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การแปลความหมายคลื่นไหวสะเทือนของหินต้นกำเนิดปิโตรเลียมยุคครีเทเชียสในแหล่งทารานากิ ประเทศนิวซีแลนด์

โดย

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โครงการนี้เป็นส่วนหนึ่งของการศึกษาระดับปริญญาตรี
ภาควิชาธรณีวิทยา คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2560

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นายณัชพล ชาญศิริ

โครงงานนี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตร์บัณฑิต
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SEISMIC INTERPRETATION OF CRETACEOUS PETROLEUM SOURCE ROCKS IN TARANAKI BASIN, NEW ZEALAND

Mister Natcharphol Charnsiri

A project submitted in Partial Fulfillment of the Requirements
for the Degree of the Bachelor of Science Program in Geology
Department of Geology, Faculty of Science, Chulalongkorn University
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Project Title:	SEISMIC INTERPRETATION OF CRETACEOUS PETROLEUM SOURCE ROCKS IN TARANAKI BASIN, NEW ZEALAND
By:	Mister Natcharphol Charnsiri
Department:	Geology
Advisor:	Dr. Piyaphong Chenrai

Date of submission ..../............/............

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(Dr. Piyaphong Chenrai)

Project Advisor

ณัชพล ชาญศิริ : การแปลความหมายคลื่นไหวสะเทือนของหินต้นกำเนิดปิโตรเลียมยุคครีเทเชียสในแหล่งทารานากิ ประเทศนิวซีแลนด์ (SEISMIC INTERPRETATION OF CRETACEOUS PETROLEUM SOURCE ROCKS IN TARANAKI BASIN, NEW ZEALAND) อ.ที่ปรึกษาโครงการหลัก: อาจารย์ ดร.ปิยพงษ์ เชนร้าย, 40 หน้า.

ชุดลำดับชั้นหินต้นกำเนิดที่สะสมตัวในยุคครีเทเชียสตอนปลายถูกพิสูจน์แล้วว่าให้ปิโตรเลียมปริมาณมากแก่แอ่งทารานากิ ประเทศนิวซีแลนด์ ซึ่งเป็นแอ่งเดียวเท่านั้นที่ให้ปริมาณปิโตรเลียมที่คุ้มค่าเชิงพาณิชย์ในประเทศ แต่ถึงอย่างนั้นการศึกษาเกี่ยวกับชุดลำดับชั้นหินเหล่านี้ในบริเวณพื้นที่น้ำลึกของแอ่งยังไม่มีการศึกษาอย่างกว้างขวางนัก ในงานศึกษานี้ข้อมูลคลื่นไหวสะเทือนแบบสะท้อนแบบสองมิติในบริเวณพื้นที่น้ำลึกถูกใช้เพื่อหาการกระจายตัวของชุดลำดับชั้นหินเหล่านี้และเพื่อแปลความหมายลักษณะต่างๆของคลื่นไหวสะเทือนแบบสะท้อน มีชุดลำดับชั้นหินสองชุดที่มีศักยภาพในการเป็นชั้นหินต้นกำเนิดปิโตรเลียม นั่นคือชุดลำดับชั้นหินราโคปิ (Rakopi) ที่เป็นหนึ่งในชั้นหินต้นกำเนิดปิโตรเลียมหลักของแอ่งทารานากิ และชุดลำดับชั้นหินที่ตกสะสมตัวไปพร้อมกับการเปิดแอ่ง (Syn-rift sediment) ที่ยังต้องการการศึกษาอีกมากเกี่ยวกับศักยภาพการเป็นหินต้นกำเนิดปิโตรเลียม จากการวิเคราะห์ลักษณะต่างๆของคลื่นไหวสะเทือนแบบสะท้อน เช่น แอมพลิจูดของคลื่นไหวสะเทือน (Seismic reflection amplitude) จุดสิ้นสุดของคลื่นไหวสะเทือน (Seismic reflection termination) และรูปแบบการจัดเรียงตัวของคลื่นไหวสะเทือน (Seismic reflection configuration) ทำให้ได้สภาพแวดล้อมการสะสมตัว ลักษณะของตะกอนที่สะสมตัว และศักยภาพในการเป็นชั้นหินต้นกำเนิดปิโตรเลียม คุณลักษณะต่างๆของคลื่นไหวสะเทือนแบบสะท้อนของชุดลำดับชั้นหินราโคปิ บ่งบอกถึงการสะสมตัวในสภาพแวดล้อมแบบดินดอนสามเหลี่ยมปากแม่น้ำที่มีการผันผวนของระดับน้ำทะเล ซึ่งมีศักยภาพในการให้ชั้นหินต้นกำเนิดปิโตรเลียมที่มีต้นกำเนิดมาจากบนบกในปริมาณมาก ส่วนคุณลักษณะของชุดลำดับชั้นหินที่ตกสะสมตัวไปพร้อมกับการเปิดแอ่งนั้นบ่งบอกถึงการสะสมตัวอย่างรวดเร็วโดยกระแสความขุ่น (Turbidity current) ที่อาจจะส่งผลให้เกิดการเก็บรักษาของชั้นหินต้นกำเนิดได้เช่นกัน

ภาควิชา	ธรณีวิทยา	ลายมือชื่อนิสิต..
สาขาวิชา	ธรณีวิทยา	ลายมือชื่ออ.ที่ปรึกษาหลัก................................
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KEYWORDS: CRETACEOUS PERIOD / PETROLEUM SOURCE ROCKS / TARANAKI BASIN / SEISMIC CHARACTERISTICS / SEISMIC INTERPRETATION / SEISMIC AMPLITUDE

SEISMIC INTERPRETATION OF CRETACEOUS PETROLEUM SOURCE ROCKS IN TARANAKI BASIN, NEW ZEALAND. ADVISOR: DR. PIYAPHONG CHENRAI, 40 pp.

Source rock sequences that were deposited in the Late Cretaceous period are proved to be responsible for tremendous amount of petroleum found in Taranaki Basin, New Zealand, the only basin that contains commercial reserves, but these sequences have yet been studied much about their potentials in deepwater area. In this study, 2D seismic data in the deepwater area were used to find their distributions and were interpreted their seismic reflection characteristics. Two potential source rock sequences have been recognized; Rakopi sequence, one of the main source rocks in Taranaki Basin, and Syn-rift sequence the sequence which lacks the studies about their potentials. By analyzing the seismic reflection characteristics such as seismic reflection amplitude, seismic terminations, and seismic configurations, depositional environments, sediments deposited at that time, and their source rock potentials are acquired. Rakopi sequence's seismic reflection characteristics suggest the deposition in fluctuated sea levels deltaic environment that have capabilities to provide a large amount of terrestrial origin source rocks. Syn-rift sequence's characteristics on the other hand, suggest the rapid deposition by high-density turbidity current which possibly resulted in preservation of source rocks as well.

Department:	Geology	Student's Signature..
Field of Study:	Geology	Advisor's Signature..
Academic Year:	2017	

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CHAPTER 1

INTRODUCTION

1.1. Background and Signification of the Research

Taranaki basin, New Zealand, has been developed through several tectonic cycles, began with Mesozoic rifting, followed by subsidence related with seafloor spreading in the Tasman Sea around Late Cretaceous and Paleogene (Grahame, 2015). As a consequence, complex geological structures were built and deposition of sediments developed though time. Petroleum produced in Taranaki basin is from about 20 fields, from gigantic gas-condensate field like Maui field (original gas reserves 3.4 tcf), to small petroleum field which reserves only small amount of oil and gas. From source rocks modeling in the shelf and onshore area done by New Zealand Petroleum & Minerals (2014), points that a large amount of oil and gas has been expelled from Cretaceous to Eocene source rocks. However, no modeling has yet been done for the source rocks farther from the shelf and onshore parts. Moreover, older pre-Late Cretaceous source rocks might be exist in Taranaki basin, especially in deep water area but are poorly studied (New Zealand Petroleum & Minerals, 2014)

Knowledge and understanding in structural geology, sequence stratigraphy, petroleum system and factors that affect petroleum system such as geothermal gradient might help us understand properties, characteristics and areas which could be accommodation space for the interested source rocks.

Studying of old and deep source rocks can be done by several methods. Interpretation using seismic reflection is one of the most efficient methods. It uses the benefits of the seismic wave reflective property (when seismic wave is shot and encounters the contact of two different strata which have different acoustic impedances), travel time and different seismic reflections to interpret depth, structures and strata sequences (Satarugsa, 2007). By using this method, the study of deep strata is more efficient and covers wider areas than other methods. Thus, interpretation using seismic reflection might be a proper method for this study.

1.2. Objective

To analyse possibility and distribution of Cretaceous petroleum source rocks from seismic reflection.

1.3. Study area

Study area is deepwater Taranaki Basin which is located at the north-west coast of New Zealand. It covers around 66,961 km^2 and composes solely 2D seismic survey data (Figure 1.1).

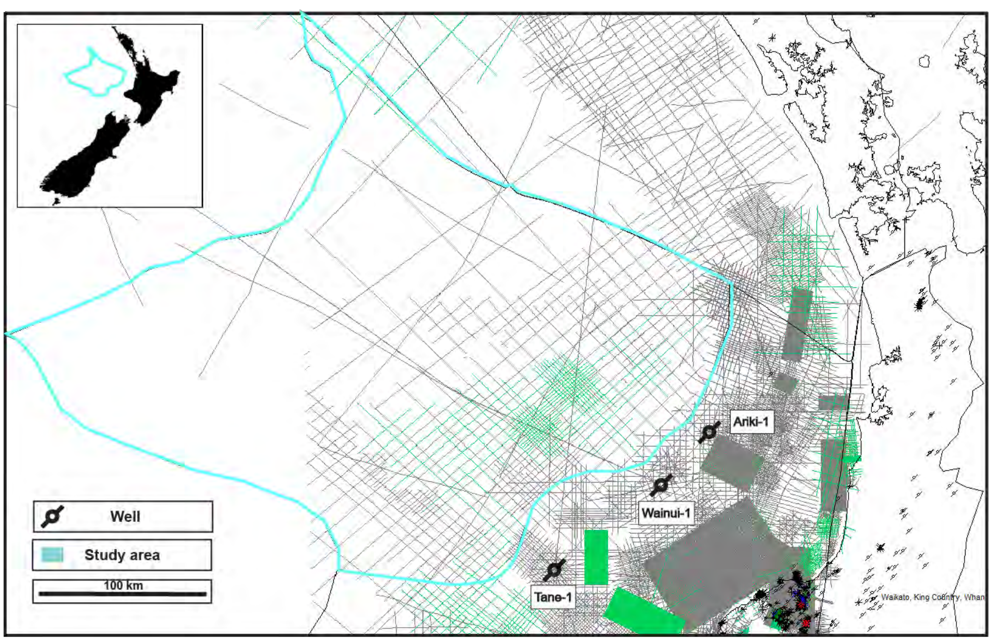


Figure 1.1 Study area, deepwater Taranaki Basin, New Zealand with 2D seismic data survey lines represented in green and grey lines and well data.

1.4. Methodology

- Background geology and related researches reviews.
- Stratigraphic sequences and well data correlation for depth and age specification of each stratum.
- 2D seismic reflection interpretation using Kingdom 8.8 software.
  a) Track top of the Cretaceous sequence to make it easier for Cretaceous petroleum source rocks to be found.
  b) Interpret seismic reflection characteristics of Cretaceous petroleum source rocks to find their distribution and proper environments for petroleum source rocks to be deposited. As well as geological structures which are used to analyse the basin development.
  c) Create horizon of Cretaceous petroleum source rocks from tracked 2D seismic reflection lines.
- Interpreted results analysis by delineating seismic reflection characteristics that appear in Cretaceous source rocks sequences.
- Discussions and conclusions.

