Seismic reflection character, mapping and tectono-stratigraphic history of the Kupe area (4D Taranaki Project), south-eastern Taranaki Basin

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ABSTRACT

The Kupe mapping area (KUP) is the first of seven offshore regions to be mapped on digital seismic reflection profiles as part of the GNS Science “4D-Taranaki Project”. This report provides an overview of this mapping and interpreted subsurface stratigraphy and structure in the Kupe mapping region.

Within the KUP area, 17 seismic horizons have been identified and mapped on an allostratigraphic basis, i.e., stratigraphic units are defined on the basis of observed bounding discontinuities. This document describes the seismic reflection character of these horizons and their associated sequences.

The 17 seismic horizons have been gridded and mapped as time-structure surfaces. They have also been depth converted to derive a set of depth-structure maps as well as a set of 16 isopach maps. A selection of isopach maps are appended to this report and, together with the time-structure and depth-structure maps. Also included are figures showing the coverage of seismic and well data, as well as four cross-sections.

The entire set of time-structure, depth-structure and isopach maps from the Kupe mapping area maps plus the digital grids and GOCAD triangulated-surfaces (t-surfaces) of the mapped horizons are additionally available for purchase.

In combination with an analysis of seismic facies character, the map suite provides a more detailed overview of the structural evolution and depositional history in the KUP area than previously existed.

KEYWORDS

4D Taranaki Project, Kupe mapping area, depth conversion, isopach maps, allostratigraphy, seismic reflection character, Cretaceous, Paleogene, Paleocene, Eocene, Oligocene, Neogene, Miocene, Pliocene, Pleistocene;
1.0 INTRODUCTION

1.1 AIMS OF THE 4DT SEISMIC MAPPING PROJECT

The Kupe mapping area (KUP), is one of seven offshore regions within the Taranaki Basin (Figure 1) that are being mapped by GNS Science as part of the “4D Taranaki (4DT) Project” (Leitner et al., 2006; Arnot et al., 2008; Leitner et al., 2008). The aim of the 4DT project is to expand geological knowledge of the Taranaki Basin through the interpretation and mapping of an increased number of significant seismic horizons from the five basin-wide horizons identified in the preceding benchmark reference work by King and Thrasher (1996). The overall objective of this multi-year project is to produce a digital atlas of the seismic stratigraphy and structure within the Taranaki Basin, and associated derivative products such as 4D petroleum generation and migration models, and structural restorations.

1.2 THIS REPORT AND RELATED PRODUCTS

This report provides an overview of the results of seismic reflection stratigraphic and structural mapping within the Kupe mapping area. Seventeen seismic horizons have been identified on an allostratigraphic basis. These have been interpreted, mapped and depth converted to derive a new set of structure and isopach maps that illustrate the distribution and thickness of the mapped sequences, from which new insights into the structural and depositional history of this part of the Taranaki Basin can be drawn. A selection of maps, related to the five basin-wide horizons identified by King and Thrasher (1996) are presented in Appendix A.

An accompanying report documents details regarding the depth conversion methodology used (Hill and Milner, 2012). The velocity model used for depth conversion is also available as purchasable digital data in two-way-time (TWT) and depth (z), both in either SEGY or in Velf format (Fohrmann et al., 2012).

All seismic mapping products (horizon two-way time surfaces, depth surfaces, fault surfaces, and isopach data) for the KUP area are available for purchase from GNS Science in cartographic form as map sheets in pdf format and as digital surfaces in 2D and 3D ascii formats (Fohrmann et al., 2012).

Other reports have been produced to outline various other aspects of the study, including well calibration (Roncaglia et al., 2008), seismic phase matching (Milner et al., 2010), project procedures and protocols (Roncaglia et al., 2010), and lithostratigraphy (Bland et al., in prep.).

The open-file portion of the seismic reflection dataset used (see below) has been exported and is available from GNS Science as standardised SEGY files (Milner et al., 2010).

1.3 KUPE STUDY AREA (KUP)

The Kupe Mapping Area is named after the Kupe gas/condensate field, which lies in the central part of the mapping area (Figure 1). The mapping area lies in the Southern Taranaki Bight, immediately south of the Taranaki coastline. The area is defined to the north by the coastline, the Taranaki Fault in the east, by the centre of the Otakeho High in the west and in the south by the 2D seismic line MohoA-dsir. The Kupe field and several petroleum exploration and development wells lie within the mapping area. However, these wells are all
located on the crest of the Manaia Anticline; no wells have drilled in adjacent synclines (Figure 2 & Figure 3).

1.4 DATA SETS USED

1.4.1 Seismic Data

A major objective of this project was to compile all the available and fit-for-purpose seismic reflection data into one composite dataset. This was completed during the project initiation phase.

Seismic data used in this project were obtained via the open-file data catalogue administered by New Zealand Petroleum & Minerals (NZP&M, formerly Crown Minerals) at the Ministry of Business, Innovation, and Employment (MBIE), or through data trade agreements with permit holders in order to achieve the best possible coverage for seismic interpretation (Roncaglia et al., 2010).

The seismic dataset used for this project consists of 207 2D seismic reflection lines (Appendix A – Figure 18) and one 3D seismic survey (Kerry 3D; Western Mining Corporation (WMC), 1996). Details of the seismic data—vintage, source, Petroleum Report references and total line kilometres—are summarised in Fohrmann et al. (2012). All available seismic data from the KUP area (Figure 2) were quality checked, phase matched, time shifted to tie at the seabed (Milner et al., 2010) and loaded into the software package SeisWare™ for interpretation.

1.4.2 Well Data

Nine wells (Table 1) have been used for this study to construct the allostratigraphic framework. All wells are located offshore, on the axis of the Manaia Anticline, except the Rimu-A1 well, which is located onshore within the Rimu-Kauri Field. There is no well control on the flanks of the anticline or surrounding basins (Figure 2 & Figure 3).

A detailed discussion of the stratigraphy, well correlation and the seismic-to well ties can be found in Roncaglia et al. (2008).

Table 1 Kupe mapping area (KUP) well database (Roncaglia et al., 2008; Roncaglia et al., 2010).

<table>
<thead>
<tr>
<th>Well name</th>
<th>Petroleum report (PR) No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kupe-1</td>
<td>662 (Shell BP Todd Oil Services Ltd, 1976)</td>
</tr>
<tr>
<td>Kupe South-1</td>
<td>1284 (Matthews and Bennett, 1987)</td>
</tr>
<tr>
<td>Kupe South-2</td>
<td>1285 (Donaldson et al., 1987)</td>
</tr>
<tr>
<td>Kupe South-3B</td>
<td>1368 (Donaldson et al., 1988)</td>
</tr>
<tr>
<td>Kupe South-4</td>
<td>1483 (Crowley et al., 1989)</td>
</tr>
<tr>
<td>Kupe South-5</td>
<td>1678 (Duff et al., 1991)</td>
</tr>
<tr>
<td>Rimu-A1</td>
<td>2447 (Harris et al., 1999)</td>
</tr>
<tr>
<td>Tahi-1</td>
<td>1030 (Palmer, 1984)</td>
</tr>
<tr>
<td>Toru-1</td>
<td>1668 (Crocker, 1991)</td>
</tr>
</tbody>
</table>
Figure 1    Kupe mapping area (KUP) location map.
Figure 2  KUP area (yellow polygon): Seismic (grey lines) and well locations. The polygon in the centre illustrates the outline of the Kerry 3D dataset.
2.0 GEOLOGICAL OVERVIEW

The KUP area lies within the Eastern Mobile Belt of the southern Taranaki Basin (King and Thrasher, 1996) and includes the offshore part of the Manaia Anticline. In the east lies the Taranaki Fault, a major north–south-orientated crustal-scale thrust that has been episodically active since at least the mid Oligocene. The fault is interpreted to represent a basement terrane boundary (Figure 3 & Figure 4) with Murihiku terrane to the east being thrust over Brook Street terrane to the west (King and Thrasher, 1996; Mortimer et al., 1997; Bland et al., in prep.).

The Manaia Fault, running north-south through the central part of the area, is the major structure in the KUP area – a significant inversion lineament. Movement on this fault was initially normal from the Cretaceous to Late Paleocene, resulting in the deposition of a thick sedimentary sequence in the down-thrown area to the east of the fault. In the foot-wall block to the west, sediments of these ages thicken off to the northwest but are otherwise generally thin or absent (King and Thrasher, 1996). Movement on this and associated faults was reversed during the latest Eocene–Oligocene and peaked in the Late Miocene (Stagpoole and Nicol, 2008), with the subsequent formation of the Manaia Anticline (Figure 3; Fohrmann et al., 2012 – Map 2). Within the study area, the anticline has a Miocene uplift age. The main centre for deposition shifted to the west of the Manaia Fault as a result of this inversion.

Two other significant reversed faults (Rua and Motumate) have been interpreted in this area, and follow a similar tectonic history (Schmidt and Robinson, 1990). The Rua Fault is a major splay off the Manaia Fault, whereas the Motumate Fault is an antithetic structure to it, occurring in the west of the mapping area and separated from the Manaia Fault by the Waiokura Syncline.

Extensional faulting occurred during the Late Neogene as a result of back-arc extension (King and Thrasher, 1996), which has resulted, for example, in the compartmentalisation of the Kupe field. Some of these faults extend down to basement and are interpreted as reactivated Late Cretaceous–Paleocene faults.

Several regional unconformities have been identified within this area, which relate to the major tectono-stratigraphic events that define the broad geological evolution of Taranaki Basin, and follow sequence boundaries documented by King and Thrasher (1996).

The age of the oldest observed unconformity upon basement rocks (refer to Mortimer et al., 1997) is not constrained in the KUP area. The overlying initial basin-fill sediments are interpreted here to be pre-Pakawau Group (>80 Ma), and may be correlatives of Ngaterian-aged Taniwha Formation located in the north-eastern margin of the Taranaki Basin.

