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# SEQUENCE STRATIGRAPHY OF PALEOCENE-HOLOCENE SEDIMENTARY DEPOSITS IN KUPE FIELD, TARANAKI BASIN, NEW ZEALAND

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**ABSTRACT**

A sequence stratigraphic study of Paleocene to Holocene sediments was conducted in the 3D Kerry seismic profiles within the Kupe field of Taranaki basin. A 3D seismic data block consisting of 286 in-lines and 734 cross-lines covering approximately 15 x 37 km$^2$ were used in this study. The seismic interpretations including seismic facies and sequence boundaries determination as well as borehole analysis were performed by Kingdom 8.8 software. The main objective of the whole analysis is to identify the sequence stratigraphic units of Kupe field and for this reason, a seismic line and Toru-1 well was chosen for detail geological interpretation. Based on seismic data, various seismic facies including parallel, sub-parallel, continuous, discontinuous, wavy, high amplitude, low amplitude, high frequency and low frequency were identified representing the sedimentary patterns of the Tertiary and Quaternary deposits. These sedimentary features were associated with particular formations and age based on well correlation. Basically, about 10 main horizons (H1-H10) were identified by a 3D seeker technique representing the sequence boundaries separating 11 different formations of Paleocene to Recent in age. In this study, after some thorough analysis, the youngest formation was decided to be divided into two parts based on the presence of a new sequence boundary namely J1 detected in the bottom of the top formation characterized by onlap stratal termination indicating a period of sea level rise.

**Keywords:** kupe field, sequence stratigraphy, chronostratigraphic, seismic facies.

## INTRODUCTION

The Taranaki Basin is predominantly an offshore basin covering an area of around 100,000 km$^2$, lies along the western margin of New Zealand North Island. The eastern margin of the basin has traditionally been delineated by the Patea-Tongaporutu-Herangi basement high, which lies immediately east of the subsurface Taranaki Fault (King and Thrasher, 1996). A sequence stratigraphic study of Paleocene to Holocene was conducted in the southern part of the Taranaki Basin, New Zealand. The study area is located within the Kupe Field and it lies on a northerly plunging, reverse-faulted inversion structure which is the Manaia anticline. In the east, lies the north-south oriented Taranaki fault that has been active since at least the mid Oligocene (Figure-1). The major fault in the Kupe field is a north-south oriented Manaia fault that running through the central part of the area (King and Thrasher, 1996). They further explains that during Cretaceous untill Late Paleocene, the movement of the Manaia fault is normal and followed by the deposition of sediment at the down-thrown area to the eastern part of the fault. By Late Eocene to Oligocene, Stagpoole and Nicol (2008) finds that the movement of Manaia fault and other faults changes from normal to reverse and peak in the Late Miocene. Thus, it led to the formation of Miocene structure which is the Manaia anticline.

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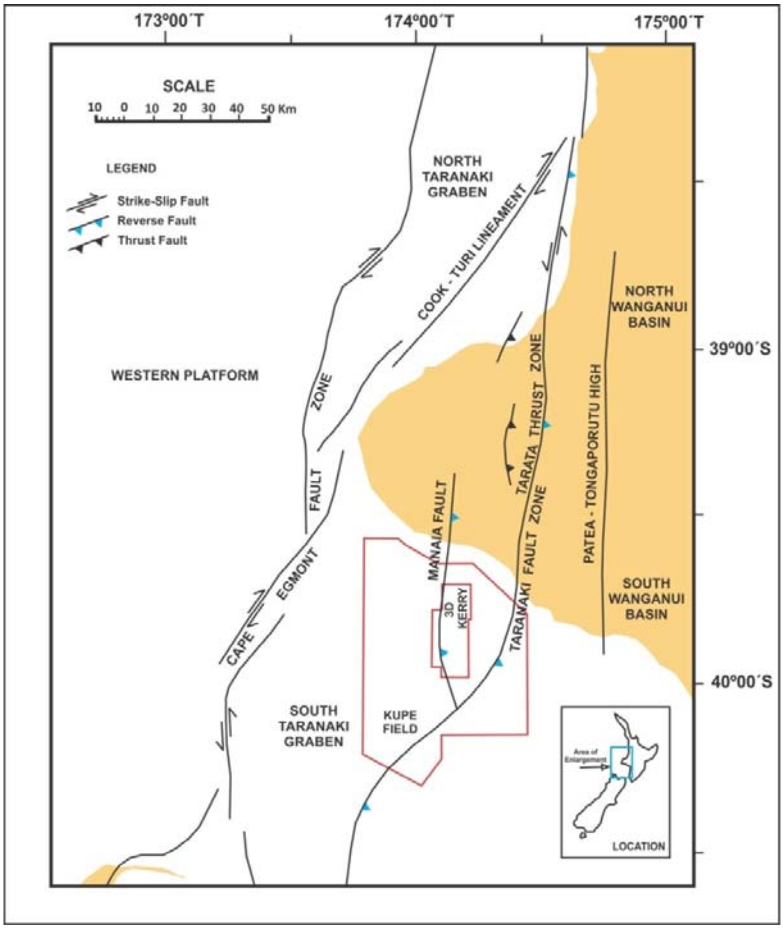


**Figure-1.** Map showing major structural elements of the Taranaki Basin indicating major faults and location of study area (Palmer, J. and Bulte, G. 1991).

Geologically, the study area consists of 12 litho-stratigraphic unit range from the Late Cretaceous to Quaternary age which are, Rakopi, North Cape, Farewell, Kaimiro, Otaraoa, Taimana, Lower Manganui, Upper Manganui, Kiore, Matemateaonga, Tangahoe and Giant Foresets Formations. The informations on these units were based on well report and also by the previous litho-stratigraphic schemes that have been reported by King *et al*. (1999) and Cooper (2004) (Figure-2). New Zealand Petroleum and Mineral (NZPM) in their report stated that Toru-1 well has penetrated Late Paleocene to recent sedimentary sequence (Croacker, 1991) and encountered hydrocarbon in Eocene sandstones of Mangahewa formation. The production drilling was later changed to Kaimiro formation after some reviews by Institute of Geological and Nuclear sciences (GNS) in 2007. Therefore the presence of hydrocarbon in northern offshore between Kupe and Kapuni was confirmed by the Toru-1 well.

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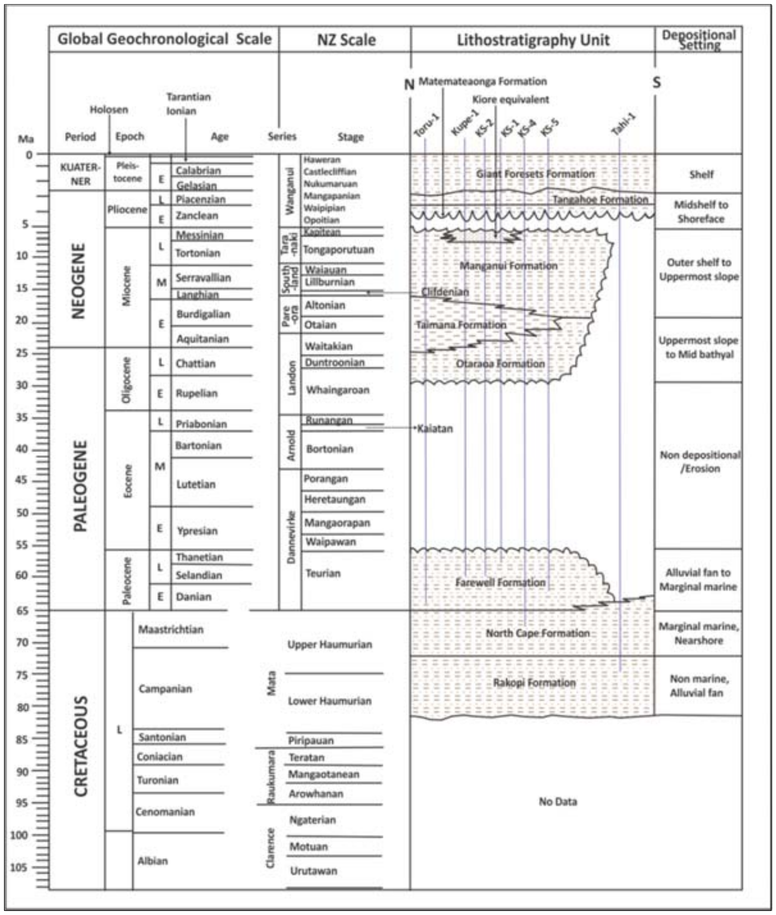


