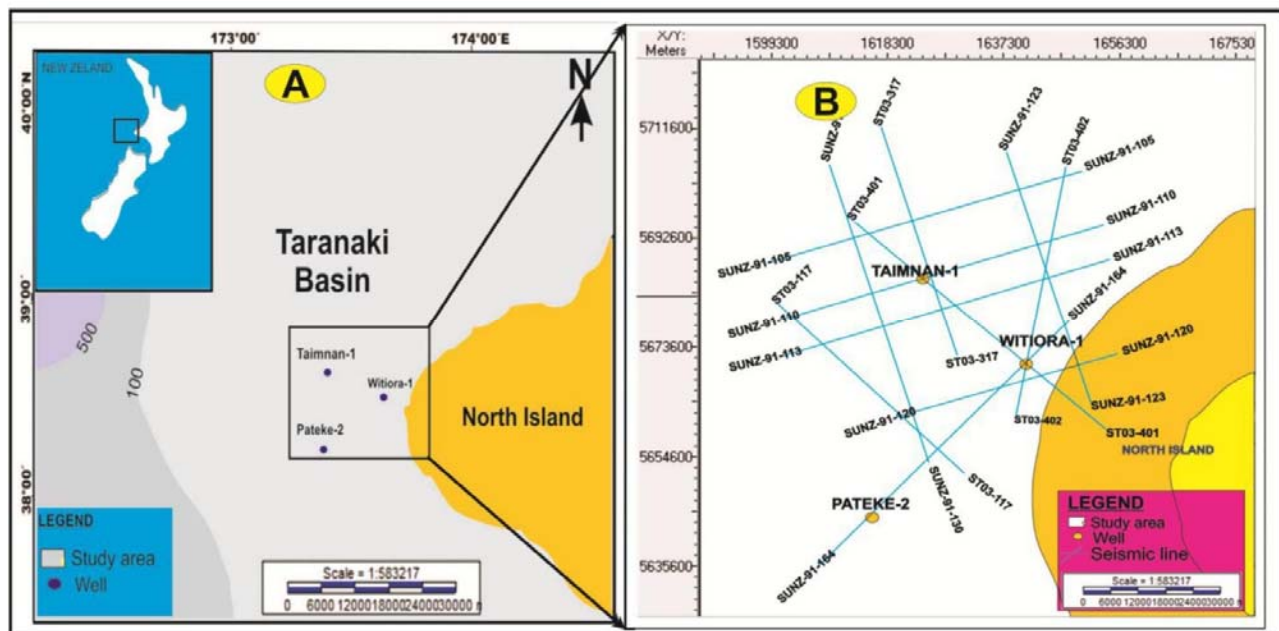
facies means the kind of geological environment in which rocks are formed. Seismic facies analysis is used to predict lithological distribution. Seismic facies parameters include reflection configuration, amplitude, continuity, and frequency as shown in Table-1.

**Table-1.** Seismic reflection parameters used in seismic stratigraphy and their geologic significance (Mitchum, *et al.* 1977b).

Reflection parameter	Geologic interpretation
Configuration	Layered (Parallel- Divergent)
	Complex Layered Sigmoid-oblique
	Chaotic
	Divergent
	Disrupted
	Contorted
	Hummocky Clinoforms
Continuity	Continuous
	Discontinuous
Amplitude	High Amplitude
	low Amplitude
Frequency	High frequency
	low frequency

The system tracts can be subdivided into lowstand LST, transgressive TST, and highstand HST systems tracts (Catuneanu *et al.* 2009). Basically, system tract is defined as the change in depositional types due to changes of sea level during the deposition period. These systems tracts forms when the rate of sedimentation is outpaced by the rate of sea level rise. As the rate of eustatic rise increase, the relative sea-level rise also increases and eventually outpaces the supply of sediment, leading to retrogradation parasequences Stacking. Such

retro gradational stacking is called transgressive system tract (TST). High stand system tracts (HST) occurs during the late stage of base level rise when the rate of sea level rise drops below the sedimentation rate. It is bounded by maximum flooding surface at the base and composite surface at the top (Tian *et al.* 2012). All data used in this study were supplied by New Zealand Petroleum and minerals (NZPM). The study area is shown in Figure-3 (A) and the position of seismic lines plus boreholes are shown in Figure-3(B).

**Figure-3.** The study area is shown in Figure-3 (A) and the position of seismic lines plus boreholes are shown in Figure-3(B).



2. METHODOLOGY

Tying the seismic lines to well data or well tie was the first step carried out in the study followed by seismic facies analysis and sequence boundary determination. In the well tie procedures, synthetic seismograms were generated by incorporating density and sonic logs to estimate the seismic impedance (Z) of each subsurface layer. Reflection coefficient (R) at boundaries between these layers was then determined by Zoepritz equation ($R = \frac{Z_2 - Z_1}{Z_2 + Z_1}$). The series of reflection coefficients were then convolved with a Ricker wavelet of 25Hz frequency value to produce both the positive and negative synthetic seismograms. A small part of seismic section preferably near the well was extracted and matched with the newly generated synthetic seismogram. Positions of synthetic seismogram and the imported seismic section were calibrated to Kelly Bushing (KB) and seismic reflection datum (SRD) elevations. After the calibration, formation tops were transferred from well positions to seismic section. Formation top positioning from well depth in meter into seismic two-way time in second was accomplished with the used of time-depth curve obtained by check-shot survey. The formation top positions were extended throughout the seismic section to form horizons with the aid of Petrel computer software. In the less deformed area, horizon picking was carried out auto tracking technique while in highly tectonic region horizon was manually determined. The positions of formation tops or horizons will automatically be transferred at the intersections of all seismic sections cutting across the completed one. Similar steps were followed for complete horizons picking in the intersecting seismic sections. Prior to horizon picking, the position of faults was firstly determined in all seismic sections. Time maps for each horizon as well as structural and thickness maps were generated upon completion of the horizon management and fault picking in all seismic sections. These maps indicate the overall morphology of the horizon surfaces and fault distributions throughout the study area. Isopach maps will generalize the thickness distribution of sedimentary deposits between the horizons. The thickness is estimated by multiplying the difference of two-way times between horizons with interval velocity of each layer obtained from either velocity model or sonic log.