Three subsequent major regional unconformities related to major plate reorganisation and changes in stress fields define group boundaries in the KUP area. The oldest regional unconformity of known age occurs at the top of the Pakawau Group (Late Cretaceous–earliest Paleocene), the second occurs at the top of the Kapuni/Moa groups (base Oligocene) and the third major unconformity occurs at the base of the Rotokare Group (Late Miocene–Pliocene). This last event is interpreted as a regional re-orientation of the basin reflecting uplift of the adjacent land area. In general, maximum erosion occurred in the southern part of the area, with almost complete removal of the Paleogene and Neogene succession.

The thickest sedimentary succession occurs in the northeast of the mapping area, just south of the Taranaki Peninsula, where the basement rocks are interpreted to lie at a depth of >11
km. Over the crest of the Manaia Anticline, to the south of Tahi-1, the succession is interpreted to be ~2 km thick, with most of this thickness comprising rocks of Pliocene age.

Figure 3  Schematic map of the main structural features in KUP (yellow polygon).
Figure 4  Map of basement geology and structural elements of the Taranaki Basin and selected petroleum wells after Kroeger et al. (2012). Black polygons indicate fault planes at top basement. Extent of basement units modified from Mortimer et al. (1997) and structure from Thrasher et al. (1995). The extent of the KUP area is annotated (yellow polygon).
3.0 STRATIGRAPHIC FRAMEWORK

An allostratigraphic approach (North American Commission on Stratigraphic Nomenclature, 1983) has been adopted for this report, whereby seismic horizon picks refer to surfaces that bound regionally extensive, time-equivalent depositional sequences. Seventeen surfaces were mapped to reflect the tectonostratigraphic evolution of the KUP area. These bounding surfaces in places represent erosional and/or non-depositional unconformities and their correlative conformities and disconformities. For reflectors that represent significant amounts of missing time, their age is nominally assigned at the oldest part of the missing time (Figure 5). In other places, the bounding surfaces represent flooding events (transgressive event and/or maximum flooding, e.g. within the Plio-Pleistocene). This approach enables the seismic mapping of strata based on their chrono-stratigraphic relationship rather than their geographic extent or local lithostratigraphic affinity. In the KUP area, 16 allostratigraphic sequences are identified in seismic data and then correlated to well log data. These surfaces approximately equate to 3rd-order cycles of c. 1 m.y. to 10 m.y. periodicity (sensu Miall, 1997; Roncaglia et al., 2010).

The corresponding lithostratigraphic units and their age relationships within the overall Late Cretaceous to Pleistocene succession are shown in Figure 5 and summarised in Table 2. Locations of seismic cross-sections are annotated in Figure 6 and two representative seismic sections are shown in Figure 7 and Figure 8. There has been widespread erosion and removal of formations throughout the mapped area, particularly over the Manaia Anticline, so a complete or near-complete stratigraphic sequence is often difficult to locate (Roncaglia et al., 2010).

3.1 NAMING CONVENTION

This report follows the nomenclature established by Roncaglia et al. (2010) and Bland et al. (in prep.) as part of an on-going regional evaluation of the sequence stratigraphy of the Taranaki Basin utilising open-file seismic and well data, but will also refer to the more commonly established lithostratigraphic names found elsewhere in the literature, e.g., King and Thrasher (1996).

In summary, mapped horizons are numbered upwards, from oldest to youngest. Reflectors are also assigned a letter prefix, according to their overall age period (K = Cretaceous; P = Paleogene; N = Neogene to Quaternary) and a number suffix (10-80) with the exception of Basement and the Seabed. These reflectors mark the base of the respectively named sequences, which are bounded mainly by unconformities. Sequences are constrained by mapping seismic stratal terminations and identifiable seismic facies. Figure 5 represents an updated version of the stratigraphy in the KUP region compared to the one presented in Roncaglia et al. (2010), although reflector names and positions have not changed for the KUP region.

Allostratigraphic sequences are named according to the reflector at the base of the respective interval (Table 2). Where two or more mapped horizons merge into one, the youngest of these is taken as the horizon name as overlying sediments will be younger than that horizon.
Figure 5 Stratigraphy of the KUP area. The figure schematically illustrates the age relationship of laterally correlative lithofacies belts (lithostratigraphic units labelled as formations) distributed along an east to west chronostratigraphic transect across the KUP area. The 17 third-order allostratigraphic sequence-bounding horizons mapped in this study (Table 2) are labelled (K80–K90 for Late Cretaceous, P10–P60 for Paleogene, and N10–N80 for Neogene to Pleistocene). The reflectors are calibrated to NZ timescale stages, but their absolute age is approximate.
Table 2 Summary of the relationship between selected main interpreted seismic horizons in the KUP area and their lithostratigraphic correlatives (see Bland et al., in prep.), including boundary type and reflector type, and as tied to wells (Table 1). N/a = Not available. Reflectors that are stated in Figure 3 but not listed in this table have not been mapped.

<table>
<thead>
<tr>
<th>Group</th>
<th>Subgroup/Formation (Member)</th>
<th>Seismic surface for base</th>
<th>Seismic surface for top</th>
<th>Allostratigraphic sequence</th>
<th>Boundary type</th>
<th>Reflector type (SEG reverse)</th>
<th>Comments referring to base reflectors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seafloor</td>
<td>N/a</td>
<td>Peak</td>
<td>Erosional</td>
<td>N80</td>
<td>Reflector ‘muted-out’ in eastern KUP area.</td>
<td></td>
</tr>
<tr>
<td>Undifferentiated</td>
<td>N80</td>
<td>Seafloor</td>
<td>N80</td>
<td>Erosional</td>
<td>Peak</td>
<td>Unconformity at the base of undifferentiated Pliocene to Recent sediments. No well ties.</td>
<td></td>
</tr>
<tr>
<td>Whenuakura</td>
<td>N70</td>
<td>N80</td>
<td>N70</td>
<td>Conformable</td>
<td>Trough</td>
<td>The reflector occurs consistently 10–40 m above the lithostratigraphic upper boundary of the Tangahoe Formation in the wells.</td>
<td></td>
</tr>
<tr>
<td>Tangahoe</td>
<td>N60</td>
<td>N70</td>
<td>N60</td>
<td>Disconformable</td>
<td>Trough</td>
<td>The reflector correlates with the lithostratigraphic boundary between the Matemateaonga and Tangahoe formations.</td>
<td></td>
</tr>
<tr>
<td>Rotokare</td>
<td>Matemateaonga</td>
<td>N50/N52</td>
<td>N52/N60</td>
<td>Erosional/Disconformable</td>
<td>Zero-crossing/Peak</td>
<td>The N50 reflector marks an unconformity of Late Miocene age. The reflector N52 marks a distinct facies change within the formation.</td>
<td></td>
</tr>
<tr>
<td>Wai-iti</td>
<td>Mangaopa</td>
<td>N48</td>
<td>N50</td>
<td>Unconformable</td>
<td>Peak</td>
<td>In the KUP area this reflector approximates to the lithostratigraphic boundary between the Otunui Formation and Mangaopa member (sensu Bland et al., in prep.).</td>
<td></td>
</tr>
<tr>
<td>Otunui</td>
<td>N45</td>
<td>N48</td>
<td>N45</td>
<td>Conformable and erosional</td>
<td>Peak</td>
<td>The base of the Otunui Formation is poorly defined as it is gradational and the corresponding seismic event is at best an approximation.</td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>Subgroup/Formation (Member)</td>
<td>Seismic surface for base</td>
<td>Seismic surface for top</td>
<td>Allostratigraphic sequence</td>
<td>Boundary type</td>
<td>Reflector type (SEG reverse)</td>
<td>Comments referring to base reflectors</td>
</tr>
<tr>
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</tr>
<tr>
<td>Manganui</td>
<td>N10</td>
<td>N45</td>
<td>N10</td>
<td>Conformable</td>
<td>Trough</td>
<td>This horizon occurs consistently 30–65 m above the lithostratigraphic upper boundary of the Taimana Formation in the wells and it approximates the base of the Lower Manganui Formation.</td>
<td></td>
</tr>
<tr>
<td>Taimana</td>
<td>P60</td>
<td>N10</td>
<td>P60</td>
<td>Conformable</td>
<td>Peak</td>
<td>In the wells, this reflector correlates with the boundary between the Taimana and the Otaraoa formations.</td>
<td></td>
</tr>
<tr>
<td>Otaraoa</td>
<td>P50</td>
<td>P60</td>
<td>P50</td>
<td>Erosional</td>
<td>Peak</td>
<td>The reflector correlates to the lower boundary of the Otaraoa Formation in the KUP area. It coincides with the upper boundary of the Turi Formation west of the Manaia Fault.</td>
<td></td>
</tr>
<tr>
<td>Mangahewa</td>
<td>P30</td>
<td>P40</td>
<td>P30</td>
<td>Disconformable</td>
<td>Trough</td>
<td>The reflector is discontinuous but high in amplitude. The reflector represents a nominal boundary between the Kaimiro and Mangahewa formations, which are in part defined on age. The reflector P35 is correlated to coal measures of cycle D in the Kapuni Deep-1 well.</td>
<td></td>
</tr>
<tr>
<td>Kaimiro</td>
<td>P20</td>
<td>P30</td>
<td>P20</td>
<td>Erosional</td>
<td>Peak</td>
<td>In the KUP area, this reflector correlates to the upper boundary of the Farewell Formation in the wells. West of the Manaia Fault it represents a regional unconformity between the Late Paleocene and Early Oligocene.</td>
<td></td>
</tr>
<tr>
<td>Farewell</td>
<td>P10</td>
<td>P20</td>
<td>P10</td>
<td>Erosional</td>
<td>Peak</td>
<td>In the southern part of KUP area (Kupe South-4 and Tahi-1), this reflector occurs close to the upper boundary of the North Cape Formation.</td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>Subgroup/Formation (Member)</td>
<td>Seismic surface for base</td>
<td>Seismic surface for top</td>
<td>Allostratigraphic sequence</td>
<td>Boundary type</td>
<td>Reflector type (SEG reverse)</td>
<td>Comments referring to base reflectors</td>
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<tr>
<td>Pakawau</td>
<td>North Cape</td>
<td>K90</td>
<td>P10</td>
<td>K90</td>
<td>Conformable</td>
<td>Trough</td>
<td>This reflector correlates with the lithostratigraphic upper boundary of the Rakopi Formation and lower boundary of the North Cape Formation in well Tahi-1.</td>
</tr>
<tr>
<td></td>
<td>Rakopi</td>
<td>K80</td>
<td>K90</td>
<td>K80</td>
<td>Erosional?</td>
<td>Peak</td>
<td>This reflector marks an intra-upper Cretaceous event which is interpreted to lie stratigraphically below the lower boundary of the Rakopi Formation. There is no evidence of the age of the sediments above and below this unconformable event. The reflector K85 marks the base of the coaly packages on seismic profiles.</td>
</tr>
<tr>
<td></td>
<td>Undifferentiated Basement</td>
<td>K80</td>
<td>Pre K80</td>
<td>Erosional?</td>
<td>Peak</td>
<td></td>
<td>No study well intersects this reflector. Possible age equivalent to the Taniwha Fm encountered in the well Te Ranga-1.</td>
</tr>
</tbody>
</table>
Figure 6  Locations of seismic profiles illustrated through this report. Numbers on the map refer to figure numbers. Selected well locations are also shown.
Figure 7 Interpreted west–east composite seismic line (2D hzt82a-130, 3D XL2720 and 2D p95-500-2664), through the Toru-1 well. Formation tops and mapped reflectors are annotated; TD = termination depth. For location refer to Figure 6.
Figure 8 Interpreted north–south composite seismic line (2D p116-81-20, Kerry 3D IL2320 and 2D p116-83-13), through the Toru-1 and Tahi-1 wells. Formation tops are annotated; TD = termination depth. Seventeen allostratigraphic sequences are interpreted in the KUP region. The approximate seismic surfaces for the base of each sequence are annotated. The structural interpretation (thin black solid & dashed lines) reveals two sets of faults; 1) normal faults that relate to the extensional phase in the Late Cretaceous and 2) Plio-Pleistocene normal faults, relating to the back-arc extension of the Kupe region (Walcott, 1987; King and Thrasher, 1996). These late-stage normal faults have reactivated some of the Late Cretaceous faults. For location refer to Figure 6.
4.0 BASMENT