**Figure-2.** Simplified chronostratigraphic of north-south section of Kupe region, southern Taranaki Basin (King, P. R., *et al*. 1999 and Cooper, R. A. 2004).

Sequence stratigraphy consists of building a chronostratigraphic framework to understand relationships between rocks and the stratigraphic evolution. Traditional methods are based on the observation of seismic facies and their distribution to build a subsurface model. Seismic reflection packages are subdivided into seismic sequences and system tracts to understand depositional processes, environment settings and predict the lithology (Vail, 1987). According to Vail *et al* (1997), and Mitchum *et al*. (1977a and 1977b), sequence boundaries of any sedimentary deposit in the seismic section can be identified by different types of reflection termination or stratal terminations such as onlap, toplap, downlap, offlap and truncation as a result of repeated sea level changes during the geological ages. Generally, onlaps formed when low-angle younger rock strata terminate progressively against an initially older inclined surface during sea level rise. Often, the older rock layer undergo an erosional process and the surface was represented by an unconformities. Onlaps can be subdivided into several types depending on its genetic or where it was formed such as proximal, distal, coastal, marine, and nonmarine. The apparent and true onlaps are onlaps representing either the seismic section line cuts perpendicular to the sedimentary layer strike or at an angle relative to the dipping direction. While the tilted onlap is the onlap which has become downlap due to tilting by a later tectonic activity after its generation in the area. Toplap is a term used in identifying the situation of inclined sedimentary strata occured below the horizontal layers which normally represents a nondeposition hiatus. Downlap is used to describe an inclined surfaces that terminates downdip against a horizontal or inclined surface. Offlap refers to a pattern of stratal packages rather than reflection termination which build upwards and outwards into the basin. The term truncation basically refers to the erosional trunction and structural truncation. Erosional truncation indicates the removal of sediment packages by erosional process and it can be clearly observed when the underlying layers have been uplifted and tilted prior to the erosion. The structural truncation is the lateral termination of a stratum by structural disruption and it can occured due to faulting, gravity sliding or igneus intrusion. The differences in reflector patterns and their relationship on seismic profile is shown in Figure-3.

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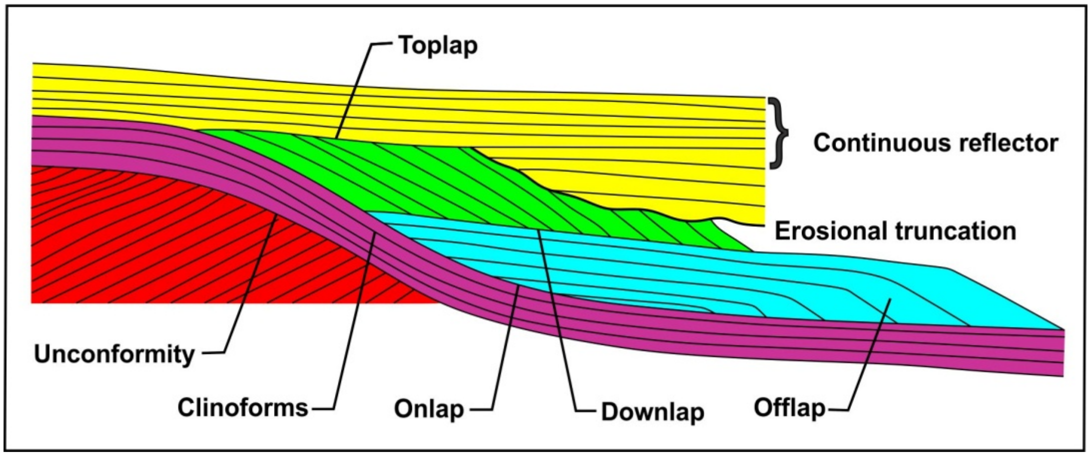


**Figure-3.** The differences in reflectors patterns and their relationship on seismic profile (Nicholas, G. 1999).

Seismic facies analysis is basically a study of seismic stratigraphy after seismic sequences were defined from the seismic section. Mitchum *et al.* (1977b) defines a seismic facies unit as a sedimentary unit whose parameters are differ from the adjacent facies units. Seismic facies analysis describes the seismic reflection parameters to interpret the environmental setting and rock units from the seismic and geologic data. 6 types of seismic reflection parameters include configuration, continuity, amplitude, frequency, interval velocity and external form and areal association of seismic facies units. Each of them provides useful information on the subsurface geology (Table-1).

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

| Seismic Facies parameters | Geologic interpretation |
|---|---|
| Reflection configuration | Bedding patterns<br>Depositional processes<br>Erosion and paleo-topography<br>Fluid contacts |
| Reflection continuity | Bedding continuity<br>Depositional process |
| Reflection amplitude | Velocity-density contrast<br>Bed spacing<br>Fluid content |
| Reflection frequency | Bed thickness<br>Fluid content |
| Interval velocity | Estimation of lithology<br>Estimation of porosity<br>Fluid content |
| External form and areal association of seismic facies units | Gross depositional environment<br>Sediment source<br>Geologic setting |

The application of sequence stratigraphy in seismic interpretation has proven to be fundamentally important to predict traps (Allan *et al.*, 2006), spatial distribution of reservoir (Abdel-Fattah and Slatt, 2013), seal (Dawson and Almon, 2005), source rocks and also in the basin analysis. The data used for this study are provided by New Zealand Petroleum and Minerals (NZPM). The Available Data directory contains the modified SEGY files that were loaded into the Kingdom software. For this paper, a seismic line numbered in-line 604 was chosen for the analysis and Toru-1 well is used for geological correlation (Figure-4). The study was carried out with two objectives which is to identify the seismic facies and to identify the sequence stratigraphic unit of Paleocene to Holocene.