In the sequence stratigraphic analysis, conformable or unconformable surfaces were identified by observing the presence of any reflection termination classified as either on-lap, downlap, toplap or erosional truncation in all seismic sections since these features defined either the top or bottom of any depositional sequence. The reflection terminations are also closely related to the depositional environments or system tracts which are associated with sea level changes. The increase in sea level will produce the transgressive system tract indicated by the presence of on lapping features easily observed in the seismic section vertically in-line to the basin slope position. The on-lap is formed when marine sediments are transported or retrograded towards the land and deposited above the continental deposits. This

phenomenon will generate fining upward deposition when fine grain clay-riched marine sediment overlies coarser continental deposits. The fining-upward condition is observed in the gamma-ray log as bell-shaped feature corresponding to low gamma ray values of sandy material at the bottom into high gamma ray values representing clay-riched material at the top. When the sea level is at its maximum position, the marine to land sediment transport is stop and the sedimentation is reversed when continental deposit started to prograde towards the sea to produce stacks of continental deposits above marine deposits. The prograding surface is shown as a downlap feature representing the maximum flooding surface. During the lowest sea level condition, the base level is at its minimum position and during this time, erosional processes will be at its maximum creating incised valleys as well as slope and basin floor fan deposits representing low stand system tracts. These kinds of deposits are represented as mound structures especially at the bottom of a depositional sequence. A complete sequence stratigraphic analysis will be accomplished by gathering information from gamma ray logs for fining or coarsening upward types of deposition and composite well logs for the age, lithology and types of depositional environments. A transgressive system tract is estimated from changes in continental deposits into marine deposits while a highstand system tract shows a reverse sequence of deposits in the composite well logs. River, lake, slope fan and basin floor fan are defined as low stand system tract deposits.

3. RESULTS AND DISCUSSIONS

Figure-4 shows the positive and negative polarities synthetic seismograms of Witiora-1 well together with a portion of seismic section close to well position for comparison. A gamma ray log and the depths of formation tops were also included in the panel. Positions of formation tops or horizon of H3 and H5 are perfectly matched with troughs of negative synthetic and field seismic section while positions of horizons H2, H4, H6, H7, and H8 was located between peak and trough of both synthetic and seismic.

Horizon H2, H3, H4, and H6 showed no changes in lithology as indicated in the gamma ray log. On the other hand, lithological changes from clay to sand as indicated by a high to low gamma reading are obvious at horizons H5, H7, and H8. The positions of complete horizons with their depths, lithological types, the environment of depositions and ages of each sequence separated by horizons are detailed out in (Figure-5. A). A total of eight Paleocene to recent sequences denoted as SEQ1 to SEQ8 were observed between horizons 1 to 8 overlying granite basement in the study area.

The oldest Paleocene Kapuni group represents SEQ8 followed by SEQ7 Moa siltstone of Eocene in age deposited in the middle to the outer marine environment. The sand-rich sediment without fossil indication may suggest a high stand system tract. The Moa siltstone contains coal measures with some mudstone may be interpreted as continental deposits of low stand system tract. SEQ6 of Oligocene to early Miocene Mokau group



Was a transgressive system tract deposit based on its environment changes from middle marine to bathyal indicating a sea level rise. This group is rich in calcareous mudstone with only minor sand which is a typical marine

deposit. The Urenui formation representing SEQ5 deposited during Miocene sea level decrease based on its environmental changes from bathyal to outer- middle neritic and eventually to coastal.