4.1.1 Seismic Sequence Character

For the purposes of this report, basement is defined solely by its seismic character—i.e. seismic basement—as rocks that could be construed as economic basement have not been encountered in any of the wells drilled within the mapping area (Appendix A – Figure 19 & Figure 20). It remains possible that economic basement lies deeper than the mapped top basement surface in some areas.

The top basement reflector is defined as the deepest, relatively continuous seismic reflector in the mapping area (Figure 8). However, even based on this definition, basement is difficult to pick in many areas within the KUP region as there is not always a strong impedance contrast recognisable on seismic data.

Basement in the KUP area shows signs of stratification. To the east of the Manaia Fault, the top basement reflector is often a strong and continuous reflector (Figure 9) underlain by an interval characterised by low amplitude, discontinuous, sub-parallel reflections.

To the west of the Manaia Fault, top basement is often poorly resolved, especially within the Pihama Sub-basin and the Waikoura Syncline (e.g. Figure 10). In that area, top basement was mainly defined on north–south lines using a grey-scale colour bar as it best highlighted the deepest, strongest, and most continuous impedance contrast.

Generally, interpretation and mapping of the seismic basement is restricted within the KUP area for a variety of reasons. These include:

- Insufficient record length—the Kerry 3D data set is less than 5 s record length,
- poor imaging due to its depth (>5000 m),
- loss of signal due to overlying coal-bearing sequences (Figure 9),
- complex ray paths in the vicinity of the major reverse faults.

4.1.2 Stratigraphic Equivalent

To the east of the Manaia Fault, the basement interval is interpreted to contain metasedimentary rocks and is tentatively correlated with the Brook Street terrane (4.1.2; Mortimer et al., 1997; Kroeger et al., 2012).

Correlation from far offset wells of the Maui and Maari area, and inferences from regional trends, suggests that the Motumate Fault is a terrane boundary, separating plutonic rocks of the Median Batholith (formerly referred to the Median Tectonic Zone, Figure 4) to the west, from low-grade meta-sedimentary basement rocks of the Brook Street terrane, to the east (Figure 4; Kroeger et al., 2012). The Median Batholith is traceable on seismic data from the Central region (CEN; Figure 1) into the Kupe region to the Motumate Fault and with less certainty eastwards to the Manaia Fault (Figure 7, Kroeger et al., 2012). There are no wells that penetrate the Brook Street terrane that can be traced westwards into the KUP area.

A clear terrane boundary separating the Median Batholith from the putative Brook Street terrane is also not identifiable; the change in seismic reflection character from east to west is rather subtle.
4.1.3 Distribution and Depth

Where the top seismic basement event can be mapped with confidence, the surface displays an overall dip to the northeast that is obliquely offset by the north-trending Manaia Fault. Basement rocks are interpreted to lie at depths of between ~2000 m bsl over the crest of the Manaia Anticline to >11,000 m bsl at the coastline near the Rimu-Kauri Field.

Figure 9 Inline 2240 (Kerry 3D volume), showing the seismic character and stratigraphic relationships of basement and overlying Cretaceous–Paleogene rocks in the KUP area, east of the Manaia Fault. Undifferentiated mid-Late Cretaceous rocks are inferred to immediately overlie basement. The top of this package is approximated by the K80 horizon. The K85 horizon marks the base of a coaly succession that forms the upper part of the Rakopi Formation in this area.
5.0 LATE CRETACEOUS

Three seismic sequences (pre-K80, K80, and K90) have been identified within the Late Cretaceous succession (Figure 9). A complete Late Cretaceous sequence has not been drilled within the KUP area. The oldest Cretaceous sediments were logged in the Tahi-1 well and are of Haumurian age (Figure 5, Pocknall, 1984; Roncaglia et al., 2008) assigned to the PM2 Zone (Browne et al., 2008).

5.1 UNDIFFERENTIATED MID LATE CRETACEOUS SEQUENCE (PRE K80 SEQUENCE)

5.1.1 Seismic Sequence Character
The Pre-K80 sequence (Fohrmann et al., 2012 – Maps 4 & 21) extends between the mapped basement horizon, upon which it lies unconformably, and the K80 horizon. The upper surface (K80) of this sequence is also an unconformity in places, whereas elsewhere it appears to be a correlative conformity (see Section 5.2.1).

The pre-K80 sequence is characterised by hummocky and laterally discontinuous, low-amplitude reflections (Figure 9). However, overall poor data quality prevents a detailed seismic analysis of the pre-K80 interval. The depositional history of this interval is complex as around the Manaia and Rua faults the internal reflections are folded and faulted.

5.1.2 Stratigraphic Equivalent
This mapped pre-K80 interval was introduced to subdivide the locally thick Late Cretaceous succession (Figure 9). It represents the oldest interpreted sedimentary sequence in the KUP area. However, the pre-K80 sequence has not been drilled by any of the wells in the region, so no explicit age and lithological constraints can be given. The interval is thought to contain the earliest syn-rift deposits of mid-Late Cretaceous (>80 Ma) age, as overlying formations are dated as younger than this (Roncaglia et al., 2008).

For the purposes of this report we refer to the pre-K80 package as undifferentiated Late Cretaceous strata. It may be a time-equivalent interval to the Taniwha Formation encountered further north in well Te Ranga-1 (Higgs et al., 2007), but there is no evidence confirming this and a direct correlation between the areas is not possible due to insufficient seismic ties. Nevertheless, the earliest syn-rift interpretation of these strata is compatible with observations from Bierbrauer et al. (2008) for the Taniwha Formation around the Te Ranga-1 well, and also with other on-going work within the Taranaki Basin (Hemmings-Sykes, 2011; Fohrmann et al., in prep.).

5.1.3 Distribution and Thickness
The Pre-K80 sequence is only present east of the Manaia Fault (Figure 21) and thickens slightly (from ~1000 m to 1500 m) towards the Taranaki Fault in the southern part of the mapping area.

5.2 LATE CRETACEOUS (K80 SEQUENCE)

5.2.1 Seismic Sequence Character
The K80 sequence (Fohrmann et al., 2012 – Maps 5 & 22) nominally extends between the K80 and K90 horizons. The basal K80 reflector is characterised as a high-amplitude horizon
that is only present to the east of the Manaia Fault (Figure 7, Figure 8, & Figure 9). The contact to the underlying sequence appears to be erosional in some places (e.g. Figure 9 between shot points 1400–1600), though the low-frequency content of the seismic data at that depth often makes the identification of stratal relationships difficult. The K80 sequence can be seismically distinguished from the underlying pre-K80 sequence by its generally more coherent reflectors. In areas where the pre-K80 sequence is absent, the base of the K80 sequence is marked by the top basement (unconformity) surface. In southern parts of the mapping area, where the upper Cretaceous and most of the Paleogene and Neogene succession has been eroded, the N50 reflector marks the upper contact of the K80 interval.

The K80 sequence has differing character east and west of the Manaia Fault. East of the Manaia Fault, the K80 sequence can be split into two units. The upper unit contains high-amplitude hummocky reflections interpreted as coaly sequences. The lower interval is acoustically transparent and is interpreted to possibly represent a marginal-marine to marine sequence (Figure 9). The units are separated by the K85 horizon. However, this horizon was not mapped for this study; it was only picked in areas where coaly packages can be inferred from seismic to provide additional control for basin modelling purposes.

West of Manaia Fault, the K80 sequence is not as distinctive in seismic character, with amplitudes being generally lower than on the eastern side. This change in reflection character is interpreted to be caused by the absence of coaly packages and a different depositional environment. The K85 horizon could therefore not be mapped to establish an intra-K80 stratigraphy in this area. In areas where the top of the sequence displays high amplitudes, these reflectors are relatively continuous (Figure 10).

5.2.2  Stratigraphic Equivalent

The K80 sequence in the KUP area encompasses the Rakopi Formation of the lower part of the Pakawau Group. The formation is considered to be the lowest stratigraphic unit with widespread distribution within graben structures across the Taranaki Basin (King and Thrasher, 1996). The Rakopi Formation has generally been interpreted based on its seismic character, in particular high-amplitude facies, reflecting coal-rich strata. In the KUP area, the upper (high amplitude) and lower (low amplitude) seismic units of the K80 sequence are correlated with the Rakopi Formation.