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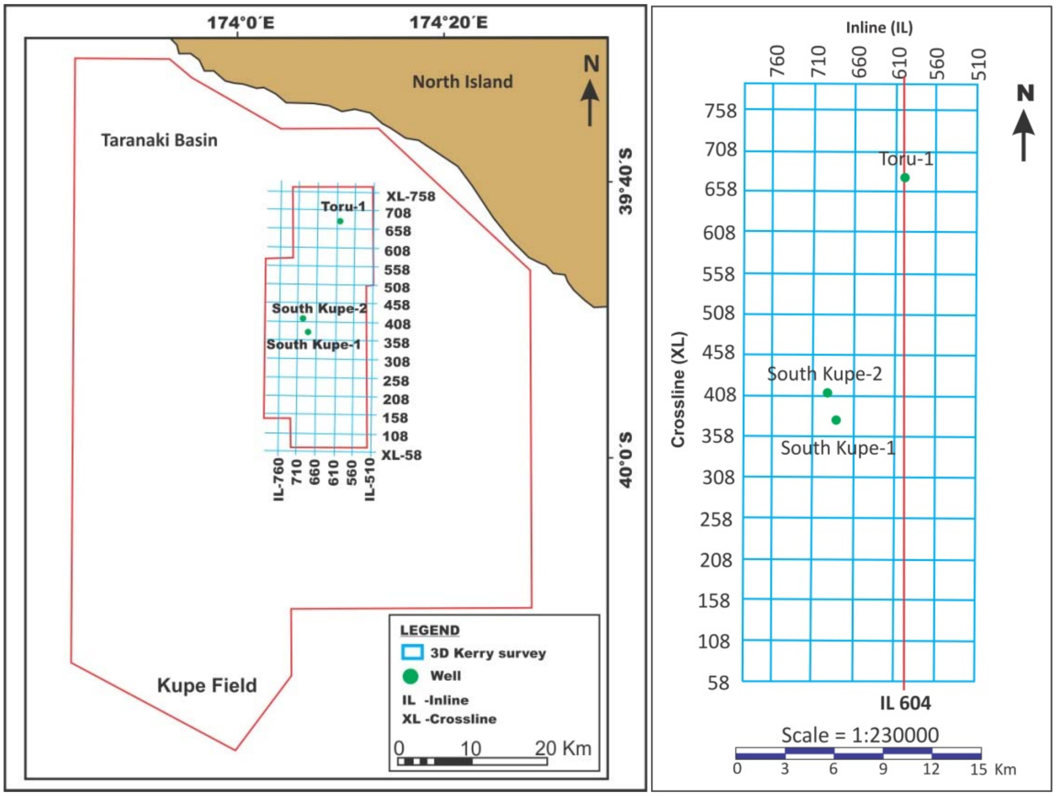


**Figure-4.** Locations of seismic profiles and wells within the Kupe field, Taranaki Basin.

## METHOD

The study involves sequence boundaries mapping using seismic data tied to well data and seismic facies analysis. A 36.7 km length of a seismic north-south line number 604 was used in this study. A deep well used for tying the seismic line is Toru-1 with a total depth of 4150.8 m based on the measure depth (MD). In the tying process, density and sonic logs were picked for developing a synthetic seismic log. Density log represents the density of the rock while the sonic log contains the velocity of sound in the penetrated rock. The positions of formation tops were identified from the synthetic seismogram, and automatically transferred into the seismic sections whereby the boundaries of the tops are then traced on the seismic sections. The age and the depositional environments of each formation are derived from the composite well logs. The composite well logs comprise of different type of logs such as the gamma-ray, density, spontaneous potential, neutron and sonic. These composite well logs have complete information on the lithology, paleontology and age of the drilled geological sections. The information given further helps to determine the sequence boundaries used in the interpretation of seismic reflection parameters.

## RESULTS AND DISCUSSIONS

Figure-5 shows the table incorporating TWT (sec), well depth (m), 2 sets of synthetic seismogram (+ and -), a portion of seismic section with Toru-1 well location and 3 traces of synthetic seismogram overlapped on the seismic section. A column on the right of this panel is the positions of formation tops indicated by H1 to H9.

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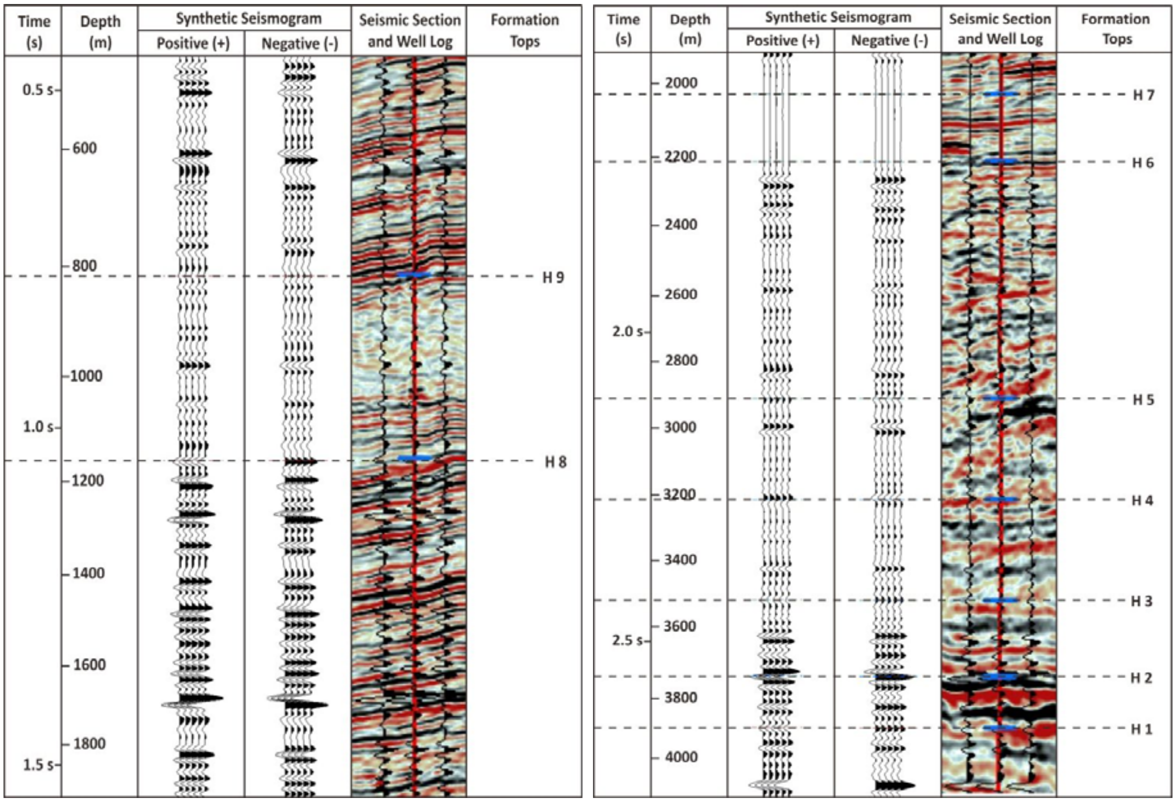


**Figure-5.** Tying synthetic seismograms, well, seismic section and sequence boundaries.

Figures 6 and 7 show table of well depth (m), gamma ray log (API), lithologies, description of the lithologies, formation tops from H1 to J1, formations, ages and the depositional environment observed from Toru-1 well.