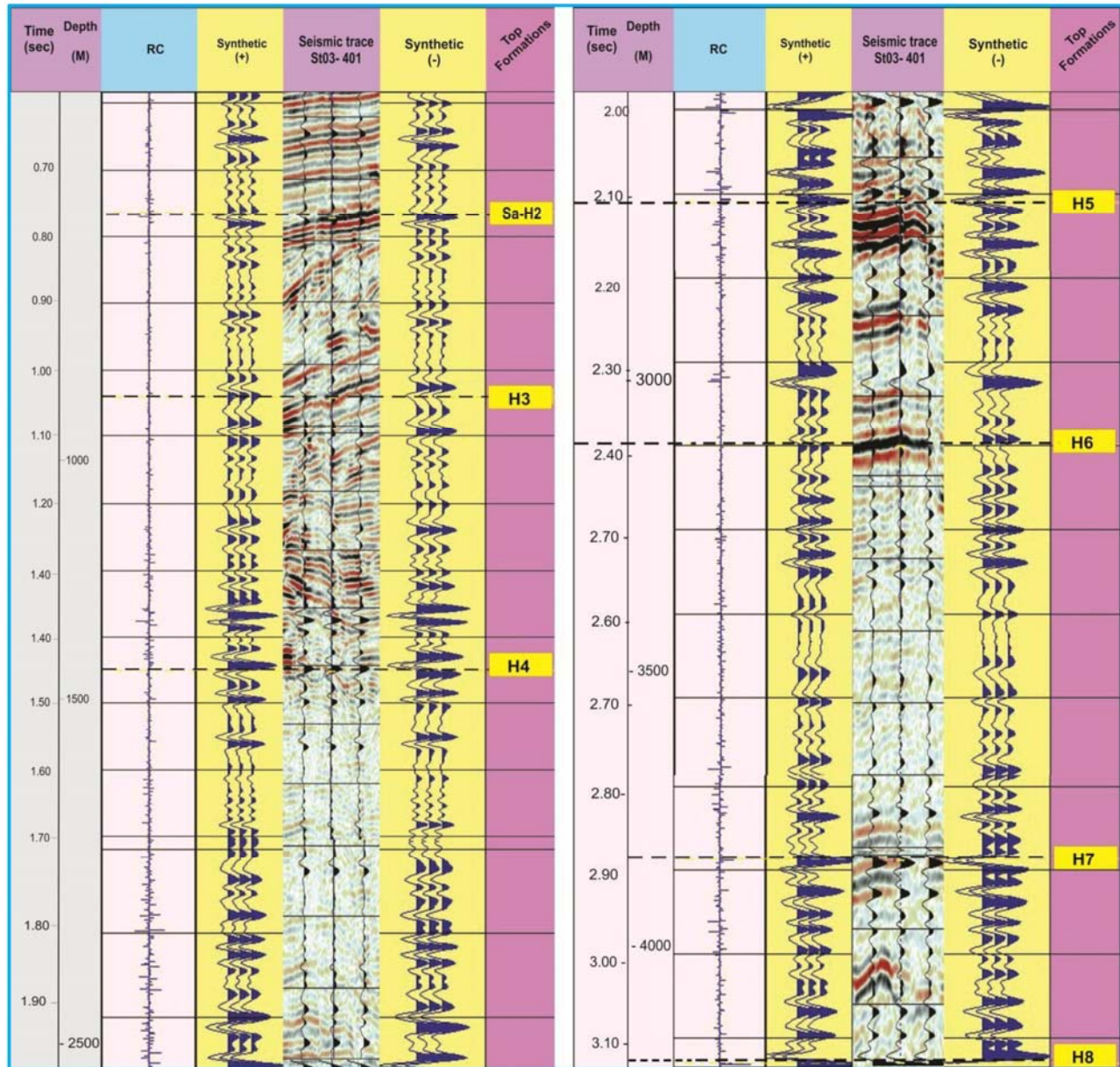


Figure-4. Synthetic seismograms tied to the seismic section, gamma ray, and sequence boundaries (kingdom 8.8).

Lithologically, it consists of soft mudstone to siltstone with calcareous interbedded sand of most likely high-stand system tract deposits. The Pliocene SEQ4 deposit overlies the Miocene deposit under increasing sea level environment. This transgressive system tract deposit was indicated by coastal to the outer neritic environment of deposition and named as lower Giant formation. SEQ3 consists of argillaceous with abundant foraminifera marine deposits representing a high-stand system tract of late Pliocene middle Giant formation. SEQ2 which is also a

similar depositional type as SEQ3 is the youngest sequence known as upper Giant formation underlying the seafloor of SEQ1 deposited during Pliocene-Pleistocene age. The above complete well information was then tied with seismic sections as shown in figures 6 to 10 whereby all depositional sequences were characterized in terms of their depositional seismic facies as well as their reflection terminations which are closely associated With sea level changes. Figure-6 shows the seismic section of line ST03-401 with well Witiora-1 and the positions of horizon 1 and



2 extended from the well position to the whole 27km long seismic line. Basically, SEQ1 is characterized by continuous, high amplitude and low-frequency seismic reflection patterns. This sequence is divided into lower transgressive system tract based on the presence of on-lap (Figure-6-B) and upper high-stand system tract deposit based on the down-lap feature overlying the maximum flooding surface (MFS).

SEQ2 represents the upper Giant formation and it is characterized by on lap reflection (Figure-6-A) features at the bottom of the sequence indicating a transgressive system tract deposit type and top lap features observed in the upper part of the sequence indicative a high-stand system tract type of deposit (Figure-6-B). As for the seismic facies, the SEQ2 is characterized mainly by high amplitude, low frequency and parallel to sub-parallel seismic configurations (Bottom of Figure-6-b).