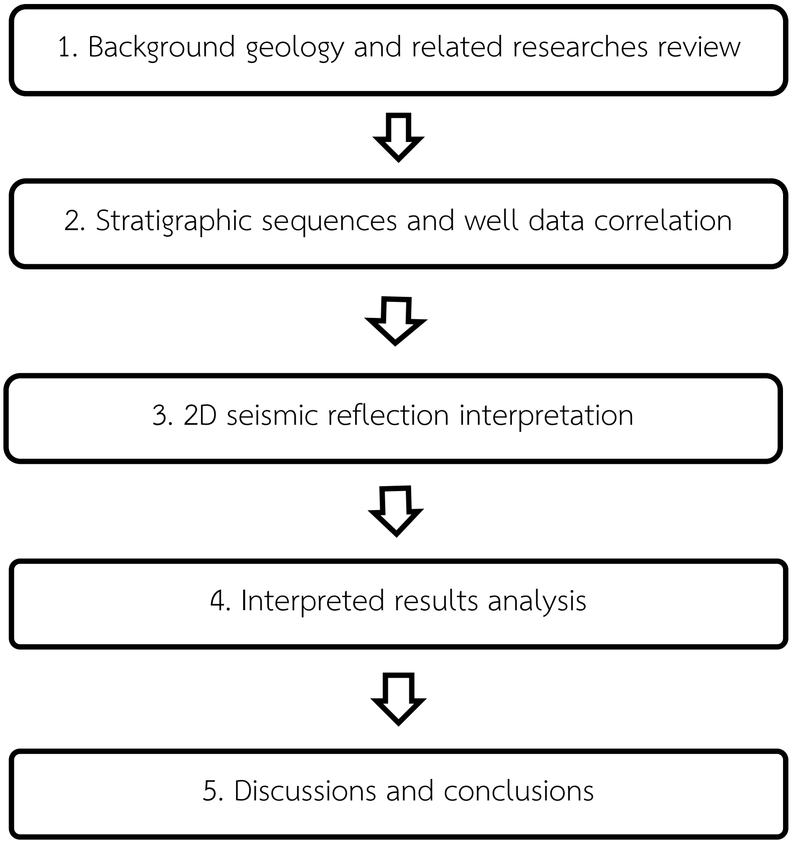


Figure 1.2 Project workflow

CHAPTER 2

GEOLOGY OF THE STUDY AREA

Taranaki Basin is next to Whanganui Basin in the north-west, separated from each other by a basement called the Patea-Tongaporutu High. Though they are close to one another and have similarities in terms of the time periods which both basins were formed and filled with sediment, these two basins are drastically different from each other whether the tectonic origins or history in detail.

2.1. Tectonic settings

Taranaki Basin particularly is an extensional basin formed around Late Cretaceous and was subjected to regional subsidence through Paleogene (Pilaar and Wakefield, 1978; Knox, 1982; Hayward and Wood, 1989). The basin is originally formed when Gondwana broke up and separated Zealandia away from it, caused a rifting which was last between 110-83 million years ago (Ballance, 2009) (Figure 2.1), followed up by Tasman Sea spreading that is assumed to have occurred around 80 million years ago (Sutherland et al., 2001). Even though many rifts were firstly active, just a few continued developing into new seafloor spreading centers, In the case of Taranaki basin which was initially a rift valley resulted from crustal stretching, it became inactive which is considered to be in failed rift system. As the Zealandia moving away from part of Gondwana, it had gradually subsided according to the evidences of Taranaki Basin's present-day shelf area (Hayward and Wood, 1989; Stern and Holt, 1994). Around 45 million years ago Zealandia collided with Pacific oceanic plate created Pacific-Australian plate boundary. This collision caused and accelerated volcanic activity as well as the tectonic in the area.

Presently, Australian plate is being subducted by the Pacific oceanic plate all the way from the north of Tonga to East Cape. On the other hand, Continental crust of the North land which is part of an Australain plate is being subducted by Pacific oceanic crust from East Cape to Cook Strait. The direction of subduction is gradually changed from due west to south west as a consequence of plate rotation which is rotating anticlockwise with a rate of 1° per million years (considering the rotation of the Pacific Plate which has a pole of rotation located at latitude 60°S, longtitude 180°). At Cook Strait which lies between the North and South Islands of New Zealand and connects the South Pacific Ocean on the southeast with the Tasman Sea on the northwest, the direction of rotation changes from extremely oblique subduction to being parallel to the boundary by the consequence of plate boundary entering continental crust. From the reality that continental crust is now on both sides of the boundary, it strongly influences on forcing the change mentioned earlier because of an inability to subduct in either side (Ballance, 2009).

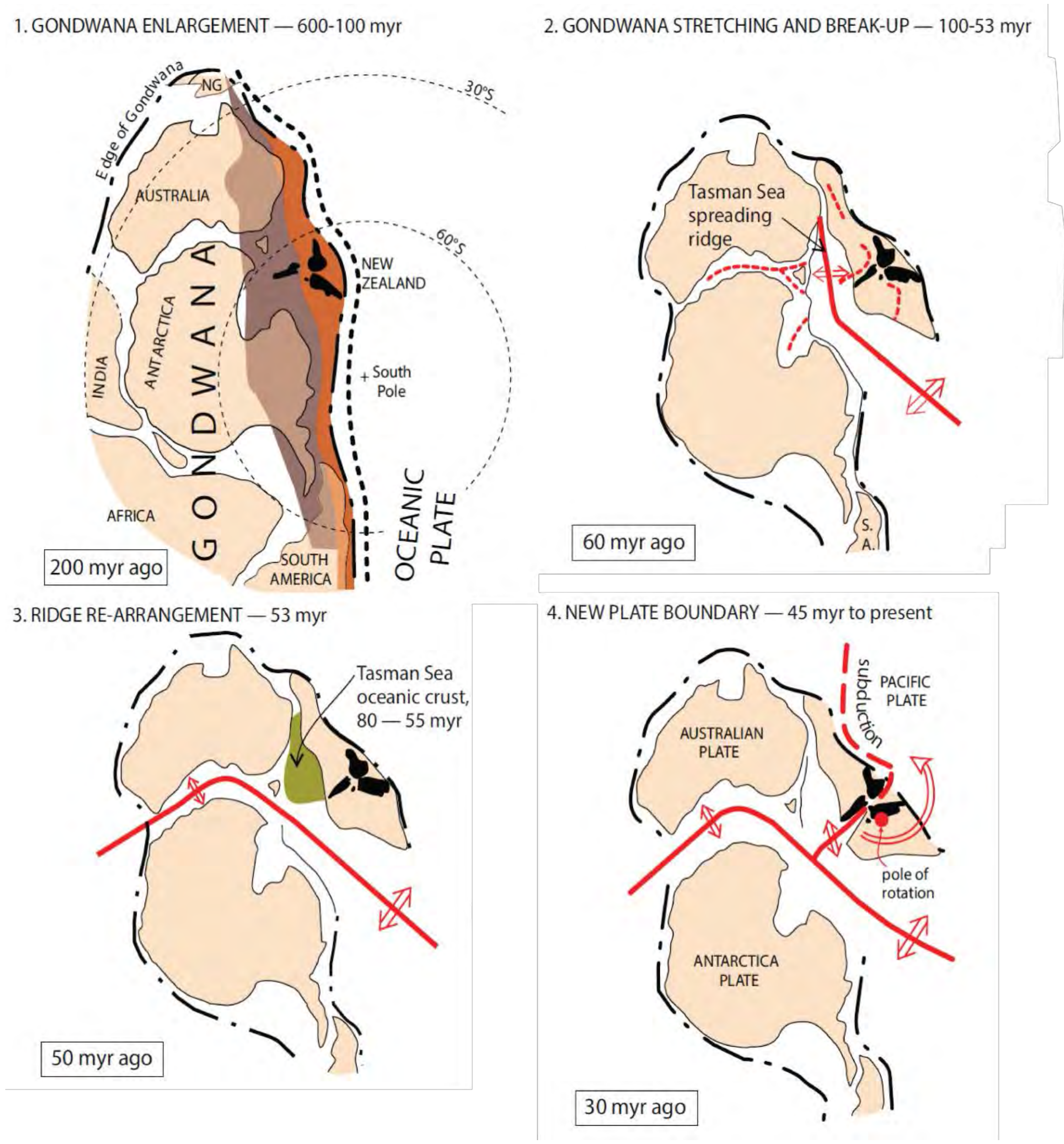


Figure 2.1 Geological development of New Zealand (modified after Balance, 2009).

2.2. Deposition and Stratigraphy

As detailed in Geological tectonic settings, it can be acknowledged that since the Taranaki Basin had been initially formed, it had been through many geological events. As a consequence, the deposition and stratigraphy of this basin had been gradually changed through the time. According to the geological events taken place in the study area, deposition and sedimentations in Taranaki Basin can be classified into 5 phases; Basement phase, Syn-rift phase, Taranaki Delta phase, Transgression phase and Regression phase (Uruski, 2007). Please note that lithostratigraphic nomenclature used in this project (Figure 2.2) is from Baure (2012).

Basement of the basin is composed of extrusive and intrusive igneous rocks and metasedimentary rocks as well. Igneous rocks comprise the Brook Street terrane mafic igneous extrusive rocks and granite of Separation Point and Karamea. Metasedimentary rocks found in Buller and Takaka terranes as well as Torlesse Supergroup was deposited in the subduction trench as an extremely large submarine fan (Bradshaw et al., 1981) before getting metamorphosed, and then accreted to the continental margin.

Syn-rift phase had possibly been deposited during the Jurassic and Early Cretaceous. Sediments deposited in Jurassic are commonly coarse-grained sediment. On the other hand, sediments deposited in Early Cretaceous are generally fined-grained sediment. Sediments deposited in both periods of time are assumed to be deposited in subduction related basins or in an actively faulting basin. A Deepwater Taranaki pre-delta sequence has been attributed to be influenced by fault scarps derived coarse clastic rocks interfingered with fluvial system deposits travelled from somewhere in the Gondwana hinterland. Areas that are low-lying have high possibility to have accumulated lacustrine, marsh and swamp sediments. The boundary between this syn-rift sequence and following delta system deposition is determined by a hiatus that is brief apparent at around 105 million years. This boundary was followed by large deltaic deposition.

The accumulation of Taranaki delta phase occurred around Late Cretaceous. Taranaki delta was developed through fluctuated sea levels. Delta sequences commenced with highstand systems tract, followed by the rise of relative sea level sequence, lowstand systems tract, and transgressive sequence respectively (Uruski, 2007). Like other deltas, general deposition is mudstone dominated with sandstone restricted in particular areas like channels shorefaces, mouth bars, and transgressive sequences. Turbidites deposited during the low stands could have provided a large influx of plant material which was possibly leaf matter dominated to the basin floor (Uruski, 2007).

Approximately 75 to 25 million years ago, transgressive phase of deposition occurred. The cause of this transgressive period was due to thermal subsidence of the whole mini-continent which is commenced after the separation from Australia. Extensional faulting beneath area of Taranaki Shelf around this period, alongside the sea-level changes in a global scale, caused complicated deposition of North Cape Formation which is marine influenced formation within the area. This formation has thickness around 1000 meters and deposited on top of the Rakopi Formation. The big picture of North Cape Formation physiography during deposition is in a similar pattern of Taranaki Delta that is the shelf edge built outwards and upwards as the process of deposition proceeded. Moreover, some units of coals have been encountered in outcrops and wells. Those coaly units appear to be Puponga and Wainui Members. A large widespread area of shelf area formed by Taranaki Delta ubiquitously influenced the topography of the study area through the Paleogene. Sediment supply was being reduced due to the continuing subsidence of the New Zealand land mass. Depositional area was commonly limited to approximately 200 meters for overall of the Paleocene and Eocene. The overall of sediment accumulated over the region was fine-grained siliclastic dominant. The deposition of carbonate started in the Late Eocene to about the end of the end of Early Miocene in the distant offshore of northwest, New Zealand. The sedimentation of carbonate was more common as the clastic supply continued to fade away due to the subsidence of the New Zealand landmass and became dominated by the

Oligocene. It could be considered that the entire Paleogene sequence can act as a regional sealing unit. Even though its sealing properties might not be even for the whole sequence. Some areas have a widespread of limestone units' fractures, which could be a consequence of compaction and de-watering, while faults created when the Eocene tectonic event occurred, cut the above units, and that included the Tikorangi Formation equivalents. During this period of transgression, basement highs beneath the margin of Northland and the Taranaki shelf were commonly flooded by sea water as evidenced by units dominated by transgressive coarse clastic sediment of the Paleocene overlying Jurassic rocks. The Challenger Plateau located along the southwest flank of the basin had also been onlapped by younger sediments as the transgression went on telling that the Plateau crest stayed emergent for some period of time and might supplied sediments into the basin from the south west of the basin.

The last phase, regression phase took place between 25 to 0 million years ago. Source of clastic sediments was introduced by the result of New Zealand landmass uplifting. A large amount of clastic sediments influxes has been provided to the present-day Taranaki shelf creating a very large channel and turbidite systems which seem to continue at least along the ancient New Caledonia Basin located on the northwest side of Deepwater Taranaki Basin (Uruski and Wood, 1991). In Deepwater Taranaki basin area, Pliocene Epoch is characterized by deposition of turbidite interrupted by extremely large mass transport which is responsible for approximately 50 percent of Pliocene succession's total volume. Mass transport units can be marked by chaotic or disrupted internal reflectors (Uruski, 2007). Moreover, mud volcanoes as well as the fields of pockmarks can be observed in many areas at the seafloor (Uruski, 2007).