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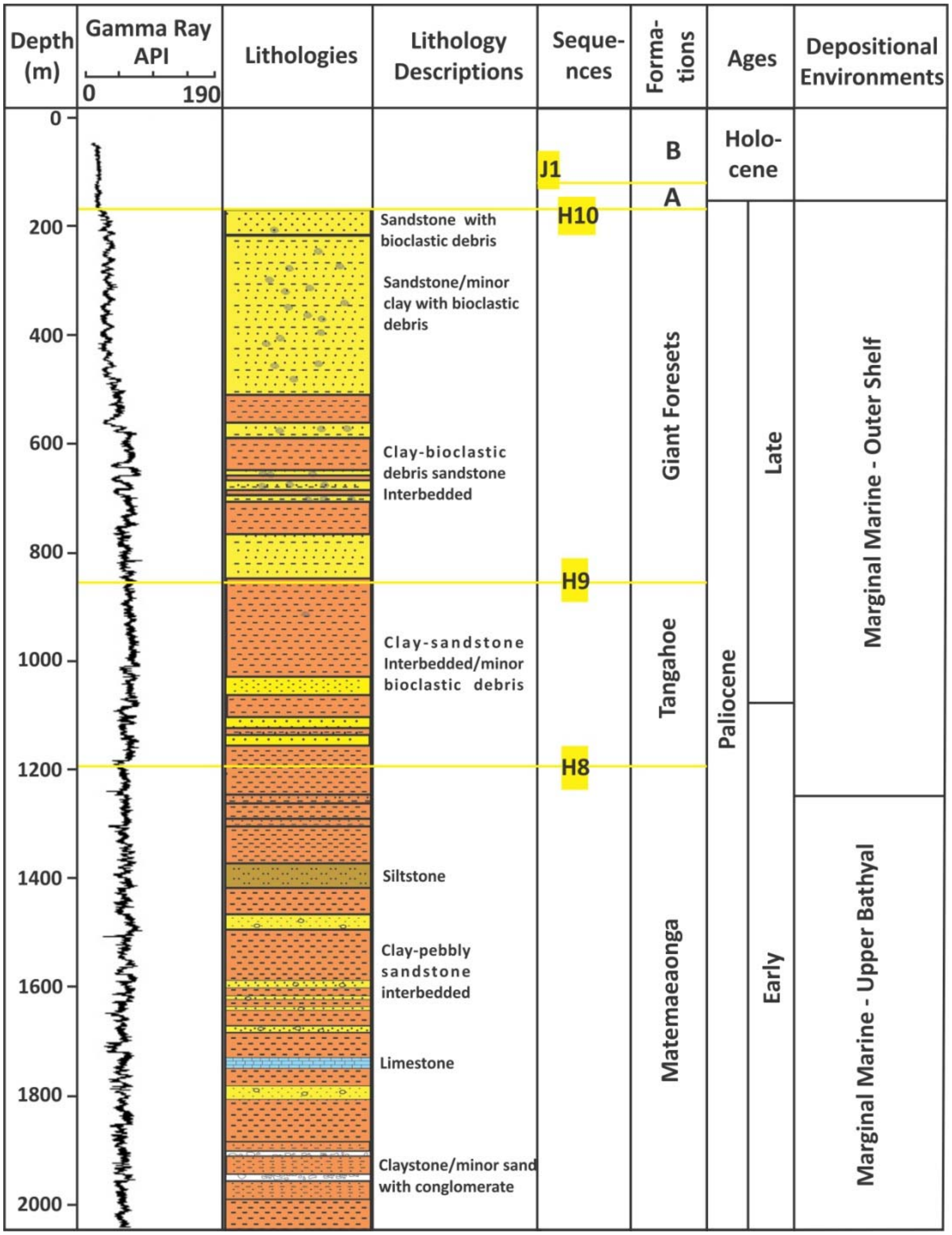


**Figure-6.** Geological information of Toru-1 well from depths of 0m to 2000m.

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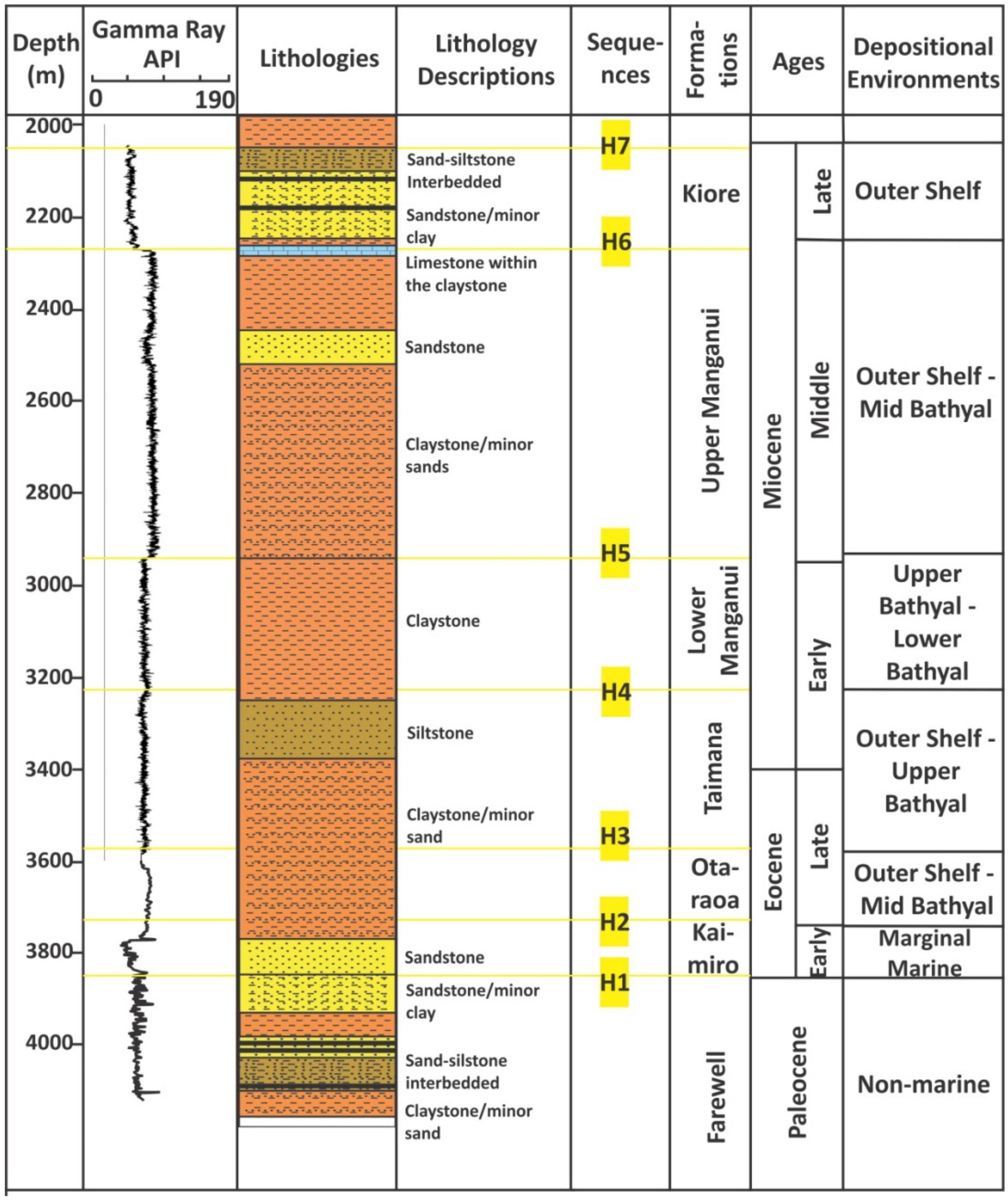


**Figure-7.** The information of Toru-1 well from 2000 m to 4150.8 m in depth.

Figures 8, 9, 10, 11, 12 and 13 illustrates the interpreted seismic section showing the positions of all 12 possible chronostratigraphic depositional units, bounded by sequence boundaries occurred within seismic line 604. These sequence boundaries are namely top Farewell, top Kaimiro, top Otaraoa, top Taimana, top Lower Manganui, top Upper Manganui, top Kiore, top Matemateaonga, top Tangahoe, top Giant Foresets Formation and top J1. These sequence boundaries are selected seismically by determining the reflection terminations such as, onlaps, toplaps, downlaps and erosional truncations. The identification process is sometime helped by seismic facies determinations which are in turn based on seismic amplitudes. General lithology was identified using gamma ray log (GRL). In the 3D Kerry block of Kupe Field seismic profile, the sequence boundary (H1) represents the top Farewell formation of Paleocene in age. Farewell Formation developed during Paleocene in a valley controlled by Mania fault. This unit consists of interbedded coarse to medium grained sandstone and siltstone deposited by a north draining fluvial system (King & Thrasher, 1996). From borehole Toru-1, coal deposits were found within the sandstone body of Farewell Formation. H1 was first identified at 2.6s two-way time with the occurence of reflection terminations represented by strong onlaps and toplaps observed on the top and