Within the KUP area, the Rakopi Formation has only been encountered in the Tahi-1 well, where it is least-deeply buried. This well penetrated non-marine silty sandstones, with coal seams in the upper 385 m of the formation only, without reaching its base.

5.2.3  Distribution and Thickness

To the east of Manaia Fault, the K80 sequence (Rakopi Formation) is between 1000–1500 m thick beneath the Manaia Anticline and ~ 500 m thick to the east of it (Fohrmann et al., 2012 – Map 38). The upper, coaly part of the formation is generally ~300–500 m thick and the top of the formation varies between ~2000 m bsl on the crest of the Manaia Anticline, to ~ 8500 m bsl beneath the south Taranaki coastline (Fohrmann et al., 2012 – Map 5).

To the west of Manaia Fault the K80 sequence is much thinner (0 to ~400 m thick; Fohrmann et al., 2012 – Map 38) and generally lies at depths of ~5500–7500 m bsl (Fohrmann et al., 2012 – Map 5). This difference in thickness is attributed to the syn-depositional topography controlling deposition patterns, with the thickest intervals deposited within the Pihama Sub-Basin, with the unit thinning onto the adjacent Otakeho High (Strogen, 2011).
5.3 **LATEST CRETACEOUS (K90 SEQUENCE)**

5.3.1 **Seismic Sequence Character**

The K90 sequence nominally extends between the K90 and P10 horizons. In the southern part of the mapping area extensive erosion during the Miocene has truncated the top of the sequence, which is here represented by the N50 reflector.

To the east of the Manaia Fault, the K90 reflector generally marks the boundary between the very distinctive underlying interval of bright and laterally discontinuous reflectors (coal-rich upper unit of K80 sequence), and an overlying interval of relatively bland seismic character, reflecting an increasing marine influence (Figure 9).

Around the Toru-1 well, the high-amplitude K90 reflector becomes very continuous (Figure 8). To the west of the Manaia Fault, the reflector is less consistent and more variable in amplitude (Figure 10).

The K90 sequence reflects a general south-directed transgression, with shallow-marine seismic reflection facies onlapping basement highs.

5.3.2 **Stratigraphic Equivalent**

The K90 sequence represents latest Cretaceous deposits, and corresponds to the North Cape Formation (Suggate, 1956) of upper parts of the Pakawau Group. The formation is present across most of the northern and central part of the KUP area (Appendix A, Figure 22 & Figure 23).

The North Cape Formation was only encountered in two of the wells within the KUP area. The upper parts of the formation were penetrated in the Kupe South-4 well, and erosionally truncated lower parts of the formation were reached in Tahi-1. The interval comprises marginally-marine, nearshore siltstone and sandstone facies (Roncaglia et al., 2008).

5.3.3 **Distribution and Thickness**

The distribution and thickness of the K90 sequence is controlled by the Manaia Fault and Miocene erosion (Strogen, 2011). Syn-depositional movement along the Manaia Fault has resulted in sediment thicknesses of around ~2000 m immediately east of the fault. In the south (south of Tahi-1) and to the west of Manaia Fault, the sequence is either thin or absent as a result of non-deposition or erosion (Figure 24).

In the Pihama sub-basin (Figure 3), in the northwest of the study area, the K90 sequence is up to ~1000 m thick (Appendix A, Figure 24).

5.4 **LATE CRETACEOUS INTERVAL–SYNTHESIS**

The age of the deepest (pre-K80) sequence in the KUP area is unknown, but it might be a time equivalent of the Taniwha Formation (earliest Late Cretaceous; c. 100–95 Ma) encountered in Te-Ranga-1 (Shell BP & Todd Oil Services Ltd, 1986; Higgs et al., 2007). The pre-K80 sequence could also potentially be somewhat younger than this. Its upper contact, the K80 horizon, is an unconformity, the youngest age of which is inferred to be mid Late Cretaceous (~80 Ma). This horizon represents the base of the Pakawau Group, which comprises the Rakopi (K80) and North Cape formations (K90; Table 2, Figure 9 & Figure 10). These formations are interpreted as syn-rift deposits and contain mixed terrestrial and
marine lithologies (King and Thrasher, 1996). The top of the North Cape Formation is interpreted to approximate the top Cretaceous (King and Thrasher, 1996).

Figure 10 Seismic character and stratigraphic relationships of Cretaceous–Paleogene rocks on line hzt82a-126. The top basement pick is associated with a high uncertainty in the vicinity of the Motumate Fault (see text for details) and was defined on north–south-trending lines. To the west of the Motumate Fault, an interval of the K80 sequence (top marked by K90, equivalent to the Late Cretaceous Rakopi Formation) directly overlies basement. A well-developed Eocene section interval is also shown between the P20 and P50 reflectors.
6.0 PALEOCENE

The Paleocene interval is represented by the P10 sequence (Figure 10). The Cretaceous-Tertiary boundary (65 Ma) corresponds to the P10 reflector, which separates the Pakawau Group from the Kapuni Group. The Paleocene-Eocene boundary (55 Ma) is defined by the P20 event (Figure 5).

6.1 PALEOCENE (P10 SEQUENCE)

6.1.1 Seismic Sequence Character

The P10 sequence extends between the P10 horizon, upon which it lies unconformably, and the P20 horizon. The P10 event is characterised as a medium- to high-amplitude, regionally-extensive reflector. Over the Manaia Anticline, the contact with the underlying sequence appears conformable (Figure 11); however, in places the contact exhibits an erosionally-truncated architecture with the underlying packages (Figure 12).

The P10 sequence consists of cycles of high-amplitude, continuous to semi-continuous reflectors, interleaved with intervals of low-amplitude, semi-discontinuous reflectors (Figure 11).

6.1.2 Stratigraphic Equivalent

The P10 sequence corresponds to the Farewell Formation in the KUP area (King and Thrasher, 1996), which represents the lowest formation within the Kapuni Group (Fohrmann et al., 2012 – Maps 7 & 24). The Teurian-Waipawan boundary (55 Ma) at the top of the formation corresponds to the P20 reflector (Figure 8, Bland et al., in prep.).

The sequence encompasses the primary reservoir interval in the Kupe Field, where it unconformably overlies the North Cape Formation and consists of terrestrial and marginal-marine facies (Roncaglia et al., 2008).

6.1.3 Distribution and Thickness

The P10 sequence is thickest in the north and east of the mapping area, reaching up to ~2000 m immediately adjacent to the Manaia Fault, which was an active normal fault downthrown to the east at the time of deposition. To the west of the fault the formation is thinner, generally less than 500 m thick, and is absent across much of the Otakeho High.

To the southwest of the mapping area, remnants of deposits overlying basement are interpreted as back-filling of valley systems that were incised during preceding lowstands; however, no age information is available regarding these sediments (Fohrmann et al., 2012 – Map 40).

The sequence is usually unconformably overlain by strata of the Oligocene Otaraoa Formation. Exceptions occur in the north and northwest of the KUP region, such as around the wells Toru-1 and Kupe-1, where the Farewell Formation is disconformably overlain by rocks of Eocene age. The formation is not present in the Tahi-1 well due to subsequent erosion. In the Kupe South-4 well, only the basal part of the formation was encountered.
6.2 PALEOCENE INTERVAL–SYNTHESIS

The P10 sequence is interpreted to have been deposited across most of the northern and central parts of the KUP area (Fohrmann et al., 2012 – Map 40), but was subsequently eroded over most of the southern part during the Late Eocene-Early Oligocene and/or Late Neogene (Strogen, 2011). Isolated pockets of possible Paleocene age remain in fault-controlled sub-basins adjacent to the Motumate Fault, although this interpretation remains uncertain, and these deposits may also be of Eocene age.

![Figure 11](image_url)

Figure 11 Seismic profile (Inline 2400, Kerry 3D) through the Paleocene succession in the KUP area. A complete succession of P10 sequence (Farewell Formation) occurs only in the hanging wall of the Manaia Fault, where it is overlain by the P20 sequence of the Kaimiro Formation (Early Eocene). Elsewhere within the KUP area, the true top of this unit is truncated by the P50 unconformity. The Paleocene Farewell Formation shows cyclic intervals of higher-amplitude reflectors, separated by blander sequences of discontinuous reflectors.
7.0 EOCENE

Two seismic sequences (P20 and P30) have been identified encompassing the Eocene succession, separated by the P30 reflector (Figure 10).

7.1 EARLY EOCENE (P20 SEQUENCE)

7.1.1 Seismic Sequence Character

The P20 sequence can be seismically identified by its ‘wormy’ character, displaying medium to high amplitude but discontinuous reflectors (Figure 12). The base of the sequence is marked by the high amplitude P20 reflector, which represents a major unconformity in the KUP area that spans most of the Eocene.

7.1.2 Stratigraphic Equivalent

The P20 sequence encompasses the Kaimiro Formation (Early to early Middle Eocene) in the KUP area, a part of the Kapuni Group, and consists of terrestrial to marginal marine clastic lithofacies and coals (Palmer, 1985; Roncaglia et al., 2008; Fohrmann et al., 2012 – Maps 8 & 25).

This interval has been drilled in the Toru-1 well, where it is overlain by the Oligocene-aged Otaraoa Formation (Roncaglia et al., 2008), and also in the Kupe South-4 well, where 5 m of Eocene-aged rocks were encountered (Bland et al., in prep.). It is absent in all other wells in the mapping area.

The Kaimiro Formation has erosional contacts with the underlying Farewell Formation and overlying Mangahewa Formation (late Middle to Late Eocene). The upper part was extensively eroded during the latest Eocene–Early Oligocene, producing the P50 unconformity horizon (Figure 12). Where the Mangahewa Formation is absent, the top of the Kaimiro Formation is defined by the P50 reflector (Bland et al., in prep.) and is overlain by the Otaraoa Formation (Oligocene).

The sequence differs from the underlying Farewell Formation in well logs, in that it has a blockier gamma log signature and decreased resistivity values (Roncaglia et al., 2008).