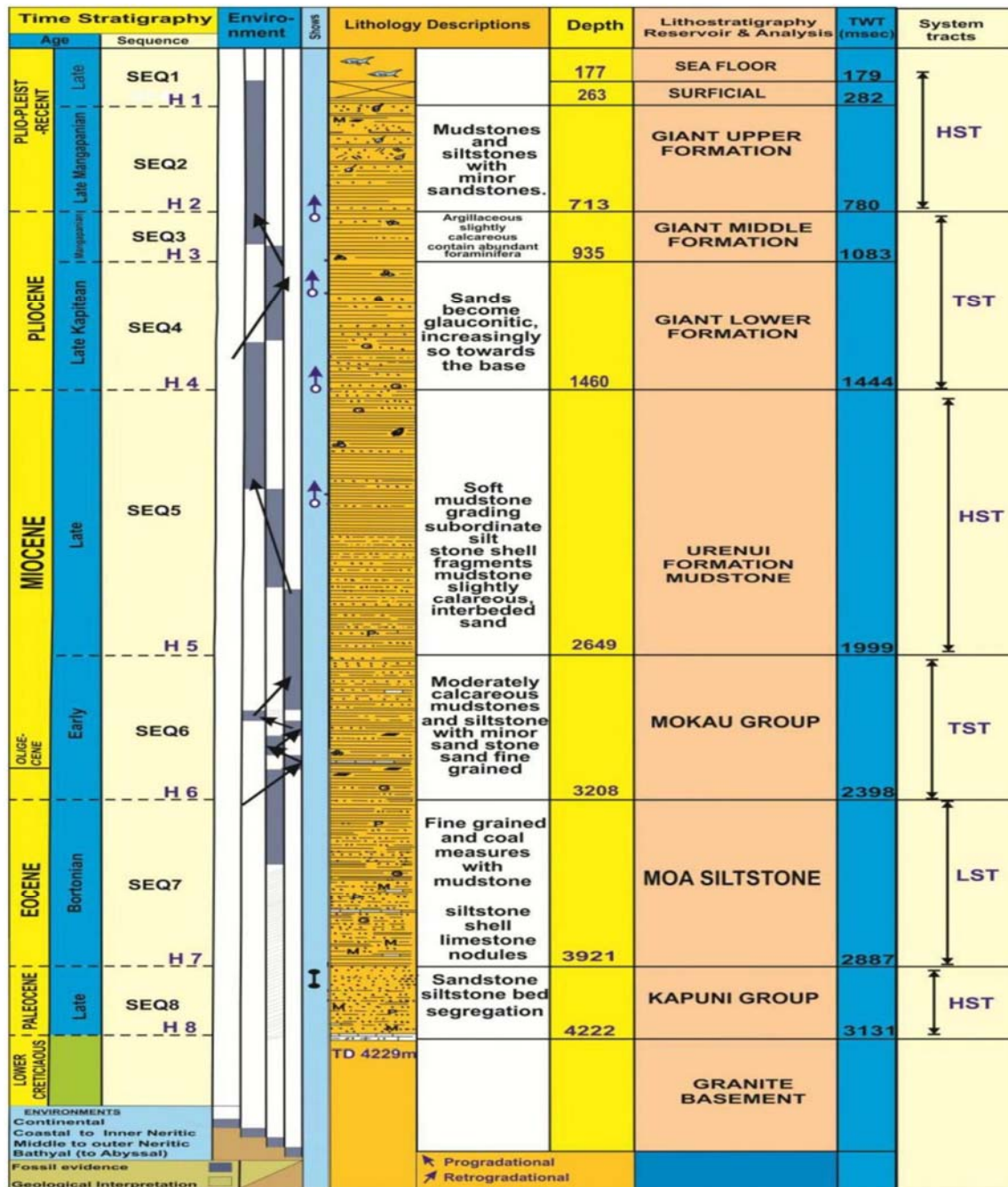


Figure-5. Show a table of well depth (m), description of the lithologies, formation tops from SEQ1toSEQ8, formations, ages and the depositional environment observed from Witiora-1 well (King, P. R., *et al.* 1999).