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bottom of this sequence boundary as shown in Figure-8. H1 separates the older Farewell Formation and the younger Kaimiro Formation of Oligocene in age. The selection of H1 is also strengthened by changes in rock material from sandstone with minor clay to sandstone. The difference in lithologies from fine to coarse grain is indicated by the decrease in gamma ray log values at the H1 position. Difference in seismic facies representing Farewell and Kaimiro formations are also observed and further justified in the horizon picking. High amplitude and chaotic seismic facies are seen in the Farewell formation located below H1 while high amplitude and sub parallel seismic facies represent the Kaimiro formations overlying the H1. The second and younger sequence boundary of H2 with an age ranging from Early to Middle Eocene was detected separating Kaimiro Formation and the Otaraoa Formation. This sequence boundary also marks the abrupt change of gamma ray values that separates materials of dominant sand to dominant clay deposits. The Kaimiro sandstone Formation is represented by low gamma while the overlying clay-riched Otaraoa Formation is characterized by high gamma value. The changes of rock materials from sandstone to claystone are also shown by similar abrupt changes in density log values. As indicated in Toru-1 well, this unit is deposited in marginal marine to lagoonal low energy depositional environment. The presence of H2 was also further supported by the existence of several onlapping features on top of its surface. The picking of H2 sequence boundary between Kaimiro and Otarao formations was also based on their difference in seismic amplitudes. The top Kaimiro formation is characterized by high amplitude reflection while Otarao formation underlying the H2 shows much lower seismic reflection amplitudes (Figure-8). The H3 sequence boundary of Late Oligocene in age separates Otaraoa and Taimana Formations. The underlying Otaraoa Formation consists of claystone with minor sandstone material deposited in bathyal to mid bathyal environment. The presents of numerous onlaps along the H3 border further proved the existence of this sequence boundary. H3 sequence boundary separates low amplitude and parallel seismic facies of Otarao formation and the sub parallel seismic facies of Taimana formation (Figure-8).

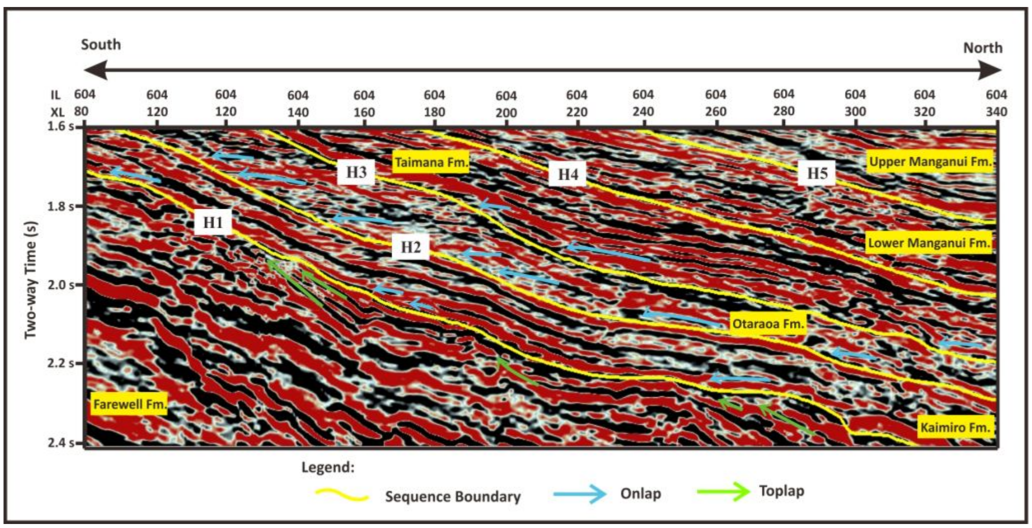


**Figure-8.** Interpreted seismic section with positions of H1-H5 sequence boundaries separating different geological units.

The sequence boundary H4 represents the Top Early Miocene of Taimana Formation. H4 separates Taimana Formation and Lower Manganui Formation. The Taimana Formation consists of materials ranging from claystone with minor sand material in the bottom and dominated by siltstone in the top of formation. It was deposited in outer shelf to upper most bathyal environment. The gamma ray values are relatively constant throughout the formation and only show a slight increase as the rocks materials changes. Different seismic facies were found in the seismic section bordering the H4 indicating the changes of depositional types with different environments. Discontinuous seismic reflection facies is observed on top of the sequence boundary within the Lower Manganui Formation while high amplitude seismic facies is found below the sequence boundary in the Taimana Formation. Onlaps observed on top of H4 further confirmed the location of the sequence boundary (Figure-9).

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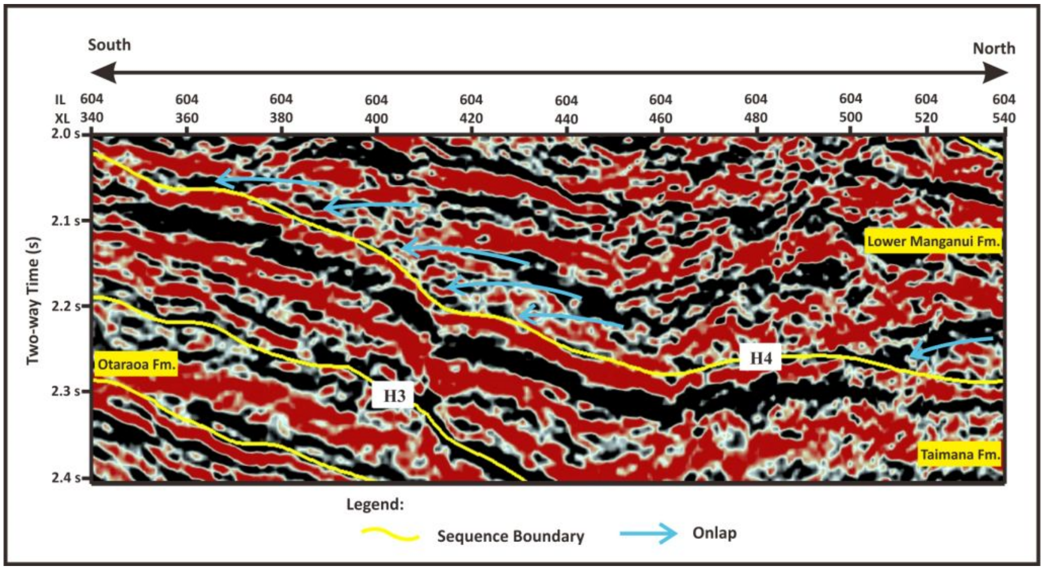


**Figure-9.** Enlarged part of seismic section showing the position of H4 sequence boundary separating the discontinuous seismic facies of lower Manganui and high amplitude seismic facies of Taimana formation.