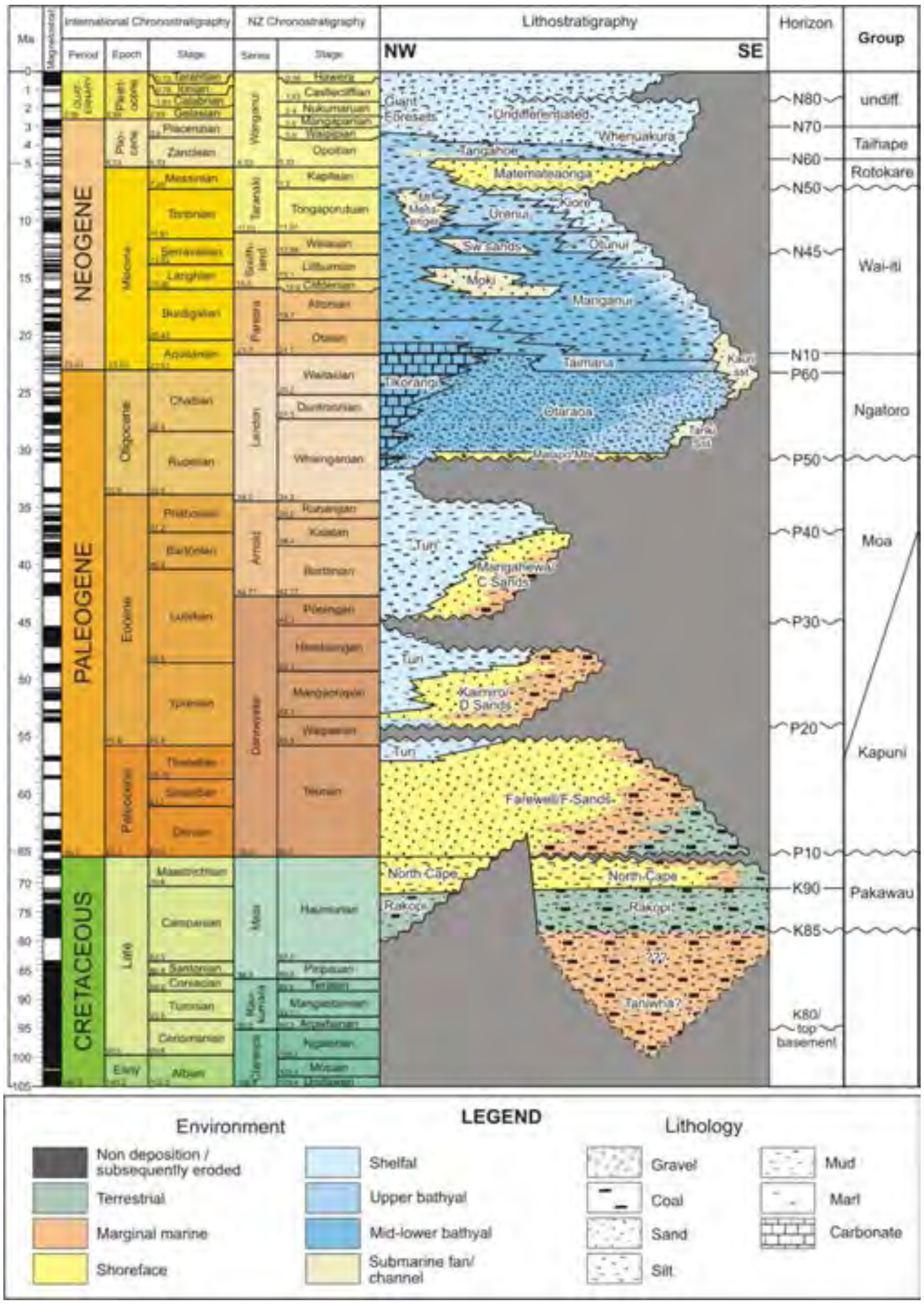


Figure 2.2 Southern Taranaki Basin stratigraphy from Baure (2012). Lithostratigraphic formations distributed from northwest to southeast area are illustrated in the central panel. Two panels on the left show international chronostratigraphy and New Zealand chronostratigraphy of Taranaki Basin.

2.3. Petroleum Geology of Taranaki Basin

Taranaki Basin is the only basin that contains commercial hydrocarbon reserves in New Zealand. There is about 1300 million barrels of estimated recoverable reserves of oil in equivalent of a total 11 discovered oil and gas fields (King and Funnell, 1997). These reserves accumulated in age varying reservoirs, with major reserves stored in Late Eocene marginal marine and coastal plain sandstone reservoirs (King and Funnell, 1997). Major fields discovered in the basin appear to involve structural traps resulted from Neogene tectonism (King and Funnell, 1997).

Oils produced in Taranaki Basin have geochemically proved to have terrestrial origin (Killops et al., 1994, King and Thrasher, 1996). Coals and carbonaceous shales of Late Cretaceous Rakopi Formation, Paleocene Kaimiro Formation, and Eocene Mangahewa Formation which have mean TOC about 10 percent are the main petroleum source rocks in Taranaki Basin considering the organic carbon content, hydrogen-richness, and maturity (King and Funnell, 1997). Oil generation window for type III source rocks of Taranaki basin have been concluded to be in the range Suggate Rank 10-15 and 12.5 for onset of oil expulsion (Suggate and Boudou, 1993) which is equivalent to the values of peak S1, peak S2, and peak Hydrogen Index of Taranaki coals (King and Thrasher, 1996). According to these values, the approximate vitrinite reflectance values are 0.5-0.6% and 0.7-0.8% for the onset of oil generation and oil expulsion respectively (King and Funnell, 1997).

Reservoirs in Taranaki Basin are age varying. Every prominent chronostratigraphic level of the basin except Cretaceous provided commercial quantities of hydrocarbons (King and Funnell, 1997). Main reservoirs found in important fields are Paleocene-aged fluvial sandstones of Farewell Formation; Eocene-aged coastal plain and marginal marine sandstones of Kaimiro, Mangahewa, McKee and Tangaroa Formations; Oligocene-aged turbidite sandstones of Otaraoa Formation; and Miocene-aged fractured limestones of Tikorangi Formation and volcaniclastic sediments of Mohakatino Formation (Figure 2.3).

Mudstones are widely distributed in Taranaki Basin. They act as intraformational seals or top seals for all clastic reservoirs (King and Funnell, 1997), even though, only a little amount of data is accessible for analyzing Taranaki mudstones sealing capacity. Additionally, carbonates of Tikorangi Formation have capabilities to be effective seal as well, due to their low diagenetic porosity and permeability. They formed good seals everywhere they distributed to except Tarata Thrust zone, where they were fractured (King and Funnell, 1997).

Important traps associated with known hydrocarbon accumulations in Taranaki Basin are structural traps resulted from Neogene tectonics which appear to be formed within the Eastern Mobile Belt (King and Funnell, 1997). There are many types of structural traps, but among them, thin-skinned overthrusts of Tarata Thrust Zone, Southern Inversion Zone inversion structures and normal fault-bounded blocks are the mains structural traps in Taranaki Basin.

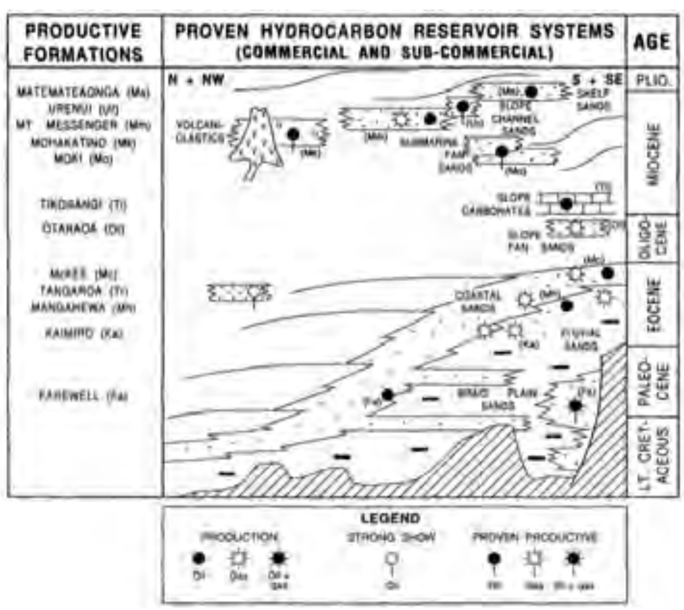


Figure 2.3 Distribution of proven reservoir rocks in Taranaki Basin (King and Funnell, 1997).

CHAPTER 3

METHODOLOGY

3.1. Data and Software Used in the Project

Main data operated in this project are 2D seismic survey lines which spread densely nearshore than farther offshore. All seismic characteristics described and analyzed in this project come solely from seismic sections of these 2D seismic survey lines. Another crucial data is well information. This information plays an important role on finding the formation tops of strata. Unfortunately, there is no well drilled in the study area. So, wells used in this project are wells located in shallower Taranaki Basin comprising of Tane-1 well, Wainui-1 well and Ariki-1 well (Figure 1.1).

Almost all processes from the beginning are associated and operated by Kingdom 8.8 software. This software provides the capabilities of seismic tracking, horizon interpretation and other important features such as isopach map and seismic attribute map as well. Moreover, well information which is crucial for stratigraphic sequence and well correlation is already in a compatible form for Kingdom 8.8 and ready to be used in the first place.

3.2. Stratigraphic Sequences and Well Correlation

Before seismic sections of each 2D seismic survey line can be interpreted, stratigraphic sequence and wells correlation is needed, because wells provide almost every possible and important information of sediment strata. Hence, these wells whether exploration well, delineation well or production well accurately help identifying top formations in the study area (Figure 3.1).

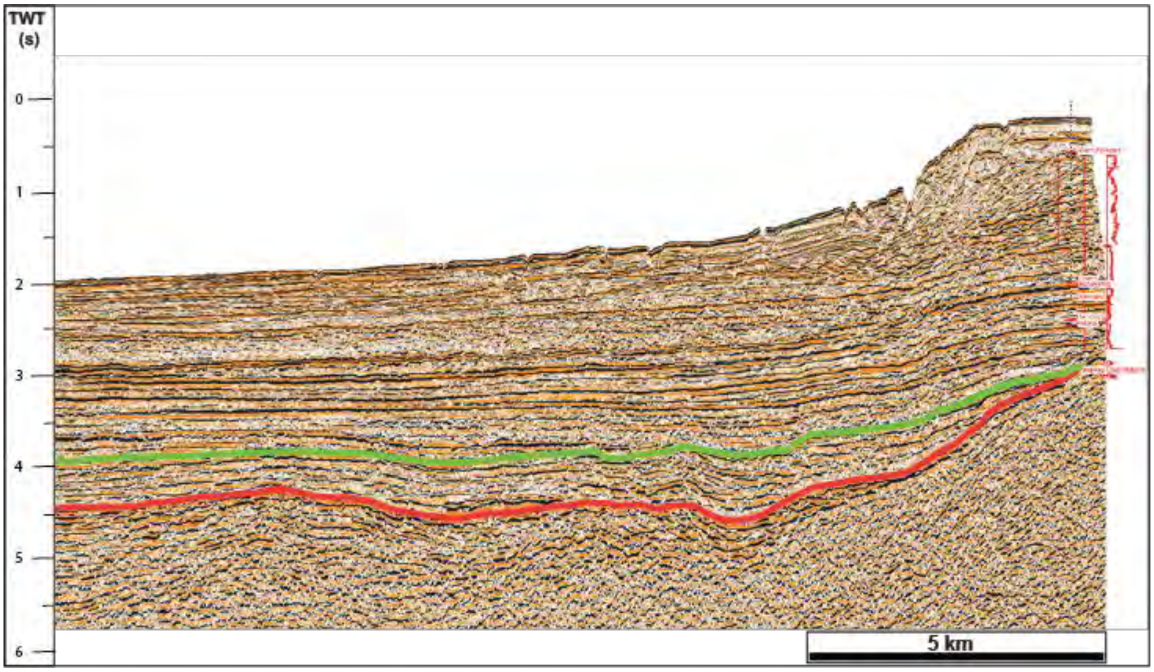


Figure 3.1 Example of stratigraphic sequences and well correlation.

3.3. Seismic Characteristic Interpretation

After finishing stratigraphic sequences and wells correlation to acquire all needed strata tops, strata tops tracking is the next task on the list as the first interpretation method (Figure 3.2). By doing so, distributions of interested sequences determined by their top stratra can be identified. But since strata top tracking is done only on the seismic section of each 2D seismic survey line, it leaves voids between seismic lines which make it hard to interpret or analyze. Hence, in order to fill these voids, horizon making comes in to help (Figure 3.3).