7.1.3 Distribution and Thickness

The P20 sequence is interpreted to have been deposited in the northern part of the KUP area on both sides of the Manaia Fault. Post-depositional erosion has removed much of the formation’s thickness, particularly in the southern parts of the KUP area. It is thickest in the north, immediately west of the Manaia Fault, where it is up to 400 m thick. Elsewhere, it averages ~100–300 m in thickness (Fohrmann et al., 2012 – Map 41).

The formation has been identified around the Kupe South-4 well, but as it is below seismic resolution (~5 m thick), it is not seismically interpretable in this area. The P20 reflector has also been interpreted at the Kupe-1 well, but sediments overlying this horizon are younger in age (Bortonian–Kaiatan) and are therefore part of the Mangahewa Formation, not the Kaimiro Formation.

The present-day distribution of the Kaimiro Formation in the study area is probably a consequence of post-depositional erosion and non-deposition with southerly onlap/offlap towards the edge of the depositional basin.
7.2 MIDDLE EOCENE–LATE EOCENE (P30 SEQUENCE)

7.2.1 Seismic Sequence Character

The P30 sequence encompasses high-amplitude reflections bounded by erosional contacts with the adjacent formations. The bright reflective packages are inferred to be coal-bearing coastal plain lithologies, one of which (P35 reflector, Figure 12) is correlated to the coal measures of cycle D in the Kapuni Deep-1 well (Shell BP & Todd Oil Services Ltd, 1984). This reflector was used as a guide to map the extent of the formation in the KUP area.

![Figure 12](image)

Figure 12 The seismic character of the Late Cretaceous Pakawau Group and Paleocene–Eocene parts of the Kapuni Group in the KUP area (Line hzt82a-127). The P20 sequence encompassing the Kaimiro Formation (Early to early Middle Eocene) is overlain by the P30 sequence or Mangahewa Formation (late Middle to Late Eocene). The P35 horizon approximates a succession of highly reflective strata that may represent coaly rocks.

7.2.2 Stratigraphic Equivalent

The chronostratigraphic interval of the P30 sequence encompasses the Mangahewa Formation (Palmer, 1985) and Turi Formation (King and Thrasher, 1996). Within the KUP area, however, the P40 reflector associated with the top of the Mangahewa Formation has not been identified due to extensive erosion associated with the Early Oligocene–Late Miocene unconformity (the P50 reflector). The P50 reflector is inferred to represent the ‘top’ of the Mangahewa Formation (see section 8.1) within the KUP area. The formation has not been identified in any of the wells drilled within the KUP area except Kupe-1, where it is below seismic resolution (~30 m) and consequently has not been mapped.
The P30 sequence unconformably overlies the P20 sequence and the top of the P30 sequence is erosionally overlain by a variety of younger formations.

7.2.3 Distribution and Thickness

The P30 sequence has only been mapped in the north-western part of the KUP area, where it reaches a maximum thickness of ~300 m. It is interpreted to have been deposited across most of the northern part of the KUP area, but was subsequently eroded during the Early Oligocene–Late Miocene. This interpretation is supported by thin deposits of Bortonian–Kaiatan age in Kupe-1. Elsewhere, the sequence is interpreted not to have been deposited—the feather edge of the formation is interpreted to run through the central parts of the KUP area (Appendix A, Figure 25).

7.3 Eocene Interval – Synthesis

The base of the Eocene succession is interpreted to represent a relative sea-level fall in which coastal plain facies have been deposited in the KUP area. The following transgression during the Middle to Late Eocene led to the landward progradation of marine mudstones of the Turi Formation, however, it is uncertain if the transgression reached as far as to the northwest corner of the mapping area.

8.0 Oligocene and Early Miocene

Two sequences (P50 and P60) are recognised within this interval. The basal P50 reflector of the P50 sequence represents a major unconformity within the KUP area.

8.1 Base Ngatoro Group Unconformity (P50)

8.1.1 Seismic Sequence Character

The P50 reflector (Appendix A, Figure 26 & Figure 27), is one of the most prominent seismic reflectors in the Taranaki Basin (Figure 13) and corresponds to a regionally-extensive unconformity across much of the southern part of the Taranaki Basin, as a result of regional uplift and peneplanation.

The P50 reflector is a high-amplitude regionally continuous reflector that defines the base Ngatoro Group unconformity. To the east of the Manaia Fault the unconformity is highly angular (Figure 8).

8.1.2 Stratigraphic Equivalent

Well information shows that within the KUP area the P50 reflector defines the base of Whaingaroan strata (Figure 5) and is overlain by sediments of Late Whaingaroan age. The erosion associated with this unconformity has removed Paleocene to Eocene-aged rocks from across most of the area, though in the southern part of the KUP area subsequent Late Miocene erosion has removed this surface. It is thought that the P50 unconformity represents a period of around 4 m.y.

8.1.3 Distribution

The P50 horizon has been mapped across most of the KUP area, except around Tahi-1, where it has been removed by subsequent Late Miocene erosion (section 10.0). Maximum
erosion of around 200–300 m is interpreted to have occurred east of the Kupe South-4 well (Fohrmann et al., 2009).

8.2 EARLY – LATE OLIGOCENE (P50 SEQUENCE)

8.2.1 Seismic Sequence Character

The P50 sequence consists of well-defined laterally continuous reflections. Reflectivity within the sequence decreases towards the top, with basal reflectors being generally more continuous and of higher amplitude than those in the upper part. The acoustically transparent top distinguishes the P50 sequence from the overlying P60 sequence (Figure 13).

8.2.2 Stratigraphic Equivalent

The P50 sequence encompasses the Otaraoa Formation of the Ngatoro Group (Palmer, 1985) in the KUP area (Fohrmann et al., 2012 – Maps 10 & 27). The sequence was probably deposited over the whole study area, but subsequently eroded (absent in the Tahi-1 well) in the southern part during the Late Neogene.

The late Whaingaroan to Waitakian sequence, dominated by marine mudstones deposited in a upper slope to mid bathyal environment (Roncaglia et al., 2008), unconformably overlies the Paleocene Farewell Formation in the KUP area wells, except for the Toru-1 and Kupe-1 wells. There, the Matapo Sandstone Member (basal Otaraoa Formation) unconformably overlies an erosionally truncated interval of Kaimiro Formation (Toru-1). In Kupe-1 the Matapo Sandstone Member unconformably overlies a thin Mangahewa Formation interval (Mid-Late Eocene, Roncaglia et al., 2008).

8.2.3 Distribution and Thickness

The Otaraoa Formation is widespread across the KUP area, although it is absent in the south-eastern parts of the area. The Otaraoa Formation is typically ~200–600 m thick with thicknesses exceeding 800 m within the footwall areas of the Taranaki Fault in the northeast and southeast corners of the mapping area, respectively (Fohrmann et al., 2012 – Map 43). The sequence thickens slightly on the footwall sides of the Manaia and Taranaki faults, indicating that the faults were active at that time. The Motumate Fault has little impact on thickness of the formation, suggesting that it was inactive at this time (Figure 7).

8.3 LATEST OLIGOCENE–EARLIEST MIocene (P60 SEQUENCE)

8.3.1 Seismic Sequence Character

The P60 sequence is characterised by low–amplitude, discontinuous reflections in its lower part, and a few high-amplitude continuous reflections at the top of the sequence. The sequence conformably and gradationally overlies the Otaraoa Formation (Figure 7).

The top of the P60 sequence is a sequence boundary that separates the Ngatoro and Wai-iti groups.

8.3.2 Stratigraphic Equivalent

The P60 sequence encompasses the Waitakian to Otaian Taimana Formation of the Ngatotro Group (King, 1988a, b; Roncaglia et al., 2008). It is dominated by calcareous marine mudstones from a predominantly upper to middle slope setting. In the south of the KUP area, the top of the sequence is defined by the N50 reflector, which formed as a result of Late
Neogene erosion. In the KUP area the sequence is conformably overlain by the N10 sequence, corresponding to the Manganui Formation of the Wai-iti Group, (Roncaglia et al., 2008).

### 8.3.3 Distribution and Thickness

The P60 sequence occurs over most of the KUP area, except for southern parts of the Manaia Anticline where it has been eroded during the Late Neogene (Fohrmann et al., 2012 – Maps 11 & 28).

The formation shows an overall thickening from west (100–200 m) to east (~700 m), but typically averages 200–500 m (Fohrmann et al., 2012 – Map 44). Localised thickening in the footwalls of the Manaia and Taranaki faults is interpreted to have resulted from syn-depositional reverse faulting.

![Figure 13](image)

**Figure 13** The seismic character of Oligocene and early Neogene strata within the KUP area (Line k89-1009). The P50 sequence (Otaraoa Formation) comprises weak but very continuous reflectors. Close to the Taranaki Fault the reflections become brighter but less continuous. Note the thickening of the P50 sequence towards the fault. The Taimana Formation, which lies below the N10 horizon, is low in reflectivity and reflectors are in general discontinuous.
8.4 **LATEST OLIGOCENE - EARLIEST MIOCENE INTERVAL – SYNTHESIS**

Two sequences (P50 and P60) are recognised within this interval. This succession comprises the Otaraoa (Palmer, 1985) and Taimana formations (King, 1988a, b) of the Ngatoro Group. The Tikorangi Formation (Figure 5), which lies between these two formations to the northwest, is absent in the KUP area. Two seismic horizons (P50, P60) have been identified and correlated to the wells within the KUP area over this interval. The P50 reflector represents the base of the Whaingaroan Stage (~ base Oligocene) and the P60 reflector represents approximately the base of the Taimana Formation (Figure 13).

9.0 **EARLY–LATE MIOCENE**

Three seismic sequences (N10, N45, & N48) associated to the Miocene Wai-iti Group have been identified and correlated to the wells within the KUP area over this interval.