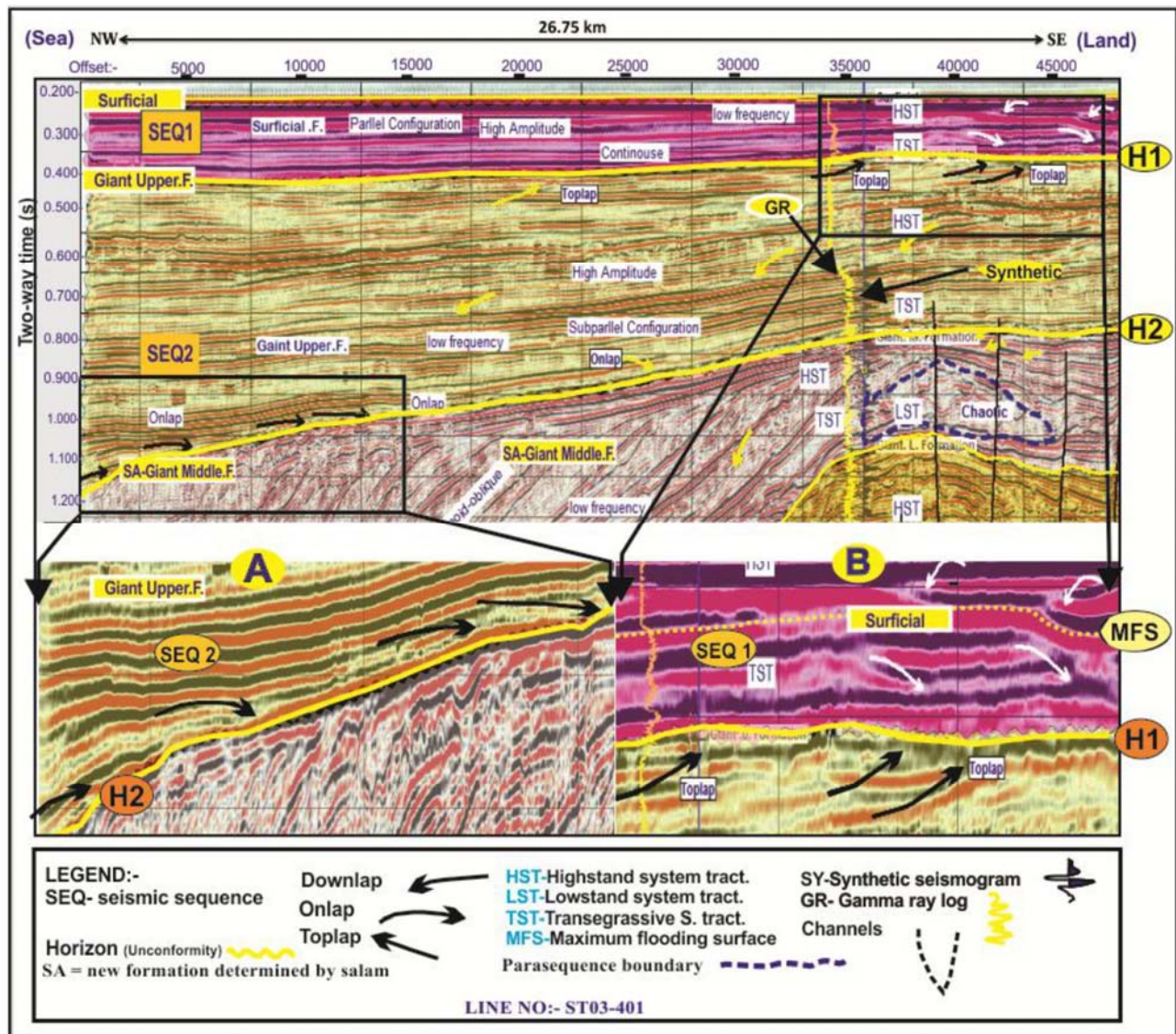


Figure-6. Interpreted seismic section showing H 1, H 2 respectively separating the upper Giant. F from the middle Giant. F and H2 separated the middle Giant. F from the lower giant. Reflection terminations are shown in yellow and white arrows, system tracts and seismic facies with GR and synthetic are posted on the section.

The middle Giant formation (SEQ3) and the lower Giant formation are separated by sequence boundary H3 (Figure-7). The H3 layer was observed to be dividing an anticlinal feature with on-laps along both of its wings. The SEQ3 is characterized by high amplitude, alternating low and high-frequency reflections. Sigmoid and oblique features also appeared in this sequence representing a lowstand system tract delta development during the lowering of sea level.

Figure-7 also indicates the position of sequence SEQ4 which is bounded by H3 and H4. The H4 is separating the lower Giant formation and the upper Urenui Formation. Down-laps observed on top of H3 towards the northwest or seaward (Figure-7.A). Many on-laps were

observed on top of H4 towards the southeast or landward (Figure-7.B) and top-laps were observed below the horizon interpreted as sea level encroachment during transgressive system tract above the low-stand system tract of incising valley. In terms of seismic facies, sequence SEQ4 shows quite a similar pattern of high amplitude, mixed frequencies, and discontinuous reflection patterns. The sequence boundary H5 of late Miocene in age separates the Urenui formation and the Mokau upper group (Figure-8). Close up along this horizon show indicates the presence of mound structure representing basin slope deposit of low stand system tracts (Figure-8.A).