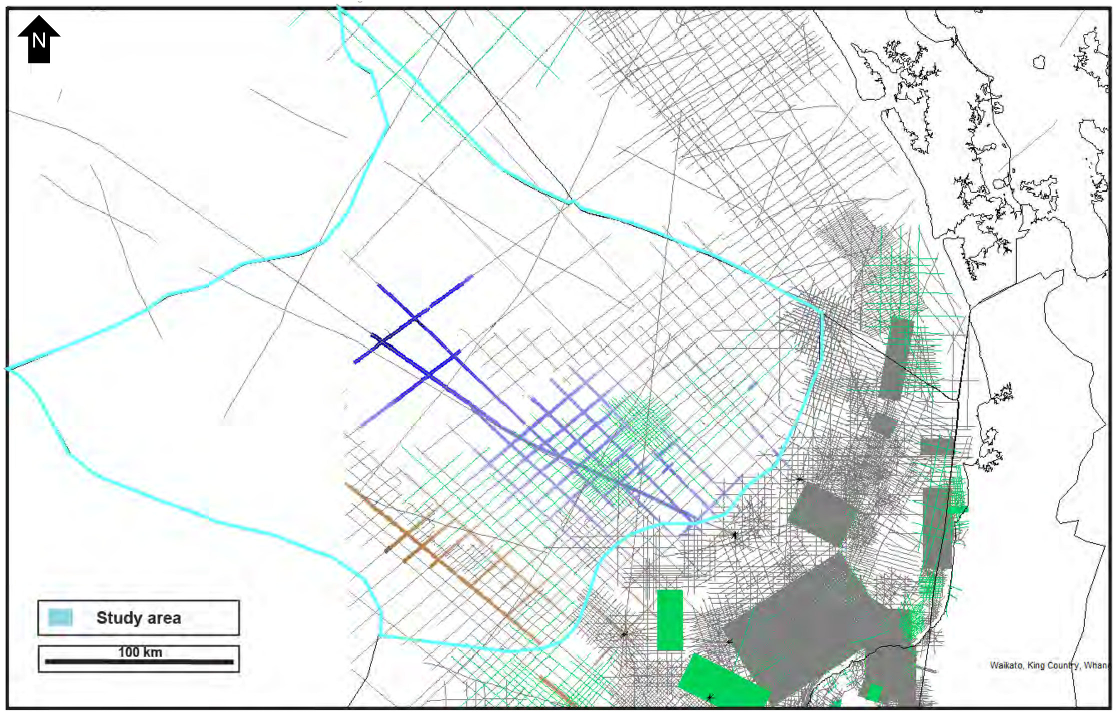


Figure 3.2 Example of tracked stratum top on 2D seismic survey lines.

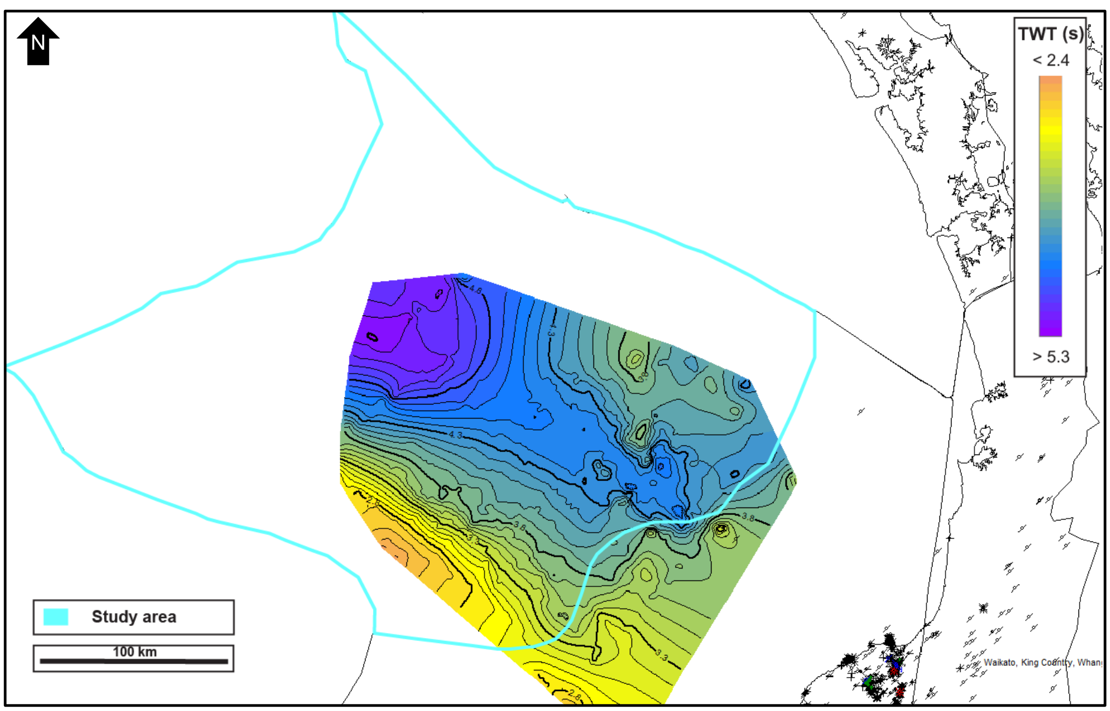


Figure 3.3 Example of horizon made from tracked seismic lines.

Characteristics of interested sequences will be interpreted solely from seismic reflections appeared in the seismic sections. Important seismic characteristics (or seismic facies as defined by Sangree and Widmier (1979) to be group of reflections that are mappable, whose elements such as amplitude, reflection pattern, etc. are different from adjacent units' elements) used in this project are seismic reflection amplitude, seismic reflection termination (Figure 3.4) and seismic configuration (Figure 3.5). In addition, seismic reflection terminations together with seismic reflection configuration is called as seismic reflection pattern (Sangree and Widmier, 1979). Each of these seismic characteristics has its own meaning and implies particular knowledge or geological information, when combined together, these characteristics give us the capability to predict depositional environments of them (Sangree and Widmier, 1979). The implications and information gained from seismic characteristics will be described thoroughly in 'Seismic characteristic analysis'.

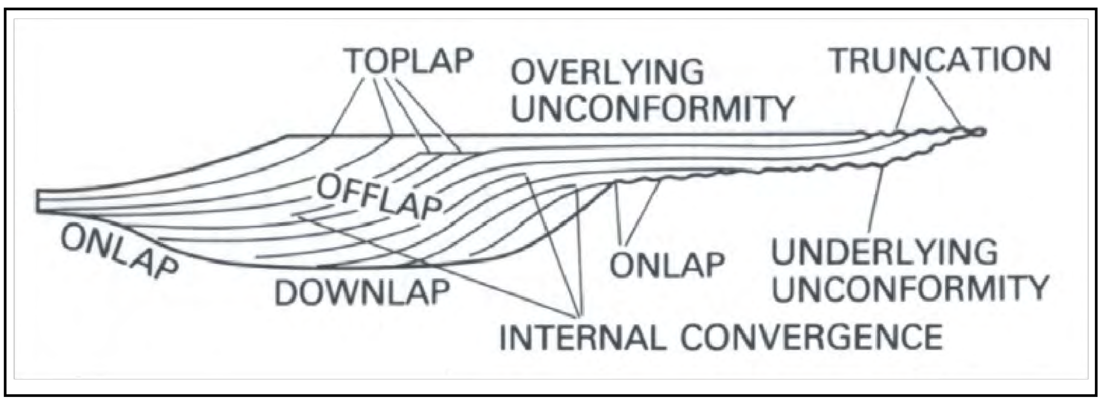


Figure 3.4 Schematic nature of seismic reflector terminations (after Mitchum et al., 1977).

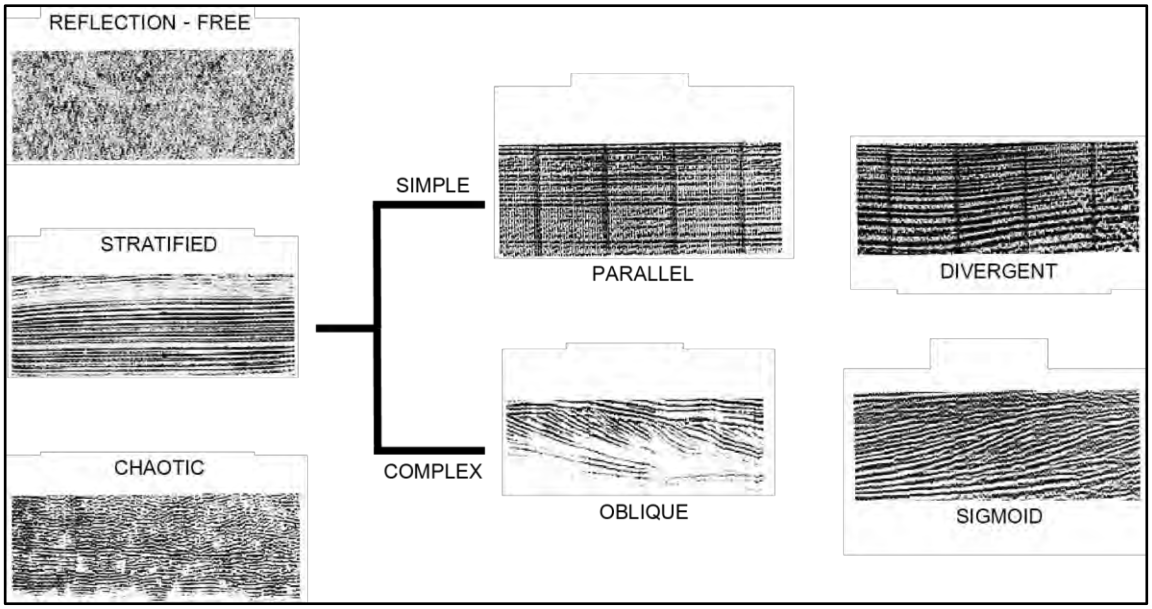


Figure 3.5 Typical seismic reflection configurations (modified after Sangree and Widmier, 1979).

3.4. Seismic Characteristics Analysis

As mentioned earlier, each seismic characteristic has its own meaning and tells particular story. Thus, it's important to understand each characteristic and analyze as carefully as possible in order to extract true implications hidden inside these seismic reflections.

According to Sangree and Widmier (1979), Seismic reflection configuration has three prominent types: reflection-free; stratified patterns; and chaotic patterns (Figure 3.5). Reflection-free configurations indicate a single, uniform lithology possibly caused by very steep slope, or intense homogenization after deposition of multiple lithologies. This type of configuration could possibly mean a salt dome or homogeneous marine shale (in clastic sediment regime), or massive carbonate reef-core environments (in evaporate-carbonate regime). Additionally, reflection-free configurations (Figure 3.5) can also be produced by massive igneous bodies as well. The second type, chaotic configurations (Figure 3.5) as can be observed by discontinuous discordant reflections may indicate deposition related to high energy deposit, beds disrupted after deposition or variability of deposition. The last type of seismic reflection configuration, stratified configurations can be classified into 2 sub-types: Simple and complex stratified configurations (Figure 3.5). Divergent arrangement and parallel of seismic cycles are included in simple stratified configurations. Parallel arrangement may indicate deposition occurred with uniform rates on a uniformly subsiding or stable surface. While divergent arrangements may indicate deposition occurred with variation in the rate of deposition, depositional surface that was progressively tilted, or both. On the other hand, sigmoid and oblique arrangements (Figure 3.5) are included in complex stratified configurations. Both arrangements are progressively developed on depositional surfaces that slope from relatively shallow-water area that have gently dipping into deeper area.

Seismic reflection amplitude can be found distinctly different in many sections. Density-velocity differences between beds and bed spacing influence these variations of seismic reflection amplitude (Sangree and Widmier, 1979). If there is a low degree of density-velocity contrast at the bedding interfaces, seismic reflection will be appear to have low-amplitude reflection. But if the contrast at the bedding interfaces is high, the result will be completely opposite. The bed spacing affects seismic reflection amplitude in a different way. Example for bed spacing is the spacing of the top and base surfaces (bed thickness), if the distance between top and base surfaces is close enough for their individual wavelets to interact with each other, summed (composite) trace will be made. Whether the summed trace of top and base surfaces' individual wavelets has high-amplitude reflection or low-amplitude reflection is up to the way their individual wavelets interfere, if they interfere constructively, composite trace will have high-amplitude reflections. Otherwise, the opposite result should be expected. Moreover, Silva et al. (2014) found that grain size also has influence on seismic signals by conducting seismic surveys in small-scale geological analogue models (transmitting ultrasonic signal through the model and record the energy reflected to receiving transducer). The models were designed to test seismic reflection response in the simulated pinch-out reservoirs with different-size glass beads fill. The result turns out that with the increment of the grain size increases, amplitude tends to increase (Silva et al., 2014) (Figure 3.6).