The sequence boundary H5 represents the top of Lower manganui Formation of Early to Mid Miocene age. It also separates the Lower and upper Manganui Formation. The Lower Manganui Formation consists mainly of claystone material deposited in the uppermost bathyal to mid bathyal environment. This unit was identified by onlap features observed on top of H5 surface. The Lower Manganui deposits is also characterized by the presence of high amplitude and discontinuous reflection patterns associated with high energy environment deposit type while the Upper Manganui formation is represented by low amplitude-low frequency seismic facies indicating different depositional environment. (Figure-10).

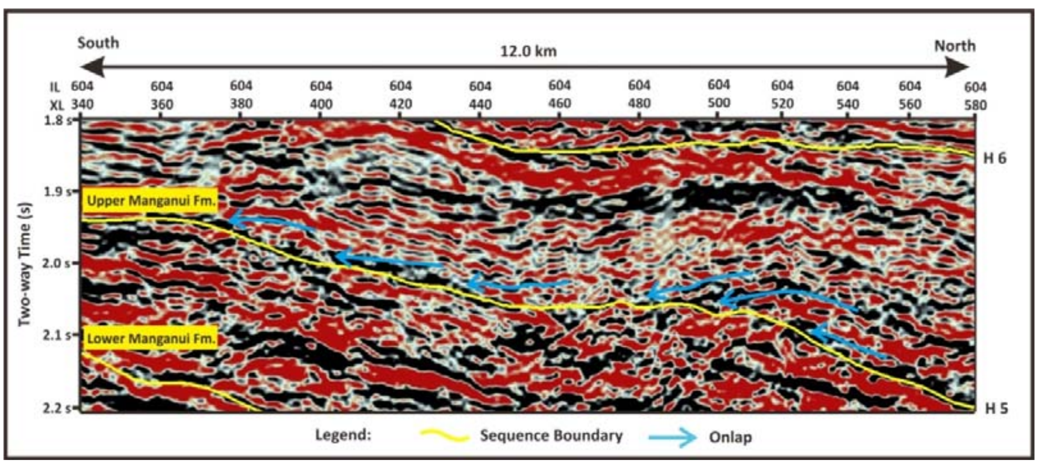


**Figure-10.** Interpreted seismic section showing H5 boundary separating the Lower Manganui Formation and the Upper Manganui Formation. The onlaps positions are as shown in blue arrows trending towards the south.

Sequence boundary 6 (H6) was observed on top of Upper Manganui Formation of Mid to Late Miocene age separating Upper Manganui and Kiore Formations. Geologically, the Upper Manganui Formation consists of mainly claystone while the Kiore Formation has dominant sandstone with minor clay deposit. The changes of sand and clay deposits are also shown in the gamma ray log. Many downlaps and onlaps events are observed on the H6 surface while few toplaps were found below the sequence boundary. This sequence boundary was also found to divide the top continuous and sub-continuous seismic facies and the bottom wavy and sub-continuous seismic facies (Figure-11). The Late Miocene top Kiore deposit has a sequence boundary named as H7 which is found

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separating Kiore Formation and Matemateaonga Formation. The Kiore Formation comprises of mainly sandstone with minor clay and interbedded of sandstone and siltstone. It was deposited in the outer shelf marine environment. Figure-11 clearly indicates the present of downlap features towards the south corresponding to the event of sediment transport on top of an erosional surface (H7). The sediment transport activity on top of an erosional surface could easily be observed in the seismic section by its difference in reflection patterns. The sediment transport is represented by Matemateaonga Formation with converging layers towards the south while the erosional surface is represented by Kiore formation of sub-parallel high amplitude type of reflections (Figure-11). Most of the layers in both formations show continuous to discontinuous seismic facies. Figure-12 shows the positions of Late Miocene to Early Pliocene sequence boundary H8 representing top of Matemateaonga formation and separating Matemateaonga Formation from Tangahoe Formation. The lithology of Matemateaonga Formation basically comprise of claystone, claystone with calcareous and pyrite, sandstone with pebble and also the conglomerate. This unit deposited in marginal marine to upper bathyal environment. It is characterized by low gamma ray value indicating sand dominant deposit. The H8 surface is interpreted as an unconformity based on the presence of onlapping features of Tangahoe formation deposit on top of it. Differences in depositional material and sedimentary environment lead to difference in seismic facies of both formations separated by H8. High amplitude and continuous reflection patterns are shown in Matemateaonga formation deposit while low amplitude and discontinuous seismic facies characterize reflector of Tangahoe formation (Figure-12). The sequence boundary H9 of Late Pliocene separates Tangahoe Formation and Giant Foresets Formation. The Tangahoe Formation consists of claystone, claystone with some bioclastic debris to sandstone. It is deposited in marginal marine to outer shelf environment. The Tangahoe Formation has higher clay and hence gamma ray responses than the underlying Matemateaonga Formation.

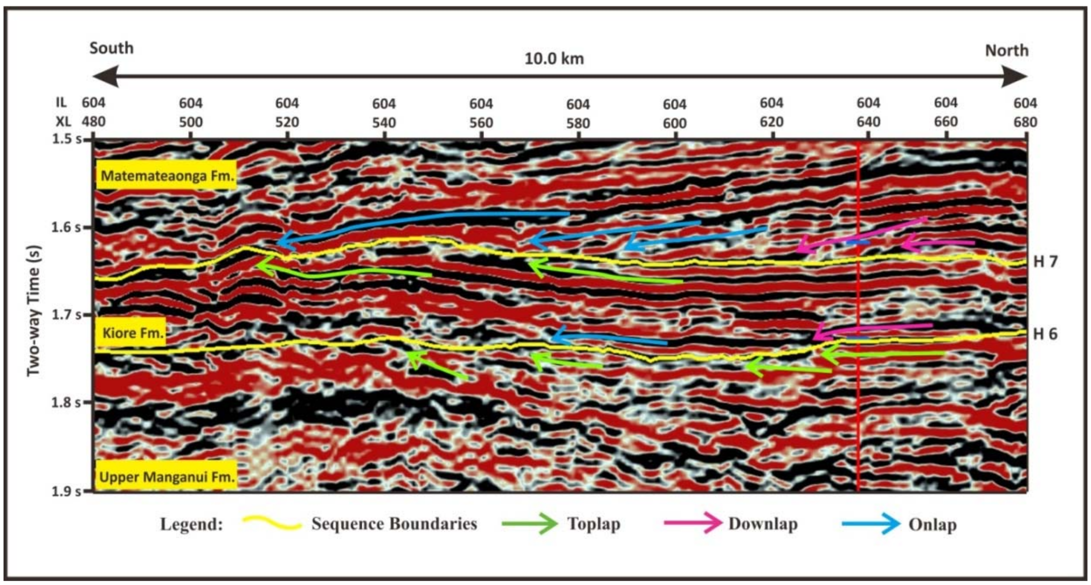


**Figure-11.** The positions of H6 and H7 sequence boundaries with clear downlaps position as shown by blue arrows towards the south indicating the direction of sediment transport.