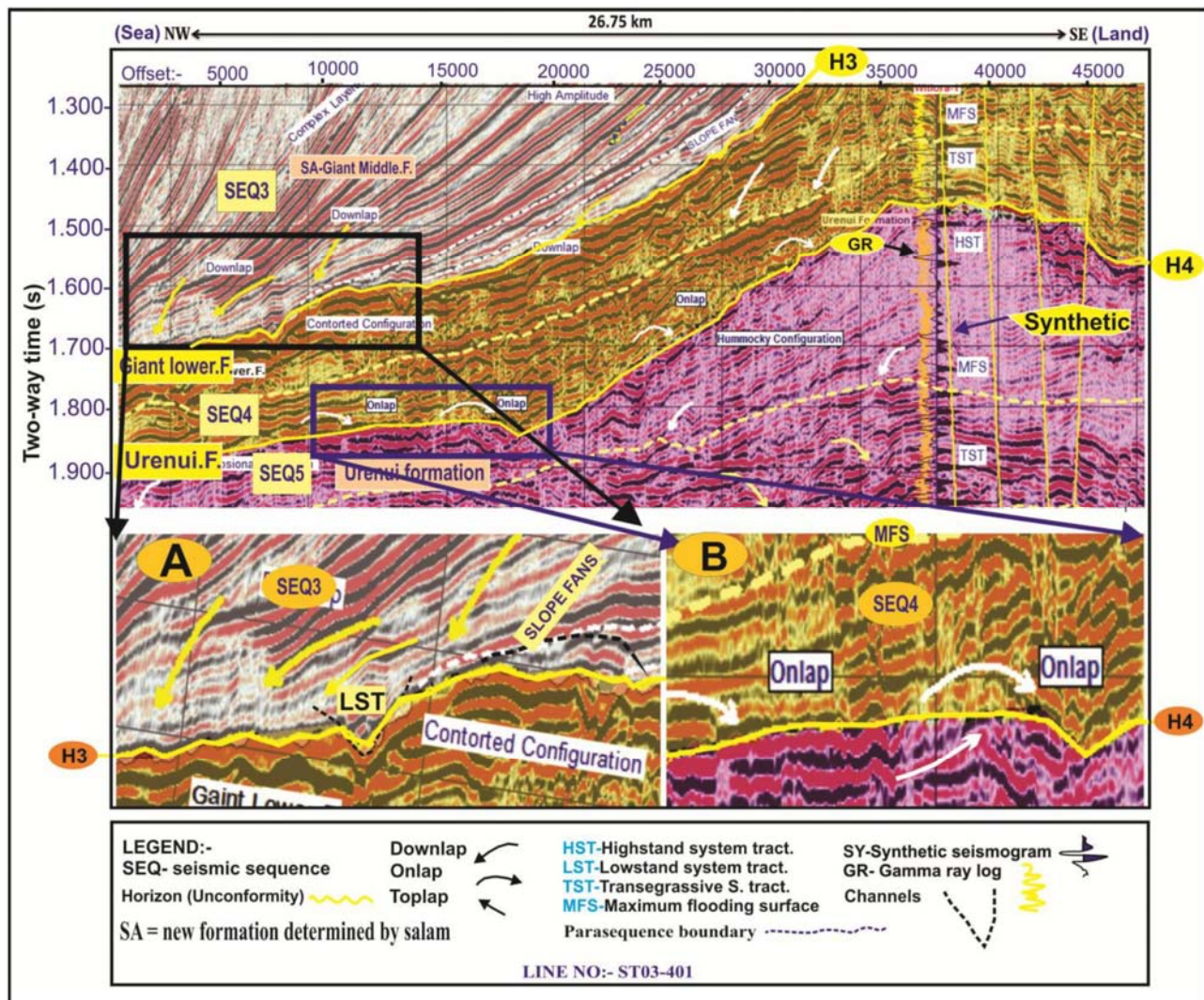


Figure-7. Interpreted seismic section showing H 3, H 4 respectively separating the middle Giant. F from the lower Giant. F and H 4 separated the lower Giant. F from the Urenui formation. Reflection terminations, system tracts and seismic facies with GR and synthetic are posted on the section.

Few on-laps were also observed on top of this deposit indicating the period of increasing sea level during the transgressive system tract. The on-lap marked the end of a long hiatus or non-deposit period suggesting that H5 sequence boundary is an unconformity. Mokau formation is basically characterized by low amplitude, discontinuous and high-frequency reflections in the upper layer and gradually becoming lower in frequency, undulating and discontinuous in the lower layer of Moa (Figure-8.C). Underlying the H5 is the Mokau formation consisting of deposits characterized by high amplitude, high frequency and discontinuous reflection patterns in the bottom part while zones of no reflection in between non-parallel discontinuous high amplitude were observed in the upper part of it. Based on well witiora-1, a period of

transgressive system tract took place during the early deposition of Mokau formation followed by two periods of short High stand system tract indicated by the lowering of sea level prior to another rise in sea level in the upper part of the formation deposit. Mokau formation was underlain by H6 sequence boundary on top of early Miocene-Eocene upper Moa group of coastal to shallow marine deposits consisting of coal measures with siltstone containing shelly limestone. In the seismic section, H6 sequence boundary is characterized by a marked change in the seismic reflection pattern separating the high amplitude in the lower Mokau formation and the non-reflection to sparse and low amplitude seismic reflections zone representing upper Moa group.