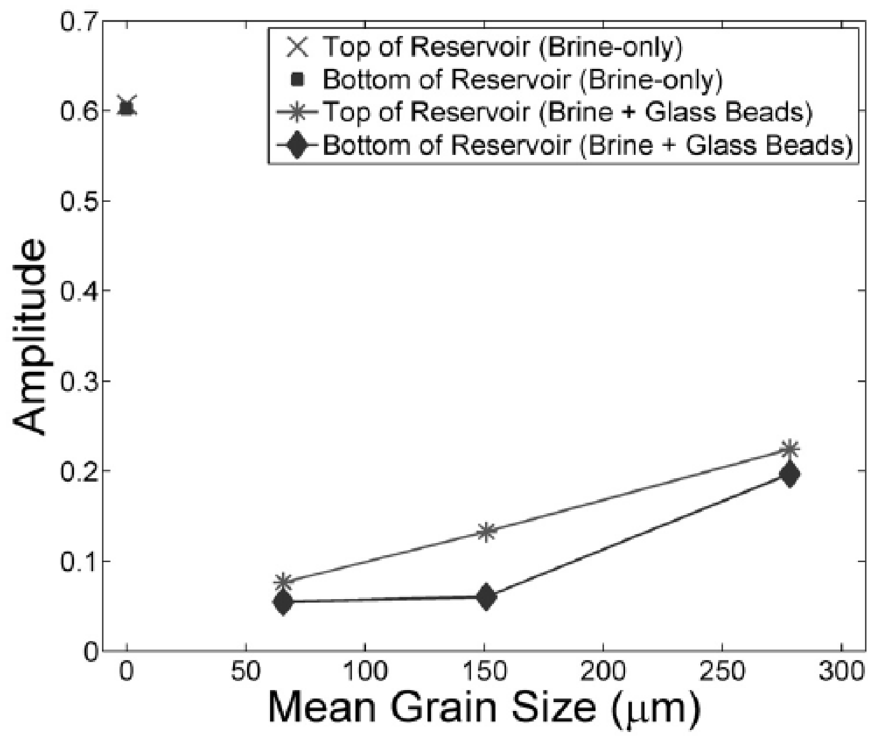


Figure 3.6 Graphic showing the influence of grain sizes to peak seismic reflection amplitudes (from Silva et al., 2014).

CHAPTER 4

RESULTS

Results acquired from interpretations and observations can be listed into three parts: 1) Regional seismic interpretation, 2) Seismic characteristics and seismic facies, and 3) Cretaceous potential petroleum source rocks distributions.

4.1. Regional Seismic Interpretation

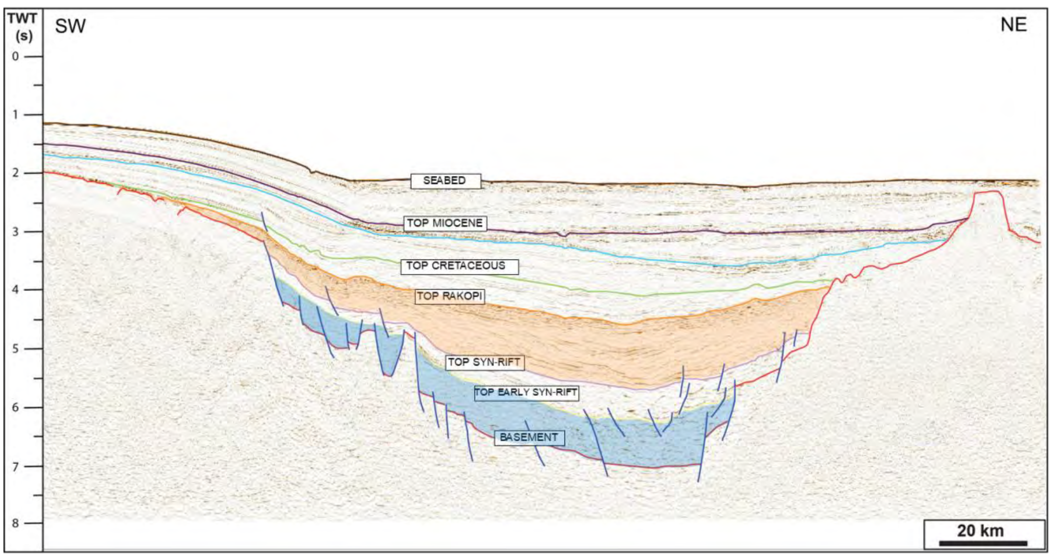


Figure 4.1 Cross section of deepwater Taranaki Basin and strata tops. Interested sequences, Rakopi sequence and Early Syn-rift sequence are painted in orange and blue colors respectively.

After performing stratigraphic sequences and well correlation, each sequence top tracking has been done to get the cross section of the study area (as shown in Figure 4.1). From all sequences older than Top Cretaceous stratum, there are one economically proved source rock sequence and one potential source rock sequence, which are Rakopi sequence (Killops et al., 1994) and Syn-rift sequence (Balance, 2009) respectively (Figure 4.1).

4.2. Seismic Characteristics and Seismic Facies

Since source rock characteristics concerned in this project are solely seismic characteristics, they are going to be described and analyzed by properties that can be seen in seismic sections such as seismic terminations, seismic reflection amplitude and seismic reflection patterns as told earlier in Chapter 3. And after being interpreted, each sequence characteristics have been recognized. Rakopi sequence has been classified accordingly by their seismic characteristics into 3 facies: facies 1 (Figure 4.2), facies 2 (Figure 4.3) and facies 3 (Figure 4.4). Syn-rift sequence has just one potential source rock facies.

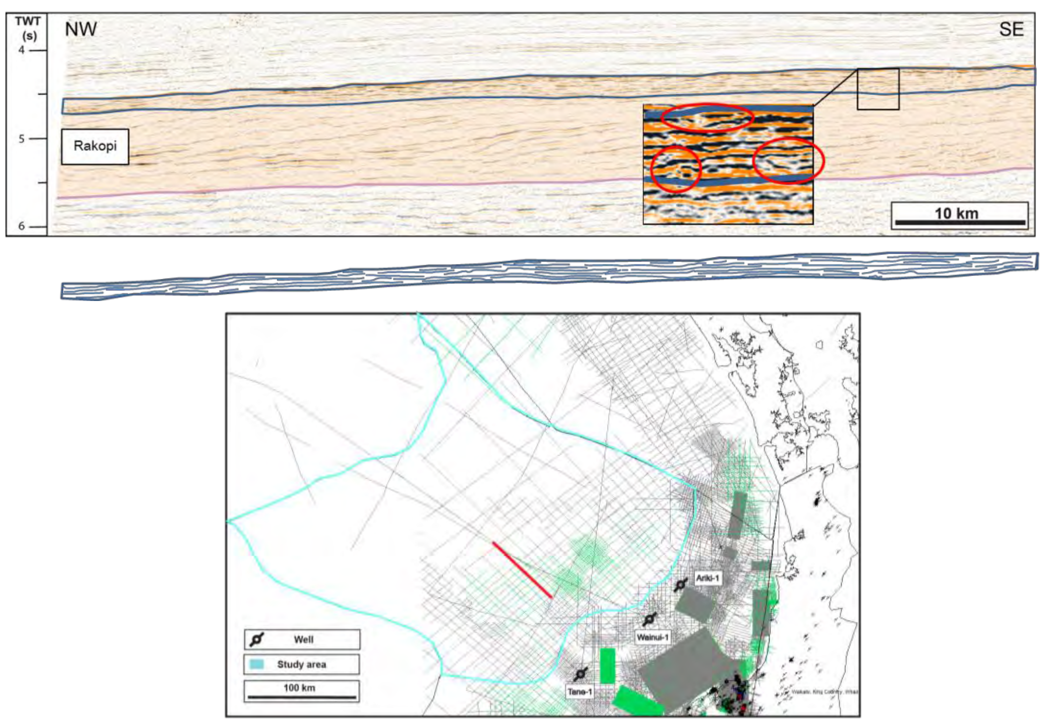


Figure 4.2 Rakopi sequence (facies 1) seismic characteristics (above) and its location in the study area (below).

Rakopi sequence (facies 1) (figure 4.2) shows relatively high amplitude seismic reflection compared to facies below it (can be seen in zoomed picture) with fairly chaotic reflection associated with erosional surface feature (in red circle of figure 4.2). Additionally, it accumulated on top of sequences that have oblique seismic configuration.

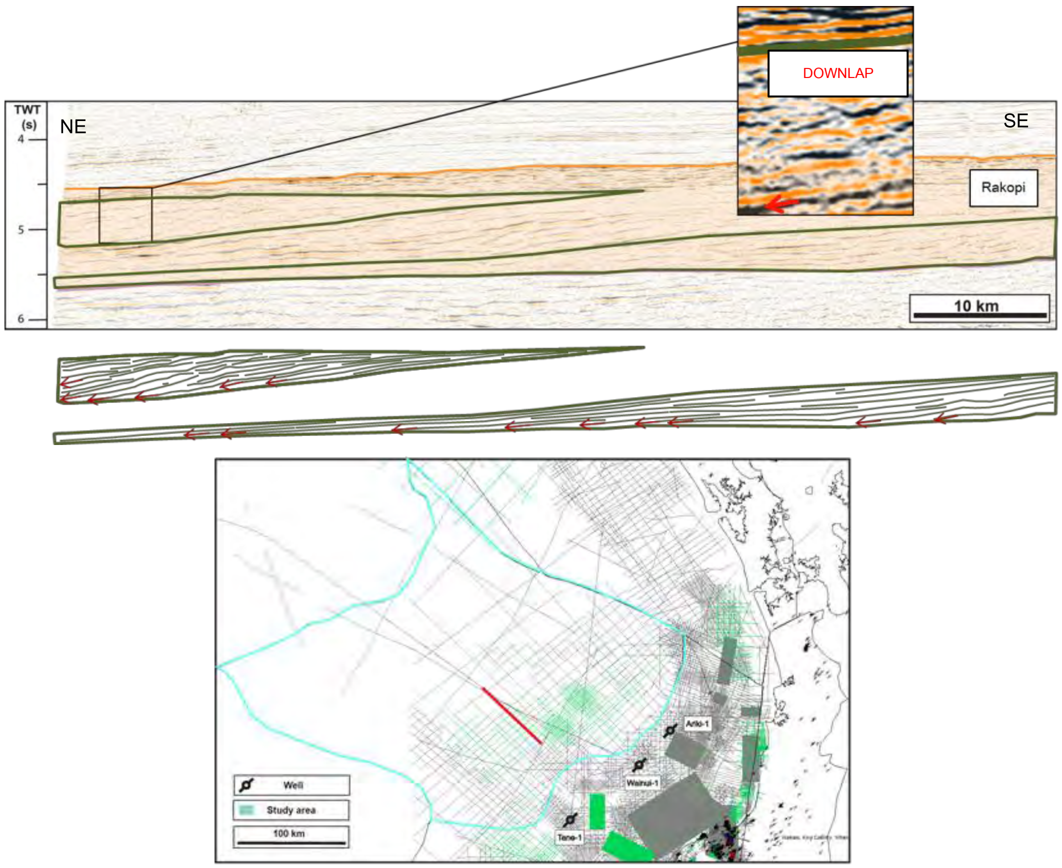


Figure 4.3 Rakopi seqeunce (facies 2) seismic characteristics (above) and its location in the study area (below).

Rakopi sequence (facies 2) (figure 4.3) shows relatively low amplitude seismic reflection compared to the upper facies (as can be easily noticed in zoomed picture of Figure 4.3). Seismic configurations of this facies appear to be parallel in the South East direction (shallower area) of the study area and gradually become sigmoid which can be recognized by the downlap terminations in the North West direction (deep water area).