9.1 **EARLY–MIDDLE MIOCENE (N10 SEQUENCE)**

9.1.1 **Seismic Sequence Character**

The N10 sequence is well defined at its base by the N10 reflector and is internally characterised by moderate to high amplitude, laterally discontinuous seismic reflectors. The top of the sequence is poorly defined, as there is no single continuous reflector corresponding to the N45 event, which is picked at the top of multi-incision channel deposition and erosion. This interpretation corresponds with the well results, which show the formation to be conformably overlain by similar lithologies. To the south-west of the Manaia Fault, isolated submarine channels are also identified in the basal part of the N10 sequence. In the southern part of the mapping area the shelf-slope to basin-floor transition is seismically imaged. The upper part of the sequence consists of well-stratified continuous reflections, which are frequently cut by channels (1 km–10s km in width).

9.1.2 **Stratigraphic Equivalent**

The N10 sequence in the KUP area encompasses the Manganui Formation of the Wai-iti Group. The Manganui Formation is informally subdivided into “lower” and “upper” Manganui Formation, where a “lower Manganui Formation” has been applied to the interval between the Taimana and Moki Formations, (the Otaian–Lillburnian interval), and an “upper Manganui Formation” is applied to the Waiauan–Kapitean section (Roncaglia *et al.*, 2008; Bland *et al.*, in prep.). The lower part of the N10 sequence comprises deep water mudstones and basin-floor sandstones of the Moki Formation.

In the KUP area, the N10 sequence conformably, but diachronously overlies the Taimana Formation. The relationship between seismic horizons and lithostratigraphic boundaries, particularly in terms of age, remains poorly known in most parts of the mapping area.

The base of the Manganui Formation (base of the Wai-iti Group) is defined by the N10 reflector and its ‘near’ top by the N45 reflector.

9.1.3 **Distribution and Thickness**

The N10 sequence of the lower Manganui Formation has been mapped across most of the KUP area (Fohrmann *et al.*, 2012 – Maps 12 & 29). It was encountered in all wells except for Tahi-1, where it was most probably deposited but subsequently removed by erosion in the Late Miocene.
The sequence has a complex and largely fault-controlled distribution. It is thickest immediately west of Manaia Fault (up to 3000 m), and thins (~1000 m) towards the north-western limit of the KUP area. East of Manaia Fault, the sequence is between 500–1000 m thick, and thickens to ~1500 m towards the Taranaki Fault in the northeast of the mapping area (Fohrmann et al., 2012 – Map 45). This demonstrates that both the Taranaki and Manaia faults were active as reverse faults through this time and also that the degree of thickening towards the faults was more severe than seen in the Oligocene (P50, P60).

In the southern part of the KUP area, erosion at the end of the Miocene has removed most of the formation, along the crest of the Manaia anticline between Kupe South-5 and Tahi-1. Elsewhere, the formation passes conformably and gradationally up-section into calcareous mudstone of the Otunui Formation.

9.2 MIDDLE MIocene – LATE MIocene (N45 SEQUENCE)

9.2.1 Seismic Sequence Character

On the seismic data, the N45 sequence can be split into a lower part of patchy reflectivity and discontinuous reflectors, and an upper sequence characterised by weak but continuous reflectors (Figure 14).

The sequence lies conformably on the underlying N10 sequence as shown from well data, but its base is poorly defined on seismic data.

9.2.2 Stratigraphic Equivalent

The N45 sequence encompasses the Otunui Formation (Gerritsen, 1994; Kamp et al., 2004; Vonk and Kamp, 2008) of the Wai-iti Group in the KUP area and it is represented by calcareous mudstones of the lower Waiauan interval (Roncaglia et al., 2008). The N45 reflector is interpreted as the ‘near’ base of the Otunui Formation. The formation is inferred to pass laterally into bathyal mudstones of the Manganui Formation to the north and west of the KUP area.

Where Neogene erosion has not removed the upper part of the Otunui Formation, the N48 reflector (Figure 14) is interpreted as the ‘near’ top of the formation. Elsewhere the N50 reflector defines the top of the sequence.

9.2.3 Distribution and Thickness

The N45 sequence is interpreted to have been deposited across the whole of the KUP area, but subsequent erosion during the Late Miocene has removed it from south-eastern parts of the area (Fohrmann et al., 2012 – Maps 13 & 30).

The formation is thickest within the foot walls of the Taranaki Fault (~1000 m thick) and the Manaia Fault (up to ~1600 m thick). The formation is thinnest on the crest of the Manaia Anticline, thinning southwards from ~500 m thick at the Toru-1 well to between 300–530 m over the crest of the Manaia Anticline, and is absent at the Tahi-1 well. As the boundaries of the Otunui Formation are poorly defined across the KUP area, the thickness of the formation outside the Kupe field area is uncertain (Fohrmann et al., 2012 – Map 46).

Over the crest of the Manaia Anticline, the Otunui Formation conformably overlies the Manganui Formation and is overlain conformably or erosionally by the Mangaoapa Member of the Kiore Formation. In the south of the KUP area, the top of the Otunui Formation is
defined by the so-called “base-Rotokare Group” unconformity—the N50 surface—and is unconformably overlain by late Neogene rocks of Matemateaonga Formation. Elsewhere, in the surrounding synclines, the Otunui Formation is conformably bounded by surrounding sedimentary rocks (Bland et al., in prep.).

Figure 14  The seismic character of the Wai-iti Group (early to middle Neogene) in the KUP area (Composite line p116-81-04 (west) and X-line 1360 (Kerry 3D, east). The Miocene section thickens into the Waikura Syncline west of the Manaia Fault. Note the high amplitudes in the upper part of the Miocene section (above the N48 horizon), and the only slightly erosive nature of the N50 horizon (base Rotokare Group unconformity) in this area. The N10–N50 interval thickens dramatically across the Manaia Fault.

9.3  LATE Miocene (N48 SEQUENCE)

9.3.1  Seismic Sequence Character

The base of the N48 sequence is often poorly defined on the seismic data, due to the overall gradational and conformable transition up-section (section 9.2).

In general, the N48 event separates a package of patchy reflectivity and discontinuous reflectors from an overlying sequence that is characterised by weak but continuous reflectors (Figure 14).
The N48 sequence conformably overlies the N45 sequence with ravinement surfaces eroded into the underlying sediments across the Manaia Anticline. They correspond to channels cut during periods of low sea level.

The top of the N48 sequence, which is extensively eroded, corresponds to the N50 reflector.

9.3.2 Stratigraphic Equivalent

The N48 sequence in the KUP area is associated with the Mangaoapa Member, a member of the Kiore Formation (Wai-iti Group; Bland et al., in prep.) as a replacement for "Kiore Formation-equivalent", as used by Roncaglia et al. (2008). The N48 reflector corresponds to the ‘near’ base of the formation.

To the north of the KUP area, the N48 sequence passes into mudstones and submarine channel deposits of the Urenui Formation. To the west of the KUP area, the N48 sequence passes laterally into undifferentiated mudstones of the Manganui and Urenui Formations (Bland et al., in prep.).

The upper part of Mangaoapa Member has been eroded by the “base-Rotokare Group unconformity” (section 10.1) and is overlain by the N50 sequence.

9.3.3 Distribution and Thickness

The N48 sequence is present in northern parts of the KUP area and is absent in southern parts due to a combination of non-deposition and post-depositional erosion during the Late Miocene–Early Pliocene (Appendix A – Figure 28; Strogen, 2011). The sequence thins southwards across the KUP area, from 600 m in the northwest to 0 m within the Kupe field area and is absent across the southern part of the KUP area. It is thickest within the core of the Waiokura Syncline, between the Manaia and Motumate faults (Figure 3), where it is up to 950 m thick. To the east of the Manaia Fault the member is thinner, between 100–200 m thick.

9.4 MIDDLE MIocene - LATE MIocene INTERVAL – SYNTHESIS

Four seismic horizons (N10, N45, N48, & N50) encompass the Wai-iti Group within the KUP area. The N10 horizon defines the base of the Wai-iti Group (King and Thrasher, 1996) and the top (Early–Late Tongaporutuan) is marked by a significant angular unconformity, the N50 reflector or the so-called “base-Rotokare Group unconformity” (Bland et al., in prep.). The N45 and N48 horizons approximate formation boundaries in the KUP area, but are generally poorly defined on the seismic data.
Figure 15  The seismic character of the Wai-itī and lower parts of the Rotokare Groups (early to late Neogene) in the northwest of the KUP area (Line hzt82a-140). The Wai-itī Group lies between the N10 and N52 reflectors. Channels are commonly observed below the N45 event and are inferred to be of Middle Miocene age.

10.0 LATEST MIOCENE / PLIOCENE – RECENT

Four seismic sequences (N50, N60, N70 and N80) have been identified within the latest Miocene to Recent succession (Figure 16) across the KUP area. The corresponding basal reflectors define boundaries within the Rotokare Group.

10.1 BASE-ROTOKARE GROUP UNCONFORMITY (N50)

10.1.1 Seismic Sequence Character

The N50 reflector corresponds to a high-amplitude, laterally continuous horizon, which marks a strong angular unconformity between the underlying Cretaceous to Late Miocene rocks and the overlying latest Miocene to Recent rocks.
10.1.2 Stratigraphic Equivalent

The base-Rotokare Group unconformity (N50; Appendix A – Figure 29 & Figure 30), a regional erosional unconformity, occurs at the end of the Miocene at approximately the Tongaporutuan to Kapitean boundary (Strogen, 2011) and divides the Neogene succession in the southern Taranaki Basin into two distinctive stratigraphic intervals: the Wai-iti and Rotokare groups. (King and Thrasher, 1996).

10.1.3 Distribution

The N50 reflector has been identified across the whole of the KUP area. The erosion associated with this surface increases from north to south. To the north, over the Kapuni field, erosion is minimal (Fohrmann et al., 2009); in the south around the Tahi-1 well, the erosion is more extensive and has resulted in complete removal of the Paleocene to Late Miocene succession, so that Pliocene rocks now unconformably overlie Late Cretaceous rocks (Palmer, 1984; Roncaglia et al., 2008).

10.2 LATE MIocene – EARLY Pliocene (N50 Sequence)

10.2.1 Seismic Sequence Character

The N50 sequence is subdivided by the N52 reflector. The lower part of the sequence has a “messy” seismic and wireline log response and marks the transgression of sediments over the base-Rotokare Group unconformity (section 10.1.2). The N52 reflector marks the top of this phase. The upper part of the sequence is characterised by “tramline” reflectors, which represent the main cyclothemic part of the sequence (Figure 16; Bland et al., in prep.).