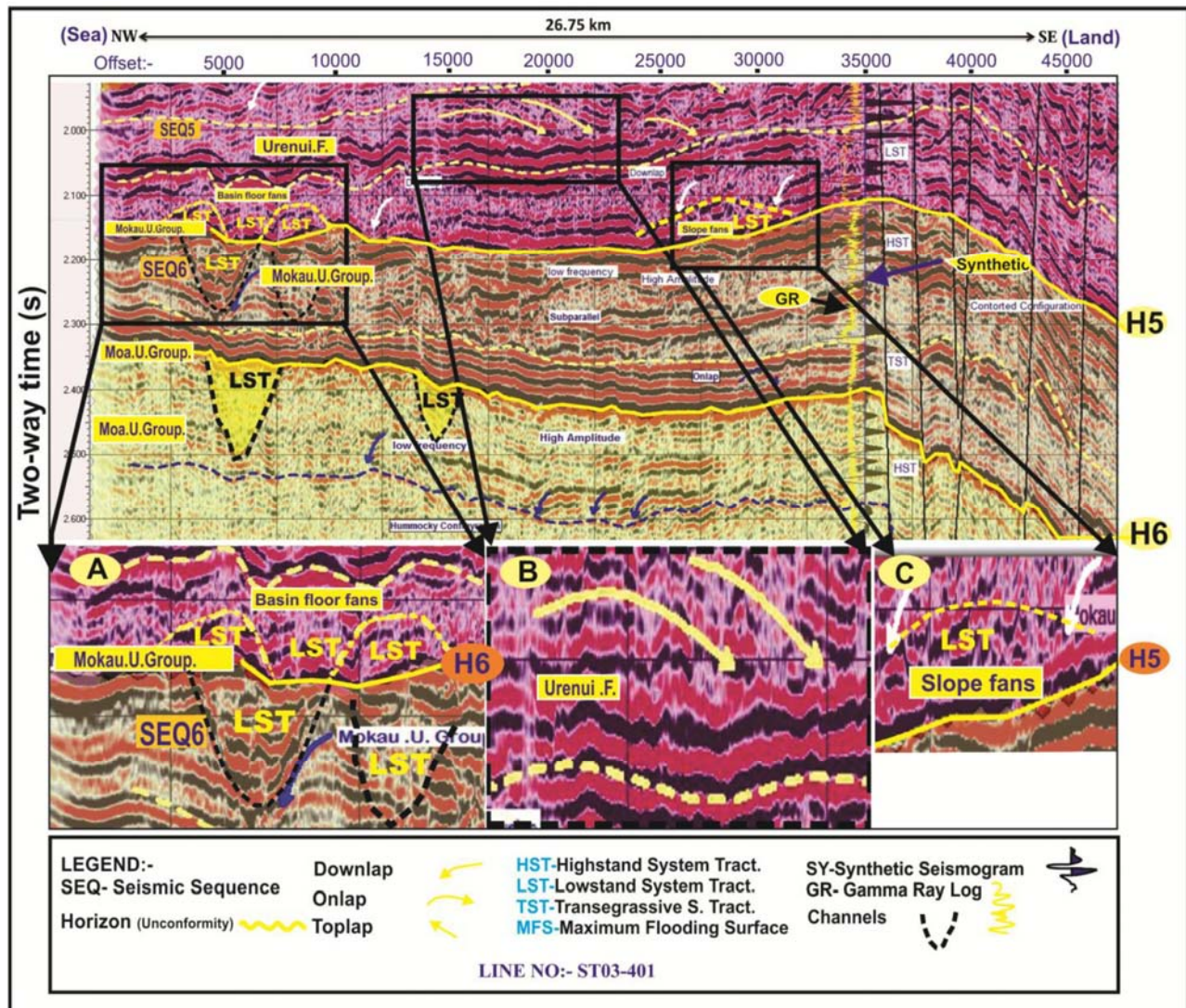
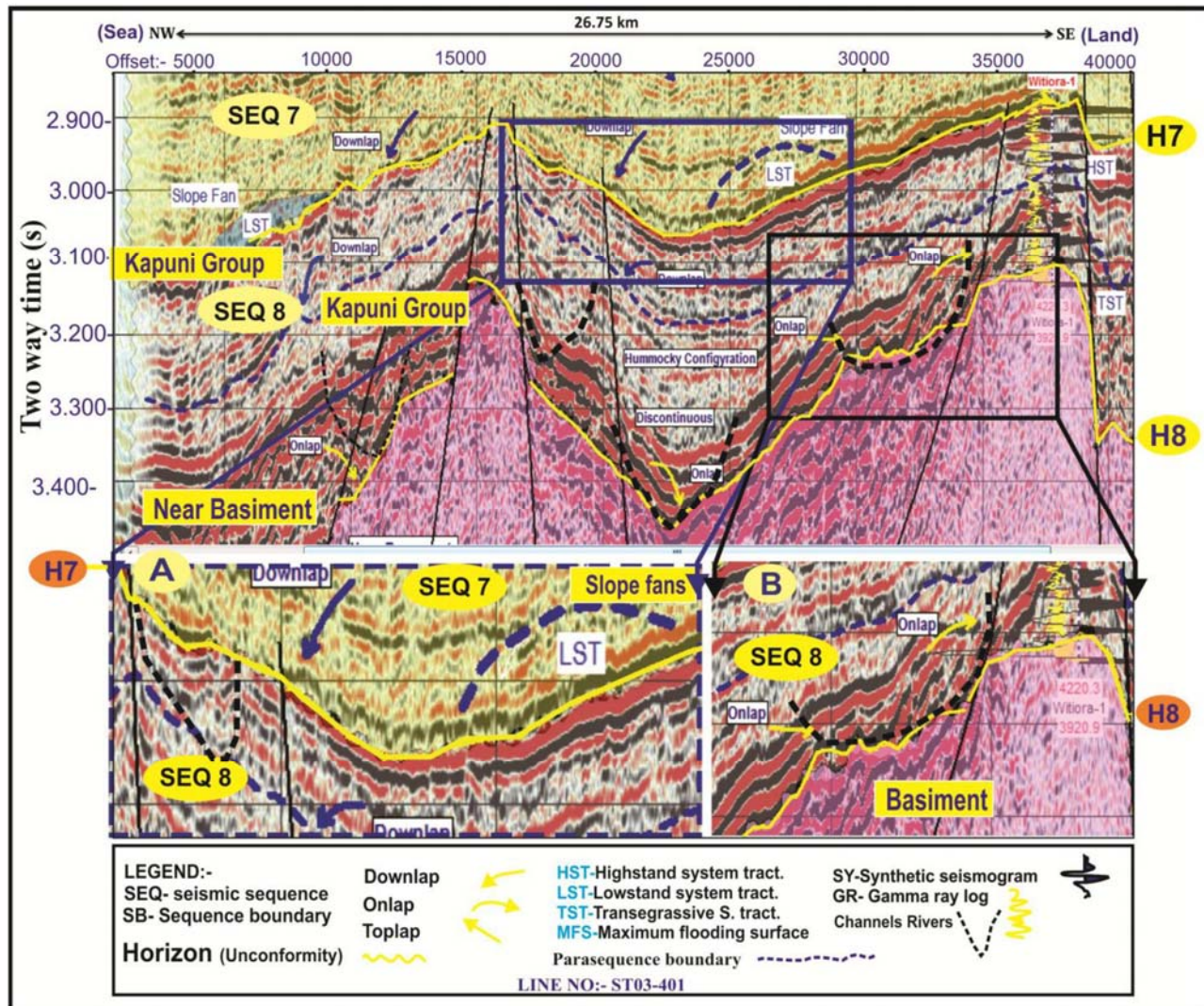


Figure-8. Interpreted seismic section showing H 5 separating the Urenui. F from Mokau Upper Group and H 6 separating Mokau Upper Group from Moa U. Group.