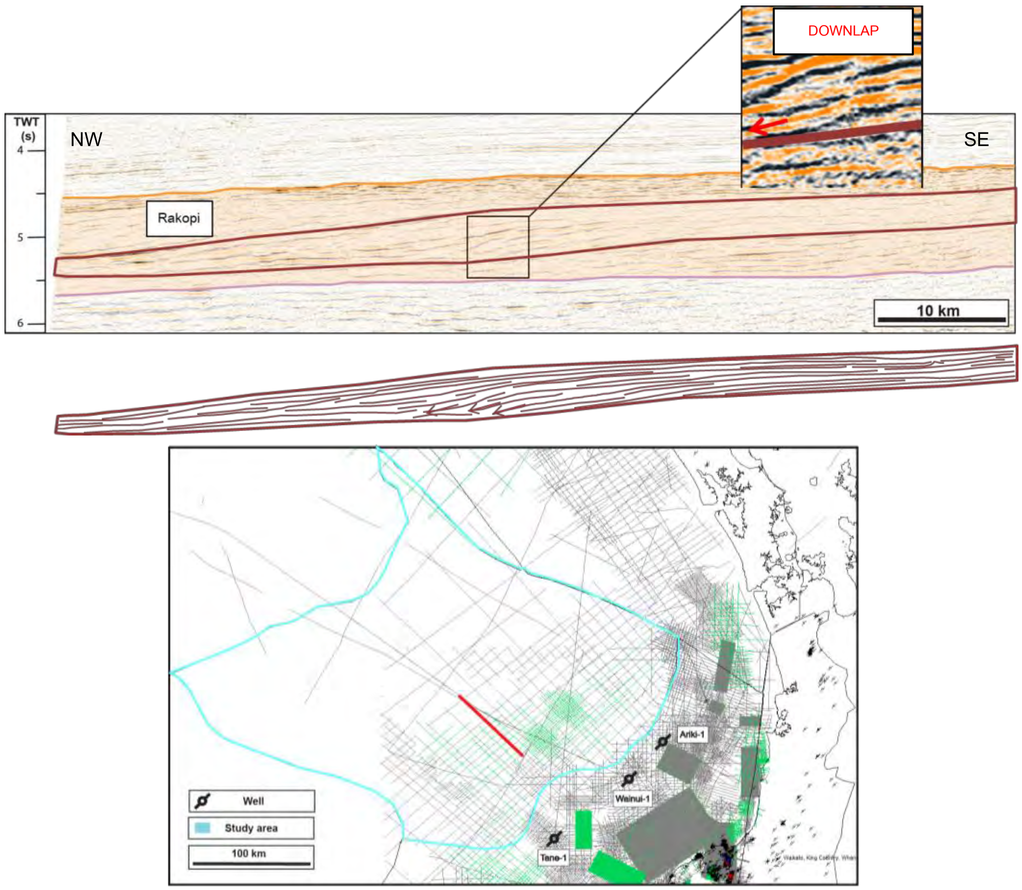


Figure 4.4 Rakopi sequence (facies 3) seismic characteristics (above) and its location in the study area (below).

Rakopi sequence facies 3 (Figure 4.4) shows relatively low to medium amplitude seismic reflection compared to seismic facies beneath it (shown in zoomed picture of Figure 4.4). Similar to Rakopi sequence (facies 2), seismic configurations of this facies exhibit parallel in the South East direction of the study area (shallower) but eventually become oblique (can be recognized by the steeper angle of downlap terminations than sigmoid configuration) instead of sigmoid in the opposite direction (deep water area).

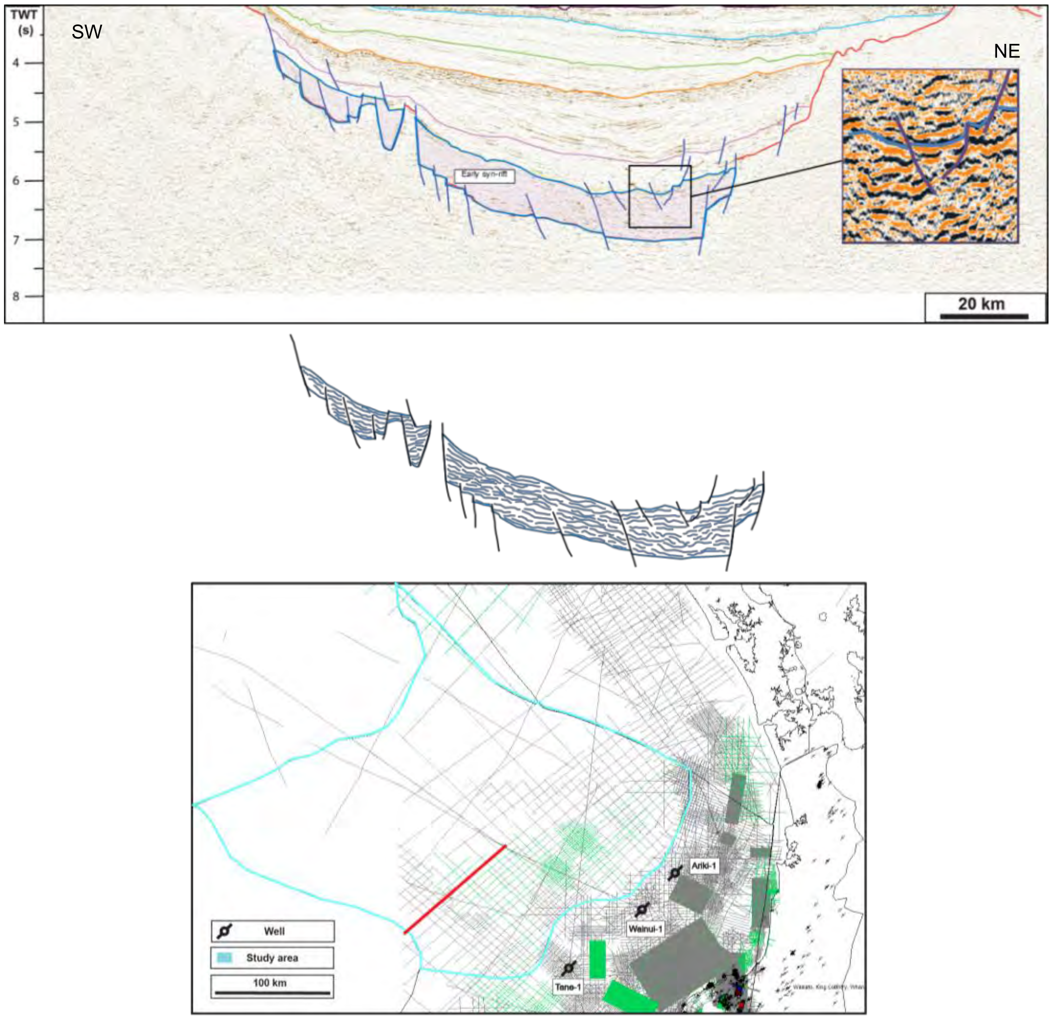


Figure 4.5 Rakopi seqeunce (facies 3) seismic characteristics (above) and its location in the study area (below).

The last sequence, Early Syn-rift sequence (Figure 4.5), shows relatively medium to high reflection seismic reflection especially in the deepest part of the sequence compared to adjoining sequences with chaotic seismic reflection configurations (as the depth gets deeper, seismic reflections become more chaotic).

Table 4.1 Seismic sections of Rakopi sequence (Order a, b and c) and Early Syn-rift sequence (Order d) with their facies observed from seismic reflection characteristics.

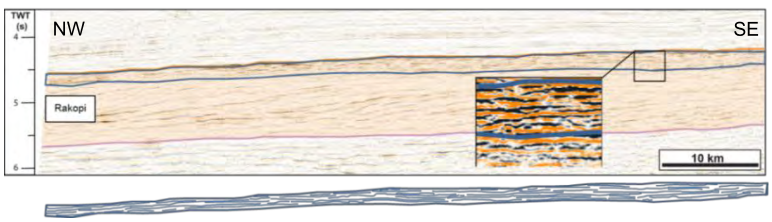
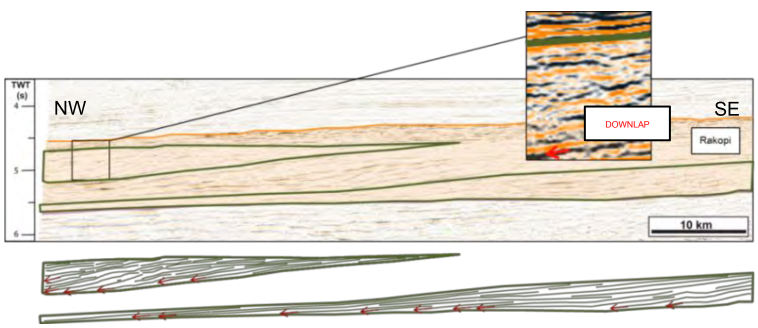
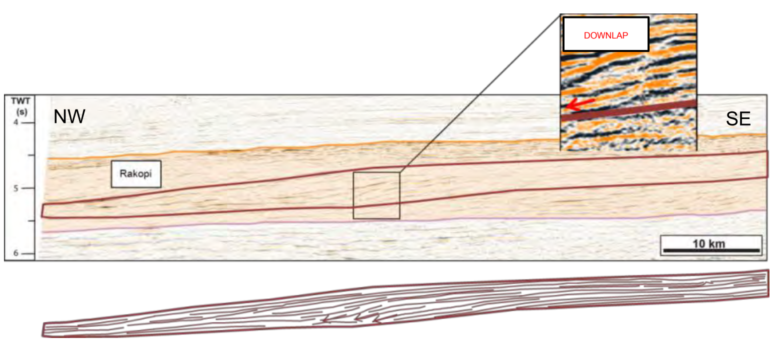
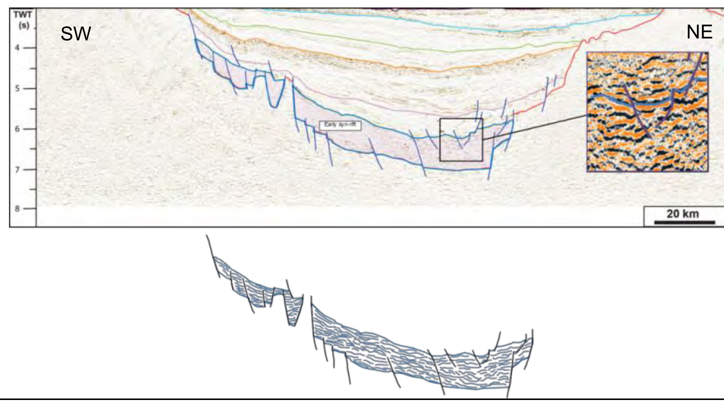
Order	Seismic sections and interpretations	Observations
a	Rakopi sequence (Facies 1)  	- Relatively high amplitude reflections - Erosional surface feature (associated with chaotic configurations
b	Rakopi sequence (Facies2)  	- Relatively low amplitude reflections - Sigmoid configuration - Low angle clinoforms
c	Rakopi sequence (Facies 3)  	- Relatively low – medium amplitude reflections - Oblique configuration - Low – medium angle clinoforms

Table 4.2 (continued) Seismic sections of Rakopi sequence (Order a, b and c) and Early Syn-rift sequence (Order d) with their facies observed from seismic reflection characteristics.

Order	Seismic sections and interpretations	Observations
d	Early Syn-rift sequence 	- Relatively medium – high reflections - Chaotic reflections

4.3. Cretaceous Potential Petroleum Source Rocks Distributions

As a result of sequences' top strata tracking from all possible 2D seismic sections in Deepwater Taranaki Basin, distributions of the interested source rock sequences had also been acquired. Shown in Figure 4.6 and Figure 4.7, is the youngest and economically proved Cretaceous petroleum source rock sequence, Rakopi sequence. Facies 1 covers more area than other two facies. Another one is the distribution of an interestingly potential source rock of Early Syn-rift sequence (displayed in Figure 4.8). This sequence distributed to a more restricted area compared to Rakopi sequence and its distribution sticks mostly to the center of the study area.