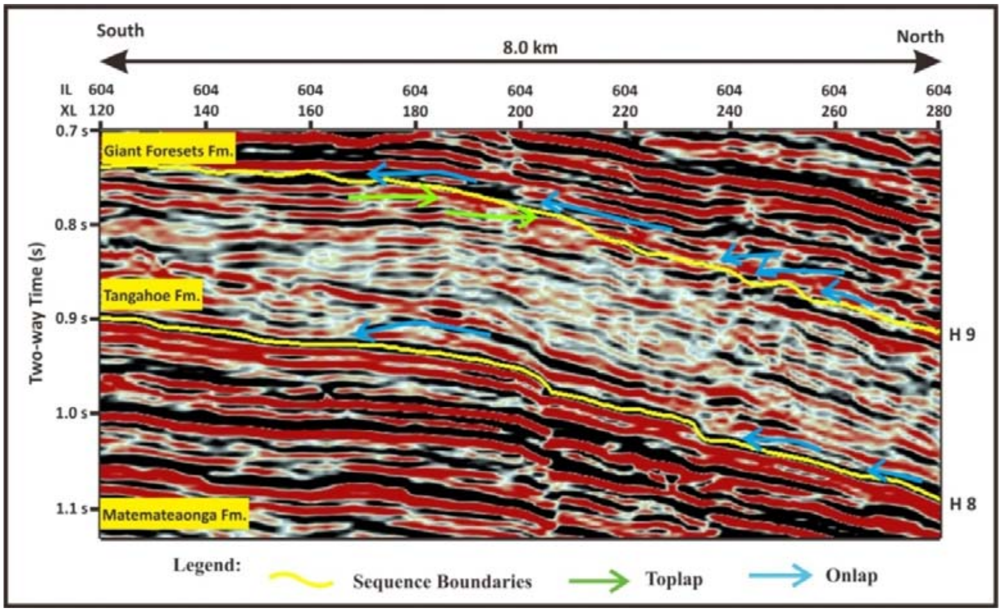


**Figure-12.** Toplap and onlap features observed in seismic section. High amplitude and continuous reflector of Matemateaonga formation overlies by low amplitude and discontinuous reflector of Tangahoe Formation.

The sequence boundary H10 of Late Pliocene in age found at the top of Giant Foresets formation. It separates Giant Foresets Formation and bottom of Formation A. Giant Foresets Formation comprises of claystone, sandstone with minor clay and also bioclastic debris within the sandstone with clay body. It is deposited in marginal marine to outer shelf environment. In the seismic section, Giant Foresets Formation is characterized by high amplitude and continuous seismic facies in contrast with Formation A of lower amplitude and discontinuous seismic facies. Downlap features are observed on top of H10 surface (Figure-13). J1 is the eleventh and youngest sequence boundary found separating Formations A and B. High amplitude and parallel seismic reflectors of formation B overlies low amplitude and discontinuous seismic facies of Formation A. Onlaps of base of formation B are clearly observed on the J1 surface especially towards the north as indicated by arrows (Figure-14).

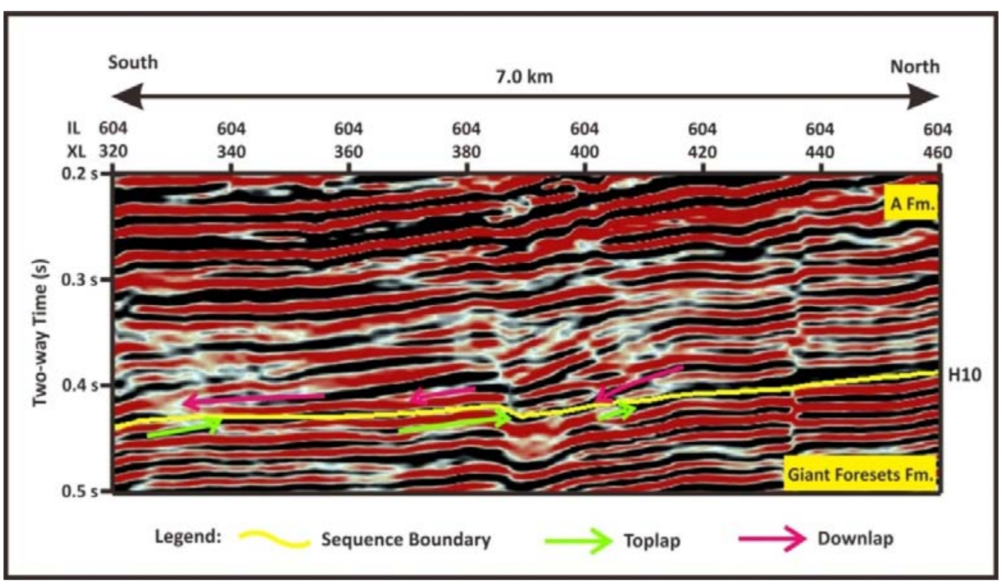


**Figure-13.** High amplitude and continuous seismic facies in Giant Foresets Formation overlies by low amplitude and discontinuous seismic facies in Formation A.

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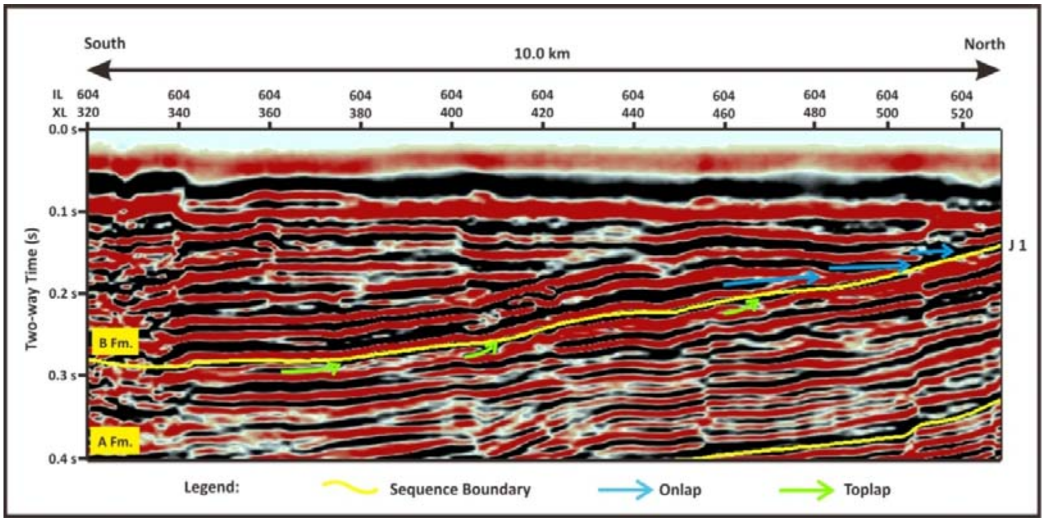


**Figure-14.** The position of sequence boundary J1 separating formations A and B with very clear onlap and downlap features.

Figure-15 shows the interpreted seismic section of line 604 which covered about 3.0 s (TWT) and depth range from 0 m to 4200 m. The section also shows the positions of all picked sequence boundaries (H1-J1) altogether with the information on the sequences formations, ages and depositional environments obtained from Toru-1 well. Figure-16 shows the sequence boundaries traced from the seismic section altogether with the positions of onlaps, downlaps and toplaps associated with the horizons. Figure-17 summarize the various interpreted seismic facies observed in the study area. It includes parallel, subparallel, continuous, discontinuous, wavy, high amplitude, low amplitude, high frequency and low frequency facies. All facies were associated with the appropriate sedimentary genetics obtained when the seismic section is tied with the well information.