This H6 boundary separates few incised valleys and rivers on top of Moa group deposits specifying it as an unconformity surface. The whole upper Moa group deposit is characterized by a non-reflection facies. The sequence boundary H7 underlies the upper Moa group deposit and marked the beginning of Kapuni group (sequence 8) which is also showing a significant

difference in seismic facies compared to sequence 7 representing upper Moa group. Kapuni group is characterized by low amplitude, low frequency and in some place free-reflection zone of most likely a coastal type of high energy deposit on top of Basement (Figure-9.A) with reflection free zone.



This Kapuni deposit overlies the granite basement (Figure-9.B) with high amplitude and undulating reflection associated with rivers and incised valleys along the sequence boundary H8. The whole interpretation of

seismic section line ST03-401 with positions of sequence boundary, sequence deposits, seismic facies and reflection terminations identified as supporting evidence in classifying the sequence stratigraphic analysis is shown in Figure-10.

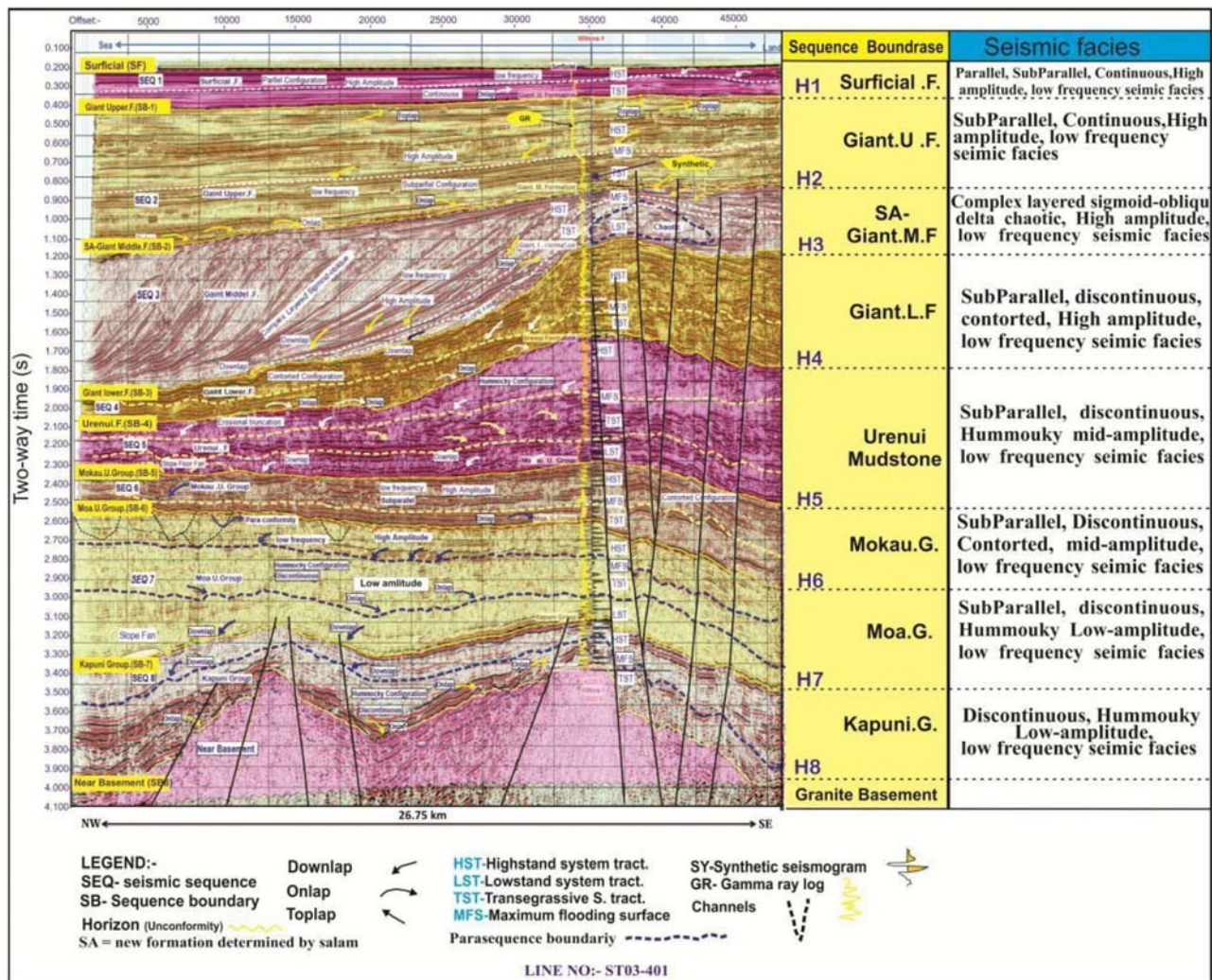


Figure-10. Interpreted seismic line 401 describes difference types of facies bounded by sequence boundaries.

4. CONCLUSIONS

A sequence stratigraphic approach has successfully been carried out in the study of part of Taranaki basin where the whole succession was successfully divided into eight separate sequences with their own environment of depositions based on seismic 2D data analysis supported by well information. Reflection terminations observed in the seismic sections strongly indicate that all sequence boundaries are unconformities and the seismic facies are found to be closely associated with types of sequence depositional environments.

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