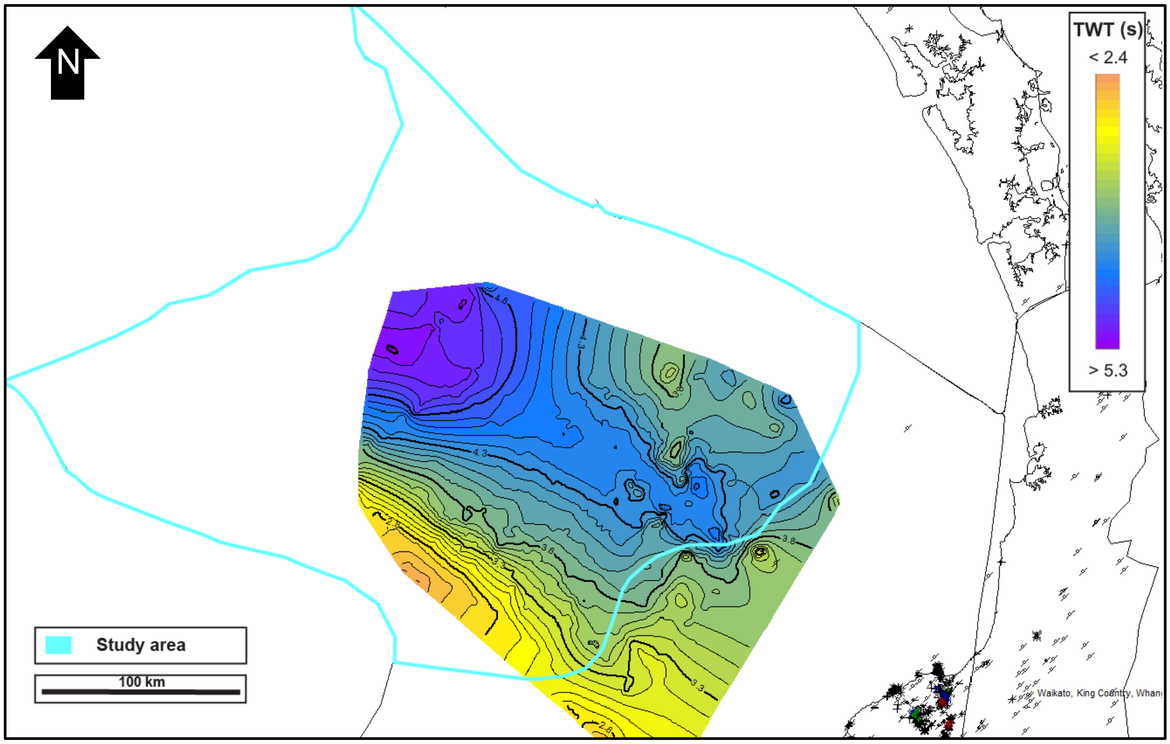


Figure 4.6 Rakopi sequence (Facies 1) distribution.

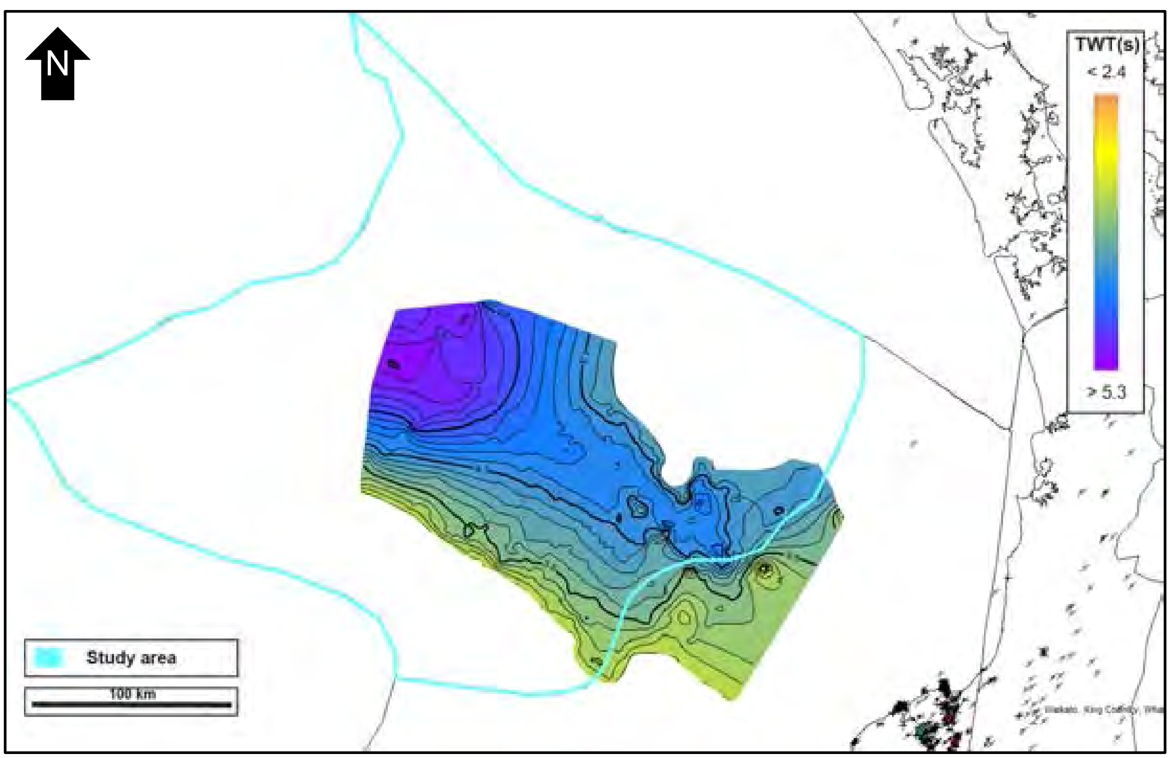


Figure 4.7 Rakopi sequence (Facies 2 and 3) distribution.

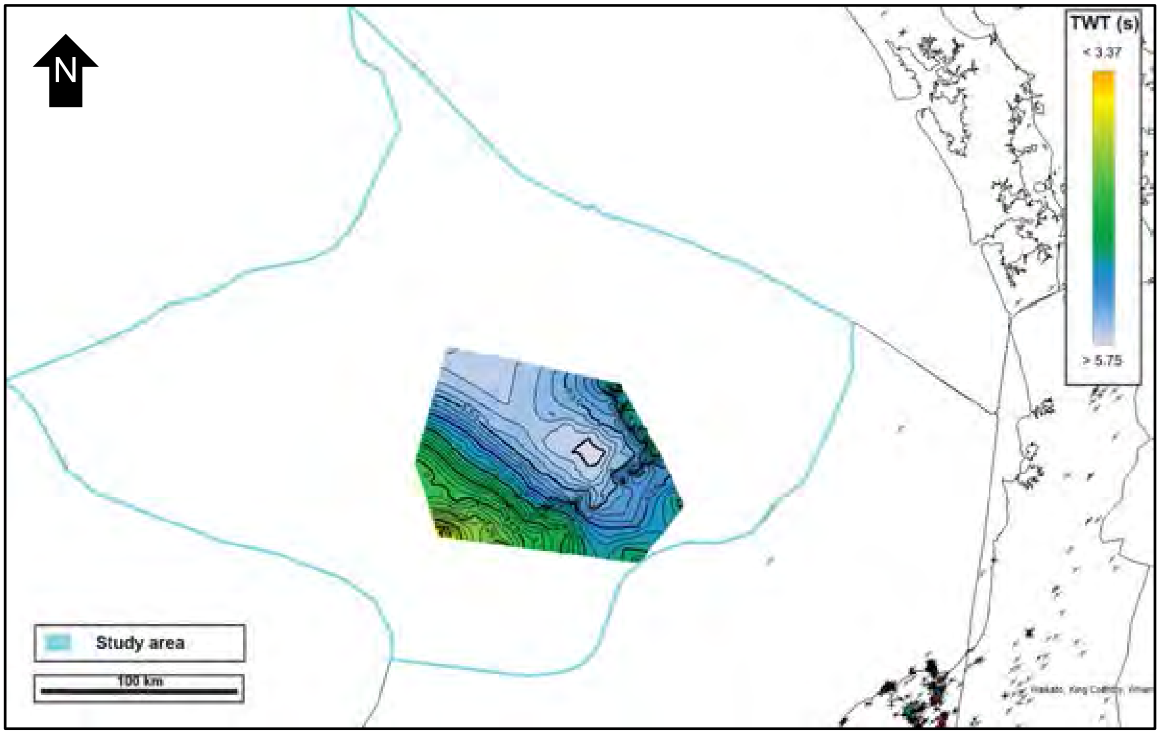


Figure 4.8 Syn-rift sequence distribution.

CHAPTER 5

DISCUSSIONS AND CONCLUSIONS

From Chapter 3, all possible seismic characteristics of potential sequences and their distributions have been interpreted. In this chapter, seismic characteristics acquired earlier are going to be discussed to see what useful information and data can be extracted from them such as depositional environments and factors affecting sediments deposited in the basin. Seismic characteristics analysis in this part will be carried out with previous studied seismic characteristics prototype mentioned in Chapter 3, literature reviews such as tectonic settings of the study area, and other researches related to analyzed topics. In this study, two sedimentary sequences are discussed on their source rock potential.

5.1. Rakopi Sequence (Facies 1)

Rakopi sequence (facies 1) (figure 4.2) as described in Unit 4 has three important seismic reflection characteristics: Erosional surface feature noticed by discontinuity of seismic reflection, relatively high amplitude seismic reflection especially where the erosional surface feature took place and the area of accumulation which is on top of sequence that has oblique and sigmoid seismic configuration. According to Bourget el al. (2014) who studied about Seismic stratigraphy and geomorphology of a tide or wave dominated shelf-edge delta (NW Australia), erosional surface feature overlain by chaotic seismic configuration reflection that has moderate to high amplitude reflection could be interpreted as distributary channel-fill. Relatively high amplitude seismic reflection usually associated with erosional surface feature might be influenced by the grain size of sediments deposited in the area. High amplitude seismic reflection could be caused by the relative increase of grain size (Silva et al., 2014). This fact supports the assumption that erosional surface feature indicates distributary channel-fill because distributary channel (in Figure 5.1) which usually forms on the delta plain deposit has strong enough flow to provide coarser grain sediments than surrounding subaerial overbank area (Nichols, 2009).

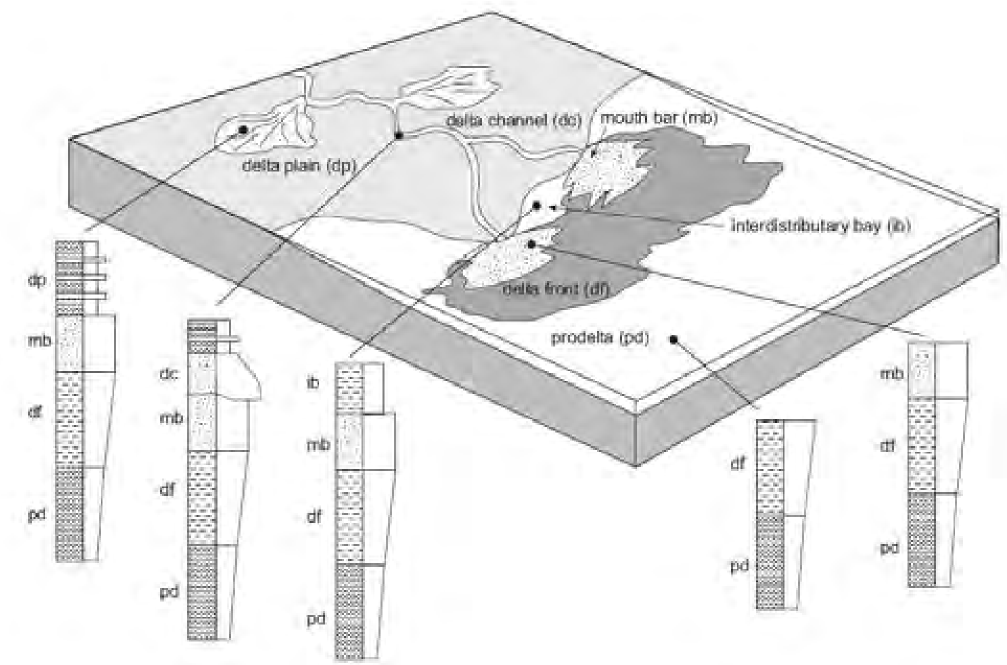


Figure 5.1 Delta deposition environments and successions which depend on the locations (from Nichols, 2009).

As a consequence, Rakopi sequence (facies 1) is interpreted as delta plain deposit. Oil which is one of the main proven, recoverable, petroleum reserves in Taranaki basin (Table 5.1), is geochemically characterized to be terrestrial derived evidenced by its waxy characteristic, high hopane:sterane ratios which indicate degradation of lignified tissues of higher plants such as waxes and leaf cuticles by bacterial activity and high C_{29} Sterane proportion which is dominantly common in terrestrial higher plants (Killops et al., 1994).

Field or Well	Reservoir Formation	Oil (10^6 bbl)	Condensate (10^6 bbl)	Gas (10^6 bbl oil equivalent)
Kora	Mohakatino	1	–	–
Mangahewa	Mangahewa	–	–	2
Moturoa	Matemateaonga	<1	–	–
Kaimiro	Mt. Messenger	na	na	na
	McKee	–	1	6
Ngatoro	Mt. Messenger	1	–	<1
Stratford	McKee/Mangahewa	–	1	4
Urenui-1	McKee	–	–	6
McKee	McKee	38	–	20
Tariki	Otaraoa	–	2	10
Ahuroa	Otaraoa	–	1	5
Waihapa	Tikorangi	21	–	4
	Kaimiro	–	<1	3
Ngaere	Tikorangi	6	–	1
Kapuni	Mangahewa	–	55	196
Toru	Farewell	7	–	20
Kupe South	Farewell	128	–	144
Maui	Mangahewa/Kaimiro	–	151	792
	Farewell	10	–	–
Moki	Moki	36	–	–
Maui-4	Mangahewa	7	–	–

*1 bbl oil equivalent = 150 m^3 gas. See Figure 1 for field locations. na = data not available.