The top of the sequence is characterised as a series tramline reflections with its top interpreted as a disconformity.

10.2.2 Stratigraphic Equivalent

The N50 sequence encompasses the Matemateaonga Formation (Arnold, 1957) of the Rotokare Group (King and Thrasher, 1996) in the KUP area. The sequence comprises a thick (>1000 m) cyclical and laterally persistent succession of shelf sandstones, mudstones, and shell beds of Late Miocene–Early Pliocene age (Roncaglia et al., 2008).

10.2.3 Distribution and Thickness

The N50 sequence has been identified across the whole of the KUP area except the south-western part (Fohrmann et al., 2012 – Maps 15, 16 & 32, 33). Strata overlying the unconformity are dated in the wells as Kapitean–Opoitian in age, which suggests that the erosion surface was transgressed diachronously. This interpretation agrees with well samples of the oldest (Late Miocene; Kapitean) parts of the sequence in north and the oldest parts (Early Pliocene, lower Opoitian) in the south. The diachronity is also reflected in the variation in thickness, with the basal transgressive strata (N50–N52) generally exceeding 200–300 m thickness in the northern part of the mapping area and decreasing to ~100 m towards the south (Fohrmann et al., 2012 – Map 48). This trend continues in the younger sequence (N52–N60), which is thickest (~600 m) in the northern part of the KUP area (Fohrmann et al., 2012 – Map 49). This reflects a phase of south-directed shoreline retrogradation that was linked with north-directed shelf progradation (Bland et al., in prep.).
In the north of the KUP area, around the Toru-1 well, the N50 sequence unconformably overlies the Mangaoapa Member of the Kiore Formation (Late Miocene), whereas in the south around the Tahi-1 well, the sequence unconformably overlies North Cape Formation (Late Cretaceous, Roncaglia et al., 2008).

10.3 **EARLY PLIOCENE – EARLY LATE PLIOCENE (N60 SEQUENCE)**

10.3.1 Seismic Sequence Character

The N60 sequence is readily identified by its much blander seismic character and prominent clinoforms rather than the “tram-line” reflectors of the bounding sequences (Figure 16). The top corresponds to the N70 horizon which marks the return to “tramline” reflections.

10.3.2 Stratigraphic Equivalent

The N60 sequence comprises the Tangahoe Formation (Arnold, 1957) of the Rotokare Group in the KUP area. The sequence disconformably overlies the Matemateaonga Formation. The base is interpreted as a marine flooding surface at the base of the Tangahoe Formation (Figure 16) and has been dated at c. 4.8 Ma (Hayton, 1998; Kamp et al., 2004).

10.3.3 Distribution and Thickness

The N60 sequence occurs across most of the KUP area (Fohrmann et al., 2012 – Maps 17 & 34). The sequence thins southwards from the present day South Taranaki coastline, where it reaches ~450 m, to around 100 m in the south of the KUP area (Fohrmann et al., 2012 – Map 50).

10.4 **LATE PLIOCENE – EARLY PLEISTOCENE (N70 SEQUENCE)**

10.4.1 Seismic Sequence Character

The internal “tram line” character of the N70 sequence in the KUP area is similar to that of the deeper N50 sequence, indicating comparable depositional styles and environments. Internally, high-amplitude but laterally discontinuous reflectors are inferred to represent variably cemented shelly units surrounded by sandy and muddy beds.

10.4.2 Stratigraphic Equivalent

The N70 sequence encompasses sediments of the Whenuakura Subgroup in the KUP area (Bland et al., in prep.). The sequence consist of cyclothemic, shelf sandstones, mudstones, and shell beds, deposited as shelf-sets (top sets) within a northerly-prograding continental margin that built out from the Marlborough-Nelson basement shield during the Early to mid-Pliocene (Kamp et al., 2004; Naish et al., 2005). The subgroup is genetically related to the slope-set and bottom-set deposits of the Tangahoe Formation (Figure 16). The base of the Whenuakura Subgroup is defined by N70 reflector (Figure 16) and the N80 reflector is interpreted as the ‘near’ top Whenuakura (Bland et al., in prep.).
Figure 16 The seismic character of the Rotokare Group (Late Miocene–Pleistocene) in the KUP area. The N60 horizon marks the top Matemateaonga Formation; this formation is characterised by high-amplitude, parallel, moderately continuous reflectors, with occasional areas of weak, discontinuous reflectors. The N60 sequence (Tangahoe Formation) shows inclined and off lapping reflectors, which are interpreted as upper bathyal slope- and bottom-set elements of a series of progradational foresets. These are overlain by the higher amplitude and more continuous reflectors (top-sets) of the N70 sequence (Whenuakura Subgroup), which can have chaotic reflection styles above the N70 reflector.

10.4.3 Distribution and Thickness

The N70 sequence occurs across most of the KUP area and diachronously overlies the Tangahoe Formation, prograding from the south of the KUP area (Fohrmann et al., 2012 – Maps 18 & 35).

It is thickest in a NW–SE-trending belt that runs through central parts of the mapping area. Thicknesses of ~2000 m occur in the NW-corner of the mapping area within the Pihama Sub-basin (Figure 3), although most of the thicker belt of this formation is ~1000–1500 m thick. Adjacent to this belt, thicknesses steadily decrease until the sequence thins to ~100 m towards the SW-corner of the mapping area (Fohrmann et al., 2012 – Map 51).
10.5 **Undifferentiated Pliocene – Recent (N80 Sequence)**

10.5.1 Seismic Sequence Character

The N80 sequence consists of reflectors that are sub-parallel to the seabed, indicative of ongoing cyclothemic-style deposition (Figure 17). The unconformities within this package are inferred to record localised deformation rather than regional-scale tectonic events.

The N80 reflector in places corresponds to an angular unconformity, showing evidence of a complex multi-incision history.

The top of this unit is defined by the seabed reflector, which in many places has been muted out during processing and has been interpreted where possible.

10.5.2 Stratigraphic Equivalent

The N80 sequence represents the youngest strata in the KUP area, and it is placed in the Rotokare Group (Appendix A – Figure 31 & Figure 32). The base of the unit—the N80 reflector—is interpreted as the ‘near’ top Whenuakura Subgroup (section 10.4.2, Figure 16). This sequence is interpreted as a succession of shelf-dominated cyclothemic sediments (Bland et al., in prep.).

10.5.3 Distribution and Thickness

The N80 sequence is up to 500 m thick in the Central Graben towards the Cape Egmont Fault (Figure 4), and is thinnest in the NE-corner (<100 m thick; Figure 33). Faulting within this sequence extends up to the seabed and shows that deformation is currently active today.

10.6 Latest Miocene/Pliocene – Recent Interval – Synthesis

The base-Rotokare Group unconformity, the N50 horizon defining the base of this interval, corresponds to a regional unconformity relating to a major re-orientation of the basin geometry in response to a major tectonic reorganisation of the Hikurangi subduction margin resulting in uplift of the adjacent land area (Section 2.0; King and Thrasher, 1992; Wallace et al., 2004; Nicol et al., 2007). The N60 horizon corresponds to a marine flooding surface at the top of the Matemateaonga Formation; the N70 horizon corresponds to a change in deposition style, relating to the progradation of top-sets over slope-sets at the top of the Tangahoe Formation, and the N80 horizon defines an extensive erosion surface at the top of the Whenuakura Subgroup and the base of the most recently deposited sediments. Overall, this interval consists of shelf-dominated, cyclothemic sediments derived from the south (Bland et al., in prep.), except for the Tangahoe Formation, which was deposited in an upper bathyal environment.
Figure 17 The seismic character of the Rotokare Group and other undifferentiated Plio-Pleistocene strata in the KUP area (Line hzt82a-144). The tramline reflection style of the N70 sequence (Whenuakura Subgroup) is clearly demonstrated. Note the thickening of the N80 unit across faults, some of which extend to the seafloor. The N80 event represents an angular unconformity that can be mapped in some parts of the Plio-Pleistocene succession.

11.0 UNCERTAINTIES

There are several factors that contribute to uncertainties in seismic interpretation and subsequent mapping and depth conversion within the KUP area; these are described below;

1) Variation in acquisition parameters:

The seismic dataset used in this project covers multiple vintages of seismic data with differing acquisition parameters, record lengths, and processing sequences. To assist with interpretation, i.e. to improve reflection identification and continuity of interpretation across the greater Taranaki region, the data were phase rotated and time shifted to tie at the seabed (Milner et al., 2010). Areas where the record length was insufficient to allow mapping of the deeper reflections, i.e., Basement and K80, are limited to the Kerry 3D data set.

2) Uncertainties due to patchy distribution of seismic coverage:

The south-eastern part of the KUP area (around Tahi-1) has limited 2D seismic coverage; hence, the current structural interpretation of this area is open to revision should more seismic data become available.

3) Uncertainties due to varying lateral and vertical resolution:
In general, a loss of high frequencies with depth results in a decrease of vertical seismic resolution. Deeper horizons and associated structures are harder to interpret and map, i.e. the K80 and the seismic basement reflectors. Additionally, some areas are more easily mapped than others due to structure or varying impedance contrasts.

4) Structural deformation around the Manaia and Taranaki fault zones:

The footwall and hanging wall zones around the Manaia and Taranaki faults are poorly imaged due to complex ray paths, reduced velocity control, and the inherent limitations of 2D acquisition. The structures within these over-thrust areas are more complex than mapped, i.e. thrust planes identified within the Rimu-A1 well are not resolved on the seismic data (Harris et al., 1999).

Interpretation around the Taranaki Fault was difficult due to poor imaging of the thrust planes and rocks between the thrusts.

5) Lack of age control on certain events:

Extensive channelling during the Miocene and a lack of well control in the synclines adjacent to the Manaia Anticline has resulted in poor age control for reflectors in these areas, i.e. the N45 and N48 reflectors to the west of the Manaia Anticline.