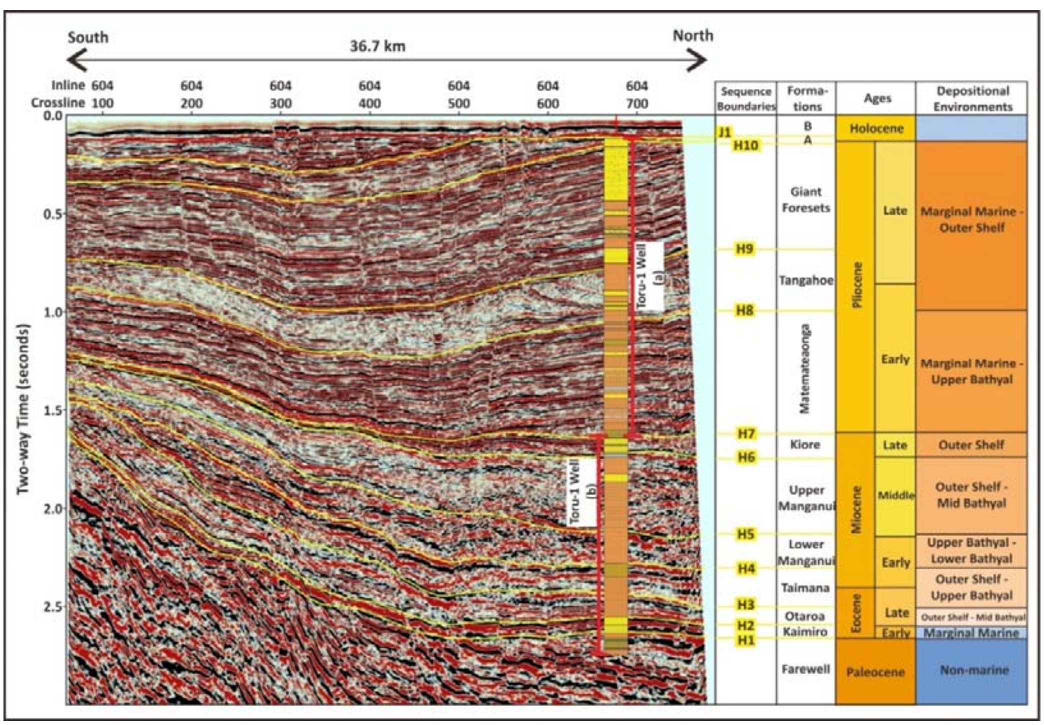


**Figure-15.** The interpreted seismic line 604 with positions of its sequence boundaries (H1-J1) as well as with information on the lithologies, formations, ages and depositional environments derived from Toru-1 well.

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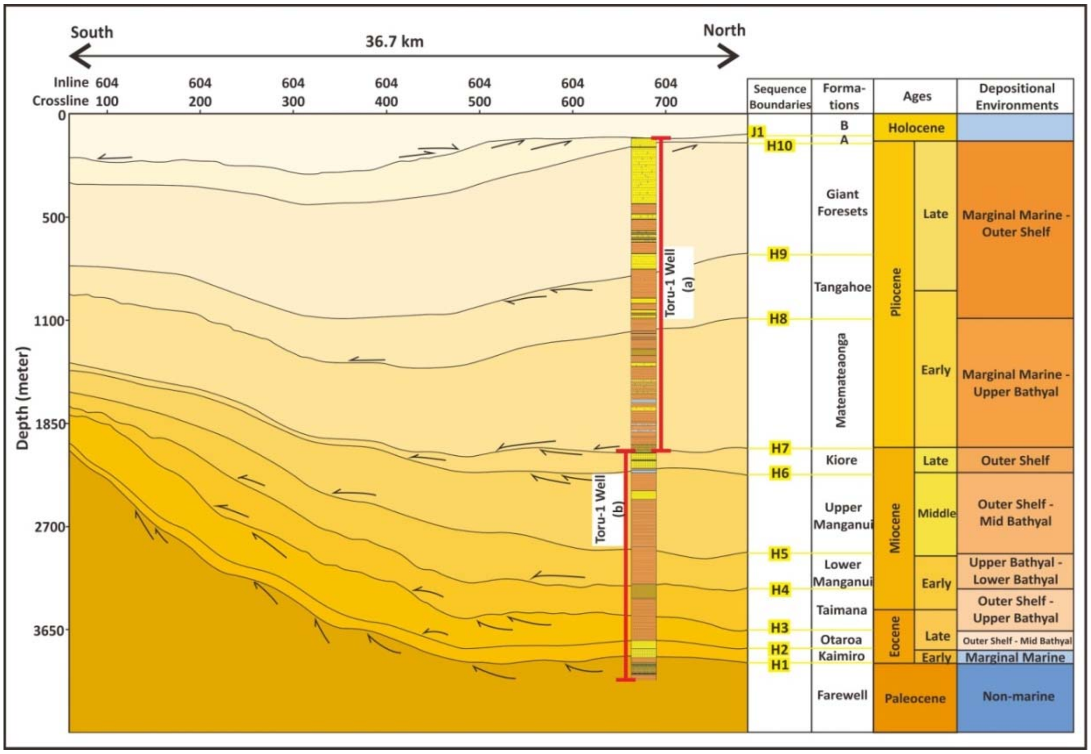


**Figure-16.** Positions of sequence boundaries (H1-J1) as traced from the interpreted seismic section with information on the reflection terminations, lithologies, formations, ages and depositional environments.

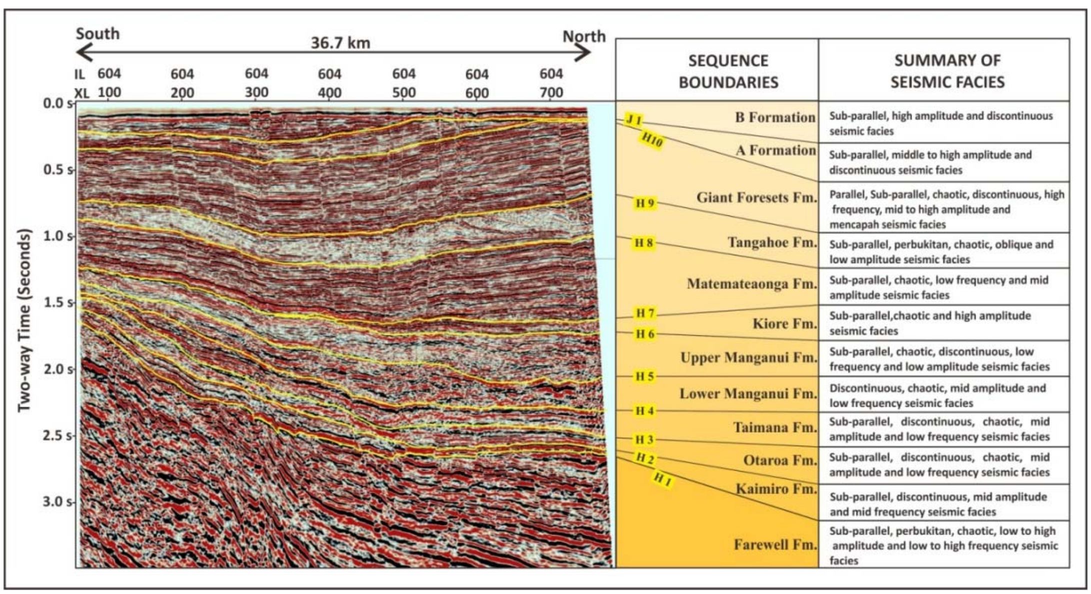


**Figure-17.** Description of difference type of facies bounded by sequence boundaries in inline 604.

## CONCLUSIONS

Seismic facies and sequence boundaries were successfully determined from one of the seismic sections in this study area. 11 sequence boundaries separating 10 formations in the Paleocene-Quaternary age namely H1 to H10 and J1 were detected based on different types of seismic facies supported by reflection terminations.

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**ACKNOWLEDGEMENT**

I would like to thank New Zealand Petroleum and Mineral (NZPM) for providing the seismic and well data.

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