Table 5.1 Shows proven, recoverable, petroleum reserves in Taranaki basin (after Killops et al., 1994)

All geochemical data of Taranaki basin oils suggest that most of Taranaki basin oil could be generated from source rocks that are deposited in the delta plain such as interdistributary channel delta plain (i.e. carbonaceous shale and coal (Aslam, 1992)) where vegetated swamps may be formed (Nichols, 2009). After creating isopach map of Rakopi sequence, it appears that the area that has the thickest strata sequence is located at the center of the distribution (figure 5.2). To simplify the distribution map of Rakopi sequence (facies 1), the map was modified to be two-tone color map. Thus, the area that has potential to deposit petroleum source rocks of this facies which is interpreted to be delta plain is shown by yellow area of figure 5.3. It is simply divided into two zones: upper delta plain (bright yellow) and Lower delta plain (dark yellow). Upper delta plain tends to deposit thicker and more continuous bed of coal than lower delta plain (Aslam, 1992)

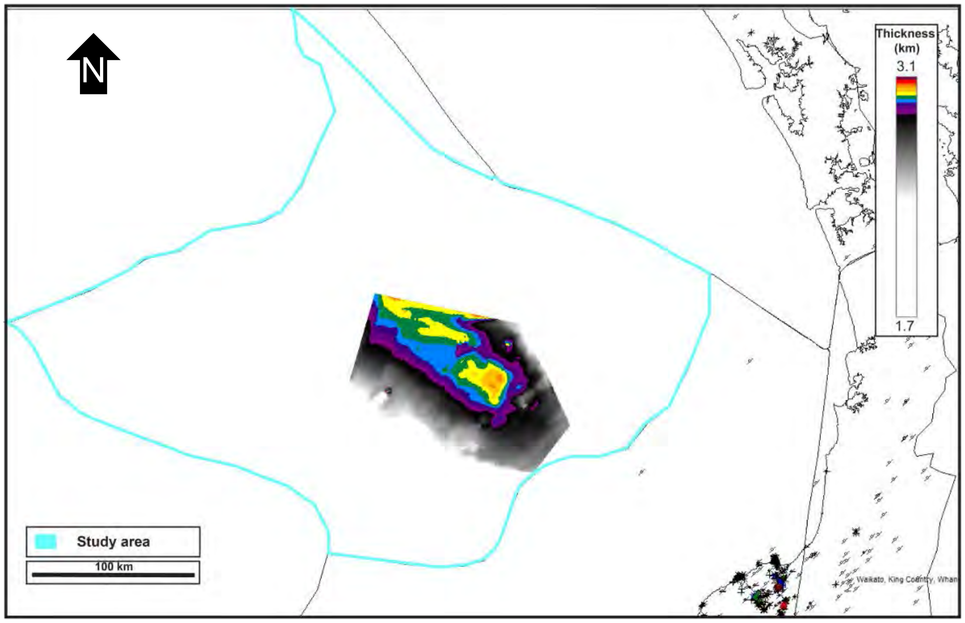


Figure 5.2 Isopach map of Rakopi sequence which shows the thickness of sediments deposited through the time.

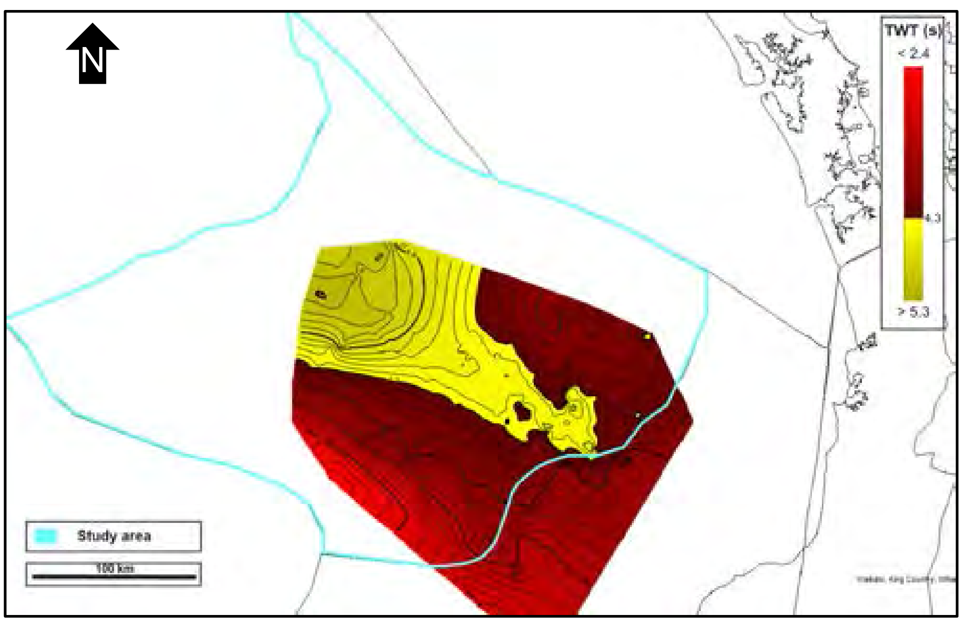


Figure 5.3 two-tone colour distribution map of rakopi sequence (facies 1) shows two areas that are drastically different in depth. Shallower area is shown in yellow color, deeper area is in red.

5.2. Rakopi Sequence (Facies 2 and Facies 3)

Facies 2 (Figure 4.3) and facie 3 (Figure 4.4) of Rakopi sequence have almost identical seismic reflection configuration. The differences between them are that downlap seismic terminations of facies 3 have steeper angle (oblique seismic configuration) than facies 2 (sigmoid seismic configuration) and seismic reflection amplitude of facies 3 is higher than that of facies 2 (figure 5.4). Oblique and sigmoid configuration imply the deposition in delta plain, delta front and prodelta environments (Sangree and Widmier, 1979). The higher seismic reflection amplitude of facies 3 compared to facies 2 could be caused by the relative increase of grain size (Silva et al., 2014).

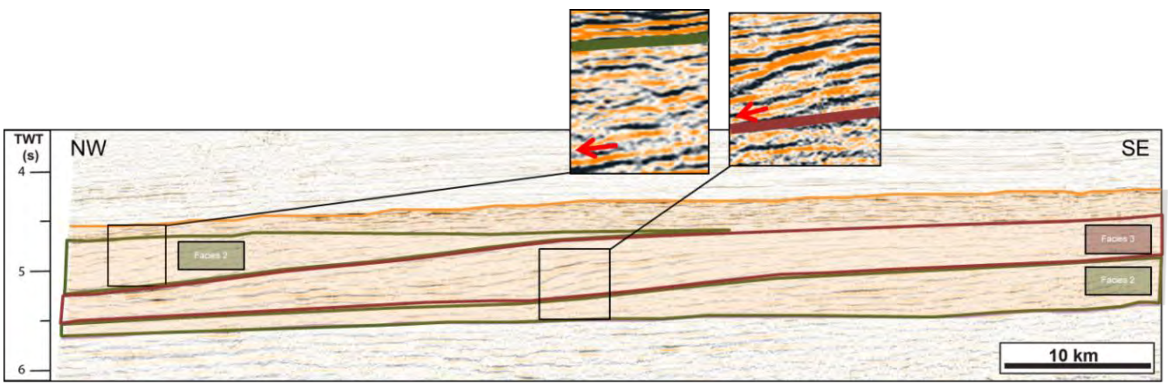


Figure 5.4 Seismic characteristics of Rakopi sequence facies 2 (left zoomed picture) and facies 3 (right zoomed picture) in comparison.

Even though facies 2 and facies 3 of Rakopi sequence have almost identical seismic configuration indicating that they might be deposited in the same depositional environment, but in in fact, they were not. Facies 3 might be deposited when the eustatic sea level was lower than that of facies 2, resulting in the mixing of coarser grain in the area (shown by relatively high amplitude seismic reflections in Figure 5.3). Thus, facies 3 is interpreted to be deposited in delta front environment. Whereas facies 2 is interpreted to be deposited in eustatically higher sea level environment that is prodelta environment.

5.3. Syn-rift Sequence

Despite being the oldest sequence deposited in Taranaki basin, this sequence strata have fully chaotic seismic configurations which is totally different from Rakopi sequence. Another important syn-rift sequence seismic reflection characteristic is the moderate to high amplitude seismic reflection especially in the deepest part of the sequence (figure 4.5). Chaotic seismic reflection configuration implies relatively high energy of deposition or bed disruption. This type of configuration can be interpreted as sediments deposited in topographic lows of basin floor by the process of high-density turbidity current and mass transport slump (Sangree and Widmier, 1979). Turbidity current is gravity-driven process. It can occur in places that have sediment supply and a slope (Nichols, 2009). Turbidity current (figure 3.9) has relatively high Reynolds number which makes the deposition rapid. This rapid deposition might provide the capability of preserving organic matter or hydrocarbon source rocks since it has less opportunity to contact and be oxidized by oxygen or be degraded by living organisms. Moderate to high amplitude seismic reflection like mentioned before could be analyzed as relatively coarse grains deposit or mixing of coarse grains. This implication can be related to turbidity current because coarse grain deposit is one of turbidite sequence features which usually occur at the bottom of sequence (Nichols, 2009).

Moreover, Balance (2009) stated that Taranaki Basin had initially been formed as a rift valley around Late Cretaceous and became inactive (considered to be failed rift) before Tasman Sea spreading occurred. And in this rift valley system, sediment fills usually contain hydrocarbon source rocks and coal measures. Then, combining the fact that rapid deposition of turbidity current which might provide the capability of preservation and research of Balance (2009) stating that initial rift valley deposit of Taranaki Basin usually contain hydrocarbon source rocks and coal measures, turbidity current was the most likely case of depositional process during Syn-rift sequence. Even though these interpretations may point to the turbidity current to be responsible for the deposition of Syn-rift sequence, it doesn't eliminate the fact that it could be slump deposit as well, since slump deposit can also provide chaotic seismic configuration just like turbidity current do. So, further study is crucial.

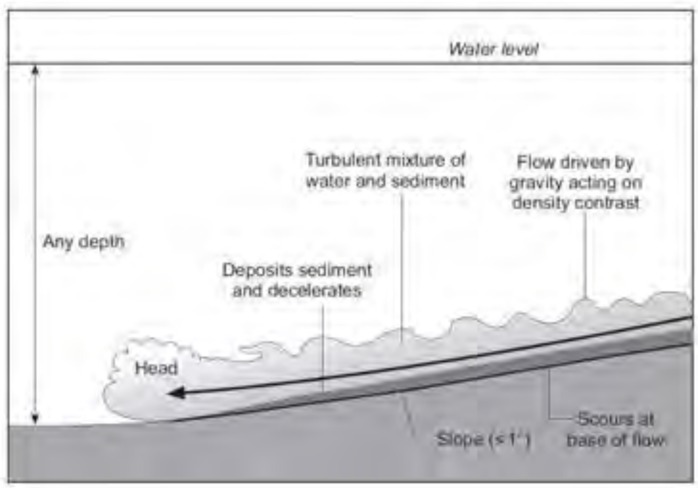


Figure 5.5 Turbidity current and mixture carried by turbidite current (called turbidite when deposited) (from Nichols, 2009).

5.4. Conclusions

In this study, two Cretaceous potential petroleum source rock sequences were identified in the deepwater Taranaki Basin including Rakopi sequence and syn-rift sequence. Rakopi sequence, an important petroleum source rock sequence in Taranaki Basin, also distributed to a wide area in deep water Taranaki Basin. This sequence was classified into 3 facies according to its seismic reflection characteristics. Each of them implies different depositional environments of the deltaic environments; facies 1 was interpreted to be deltaplain deposit, facies 2 was interpreted to be prodelta deposit, and facies 3 was interpreted to be delta front deposit. Combined together, they suggest the fluctuated sea levels during the depositions. Facies 1 and facies 2 tend to be capable of preserving terrestrial origin source rocks and mixed terrestrial and marine source rocks respectively. Facies 3 on the other hand, does not, due to the mixing of coarser grain sediments implying that the petroleum source rock preservation might be disturbed by high energy deposit.

Syn-rift sequence distributed to a much narrower area than Rakopi sequence. Its seismic reflection characteristics suggest the deposition by turbidity current or slump deposit. The deposition occurred by these processes tend to be able to preserve petroleum source rocks. Anyway, the origin and type of potential petroleum source rock of syn-rift sequence could not be concluded by the seismic reflection characteristics.

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