12.0 3D MODELLING AND DEPTH CONVERSION

Horizons and faults that were seismically mapped were modelled as 3D surfaces and fault planes, respectively, using GOCAD software. This was undertaken as a quality check on the mapping, and involved iterations of the following key steps:

12.1 CONSTRUCTION OF A FAULT MODEL BASED ON FAULT STICKS

All fault planes were triangulated with triangles having a maximum size of 2000 m. Typically, fault planes were extended along strike (with variable extension of 1–5 km) and up and down dip (with variable extension of 500 ms–1000 ms). Generally, subsidiary smaller fault planes were made to branch from larger fault planes. In cases where major/minor fault relationships were not clear, the faults were allowed to cross.

12.2 3D HORIZON MODELLING

All TWT horizons were triangulated with variable resolution. The lengths of the sides of the triangles vary depending on the density of interpretation data, and the requirement for variable smoothing, but are at most ~1000 m. All surfaces were re-calibrated to well horizon markers.

12.3 MODELLING OF FAULT – HORIZON CONTACTS

Each fault-horizon intersection was modelled. In most cases it was necessary to project offset profiles along strike beyond the last interpreted fault sticks.

12.4 DEPTH CONVERSION

The depth conversion methodology is fully documented in a companion report by Hill and Milner (2012). In summary, the time surfaces were depth converted using a layered velocity
model. The velocity for each layer was modelled with the $V_0-k$ method (Marsden, 1992), where the variation of velocity with depth is described by either a constant or linearly increasing velocity function. These velocity functions were derived from the well data within the KUP area. For deeper intervals not intersected by well data, velocity data from other wells in the Taranaki Basin were used.

To extend the velocity model across the whole of the KUP area, well-velocity data were kriged at 1 km resolution, using stacking velocity data to define the horizontal velocity trend.

A GOCAD cellular model (voxet with resolution 1 km x 1 km x 100 ms) covering the KUP area was populated with instantaneous velocity values. These values were smoothed, converted to average-velocity, and then calibrated to well-average-velocity values.

The time surfaces were then depth converted using this 3D velocity cube to generate depth and isopach maps.

13.0 CONCLUSIONS

The interpretation and mapping of 17 seismic horizons over the KUP area has led to a greater understanding of the area's geological and structural development, through the improved lateral and vertical resolution of the new time-structure and depth-structure maps, compared to those from Thrasher et al. (1995) and King and Thrasher (1996).

13.1 STRUCTURE

The major faults show initial normal movement (Cretaceous–Late Paleocene), then reverse displacement (Late Eocene/Early Oligocene–Late Miocene) and finally, on certain faults, normal movement (Pliocene–Recent).

13.1.1 Taranaki Fault

The Taranaki Fault uplifts basin-fill strata in a series of imbricate wedges in the north-eastern part of the KUP area. These thrusts are characterised by shallow-dipping basal planes that steepen upwards. The fault alters its appearance further southwards around the latitude of the Kupe South-5 well, where it transforms into one steeply dipping reverse fault.

13.1.2 Manaia Fault

The Manaia Fault controlled the thickness of the Cretaceous–Eocene succession across the KUP area when it acted as a normal fault. The main depocentre during this period lay to the east of Manaia Fault, which during this time had half-graben geometry with normal displacement. A thinner succession was deposited on the adjacent horst to the west of the fault.

Reverse movement on Manaia Fault is interpreted to have begun c.34.5 Ma, between the latest Eocene (Runangan) and the Early Oligocene (Whaingaroan) for the following reasons:

- The Eocene isopach map shows a thicker infill east of the Manaia Fault than to the west, indicating that the depocentre east of the Manaia Fault was still subsiding.
- A depocentre is established on the west of the Manaia Fault, whose basal sediments are of Late Whaingaroan age.
Regional uplift complicates the situation, but there is progressive southward erosion of the pre-mid Oligocene units, highlighted by the unconformable character of the Early Oligocene (P50) seismic horizon. The oldest Oligocene rocks drilled in this area are of Late Whaingaroan age (30–27 Ma).

A similar situation of Oligocene sediment thickening is interpreted in the footwall of the Taranaki Fault, consistent with a shift from predominantly extensional to compressional tectonics.

The main phase of structural inversion along the Manaia Fault occurred during the Miocene. Up to 1500 m of sediments have been deposited in the depocentre to the west of the Manaia Fault, (Figure 7). The relatively large increase in deposition and accommodation space reflects a period of rapid deformation of the Manaia structure. The antithetic Motumate Fault did not become active until the late Early–early Middle Miocene.

A detailed discussion on the function of normal faults in up-sequence flow of gas has in the Kupe mapping area can be found in Hemmings-Sykes (2011) and Ilg et al. (2012).

13.2 SEDIMENT DISTRIBUTION WITHIN THE KUPE MAPPING AREA

The thickest sedimentary succession occurs in the northeast of the mapping area where the top of basement is interpreted to lie at a depth of ~11 km. The succession further increases in thickness below the Taranaki Peninsula. The thinnest succession lies on the crest of the Manaia Anticline, to the south of Tahoe-1. Here, the succession is interpreted to be ~2 km thick, with most of this thickness comprising rocks of Pliocene age. Several phases of erosion have significantly altered the thickness and distribution of sediments within the KUP area, especially over the southern part of the area.

The presence of undifferentiated, inferred Late Cretaceous sedimentary rocks east of the Manaia Fault suggests that deposition was controlled by faults active during that time. The area into which the sediments were deposited was probably an actively forming half-graben or graben, in which alluvial deposition occurred. Adjacent areas were probably upstanding horst blocks, upon which there was relatively little net sedimentation (Bland et al., in prep.).

The upper part of the Rakopi Formation, to the east of Manaia Fault, is interpreted to consist of an upper thick coaly sequence and a lower package of a possibly more marine origin. This is consistent with results from wells in adjacent areas, e.g. Maui-4 (e.g., King and Thrasher, 1996).

The overall Cretaceous–Paleocene depositional setting is one of rifted margin sedimentation, filling pre-dominantly N–S trending graben structures controlled by the Manaia Fault. The main depocentre was located east of the Manaia Fault, whereas the area to the west was a structural high (Otakeho High) with latest Cretaceous–Paleocene strata onlapping from the northwest, where a local depocentre (the Pihama Sub-basin) was present.

Eocene strata are only present in the northern part of the KUP area, near the Toru-1 well, and thin away from the onshore Kapuni field. There is no evidence for significant faulting in the Eocene section. A Late Eocene–Early Oligocene regional unconformity is associated with a phase of tilting and erosion (King and Thrasher, 1996; Bland et al., in prep.), and the onset of inversion on the major faults.

The Oligocene–earliest Miocene strata of the Ngatoro Group are interpreted as shelf and upper bathyal lithofacies that lie unconformably overlie the Kapuni Group across the KUP
area. The top of Ngatoro Group is considered to represent a maximum flooding surface over Taranaki Basin, reflecting a period of near-maximum submergence characterised by the deposition of carbonate-rich rocks, before returning to terrigenous-dominated sedimentation following the movement of the modern plate boundary through the New Zealand subcontinent.

The Ngatoro–Wai-iti Group boundary is interpreted to be conformable but diachronous across most of the mapping area.

The developing Manaia Anticline is interpreted to have controlled sediment distribution within the Wai-iti Group. Shelf and upper bathyal sediments were deposited over the crest of the anticline; deep bathyal mudstones accumulated in the developing synclines (Roncaglia et al., 2008).

The top of the Wai-iti Group is marked by an angular unconformity separating Late Miocene rocks from latest Miocene–Recent strata of the Rotokare Group. The origin of this unconformity is attributed to a significant phase of structural reorganisation from the latest Miocene onwards, driven primarily by changes in convergence across the developing plate boundary. This resulted in large parts of the southern Taranaki Basin and Taranaki peninsula becoming uplifted and eroded (King and Thrasher, 1996; Vonk and Kamp, 2008; Strogen, 2011; Bland et al., in prep.).

The Rotokare Group contains a linked succession of shelf, slope, and bathyal rocks of latest Miocene to Pleistocene age that were deposited as part of at least two progradational depositional systems, reflecting repeated regression and transgression.

Basal parts of the Matemateaonga Formation record south-directed marine transgression over the base-Rotokare Group unconformity in the latest Miocene and earliest Pliocene. It is overlain by the Tangahoe Formation, encompassing overstepping, progradational shelf topsets of upper Opoitian-Waipipian age that accumulated after a phase of rapid, tectonically-driven subsidence in the late- Early Pliocene (Hayton et al., 1997; Kamp et al., 1999; Bland et al., in prep.).

Strata of the Whenuakura Subgroup were subsequently conformably deposited as topsets within a northerly-prograding continental margin that built out from the Marlborough-Nelson basement shield during the Early to mid-Pliocene (Bland et al., in prep.), followed by a succession of shelf-dominated cyclothemic formations until the Recent, which contain localised unconformities that are interpreted to record localised deformation rather than basin-scale tectonic events (Bland et al., in prep.).

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15.0 REFERENCES


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Figure 18  Seismic and well locations. The yellow polygon in the centre illustrates the outline of the Kerry 3D dataset.
Figure 19  Two way travel-time to top Basement horizon.
Figure 20  Depth to top Basement horizon.
Figure 21  Isopach map for the undifferentiated mid-Late Cretaceous interval of the pre-K80 sequence.
Figure 22  Two way travel-time to P10 horizon (Base Paleocene)
Figure 23  Depth to P10 horizon (Base Paleocene)
Figure 24  Isopach map for the K90 sequence. This approximates to the North Cape Formation.
Figure 25 Isopach map for the Middle Eocene interval of the P30 sequence. This approximates to the Mangahewa Formation.
Figure 26  Two way travel-time to P50 horizon (Base Whaingaroan)
Figure 27  Depth to P50 horizon (Base Whaingaroan)
Figure 28  Isopach map for the Late Miocene N48 sequence. This approximates to the Mangaopapa Member of the Kiore Formation.
Figure 29 Two way travel-time to N50 unconformity (Base Pliocene).
Figure 30  Depth to N50 unconformity (Base Pliocene).
Figure 31   Two way travel-time to Seabed horizon.
Figure 32  Depth to Seabed horizon.
Figure 33  Isopach map for the undifferentiated Pliocene–Recent N80 sequence.