Integrated Sequence Stratigraphic and Seismic Facies Analysis for Hydrocarbon Prospectivity of the Taranaki Basin, New Zealand

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Abstract:- This study analyses the hydrocarbon potential and basin characteristics of the Taranaki Basin in New Zealand, the country's primary petroleum-producing region. The research, which uses a robust methodology involving 2D seismic data, well logs, and other geological information, examines the basin's stratigraphy, structural features, and petroleum systems. Key findings include the identification of two genetic sequences with associated system tracts, multiple reservoir and source rock units, and both structural and stratigraphic trapping mechanisms. Seismic facies analysis revealed eight distinct facies types which characterize the depositional environments. Play fairway mapping identified sweet spots where all petroleum system elements overlap. Risk assessment highlighted factors like gas chimneys and fault-compromised seals. The study concludes by presenting the geologic chance of success for three identified plays and one prospect in different stratigraphic intervals. This comprehensive analysis provides new insights into the under-explored portions of the Taranaki Basin and its hydrocarbon potential. By enhancing the understanding of the basin's stratigraphic architecture and depositional history, this study aims to improve reservoir distribution and quality predictability. Moreover, integrating seismic facies analysis with sequence stratigraphy offers a robust tool for delineating potential hydrocarbon-bearing zones, thereby reducing exploration risk and aiding the efficient reassessment of existing prospective zones and future exploration efforts.

Keywords:- *Taranaki Basin, Hydrocarbon, Seismic Facies, Gas Chimney, Petroleum System Elements.*

I. INTRODUCTION

The Taranaki Basin, located on the western margin of New Zealand (Figure 1), is a key player in the country's petroleum industry. With a rich history of hydrocarbon exploration and production, this basin has been a focal point for geoscientists aiming to understand its complex geological evolution and significant resource potential. It holds the distinction of being the only known commercial hydrocarbon reserve in New Zealand, with these hydrocarbons mainly originating from late Cretaceous and Paleocene-Eocene coals [1, 2, 3]. Most petroleum reserves in this basin are located within a broadly NE-SW trending fairway of Paleogene shallow marine and Pliocene turbiditic sandstones [2, 4 – 8]. Previous geochemical studies indicate that the hydrocarbons in the Taranaki Basin mainly originate from terrigenous organo-facies within the Late Cretaceous-Paleocene source rocks, which lie unconformably above the basement complex [9 – 11, 8]. The U.S. Geological Survey utilised a geology-based assessment methodology to estimate that the greater Taranaki Basin and East Coast Basin of New Zealand contain approximately 806 million barrels of oil and 17.0 trillion cubic feet of gas [12]. Most identified petroleum reserves have been found along the Paleocene shoreline and in coastal plain sandstone deposited in a late-rift or post-rift passive margin setting [13]. The basin's formation has been influenced by multiple deformation events, including the fault-controlled rift transform from the Late Cretaceous-Paleocene, the passive contractional margin from the Eocene-Early Oligocene, and the active margin from the Oligocene to the present [14 -15].

This research aims to comprehensively assess the Taranaki Basin's hydrocarbon potential through an integrated approach that combines sequence stratigraphy and seismic facies analysis. Specific aims include: (1) delineating and interpreting the stratigraphic sequences and systems tracts within the basin and establishing a chronostratigraphic framework that helps identify potential reservoir, source, and seal rocks. (2). To analyse seismic reflection data to identify and interpret various seismic facies indicative of different depositional environments and lithologies, thereby aiding in predicting hydrocarbon reservoir distribution. (3). To assess the hydrocarbon systems within the Taranaki Basin, including identifying key source rocks, maturation histories, migration pathways, and trapping mechanisms.

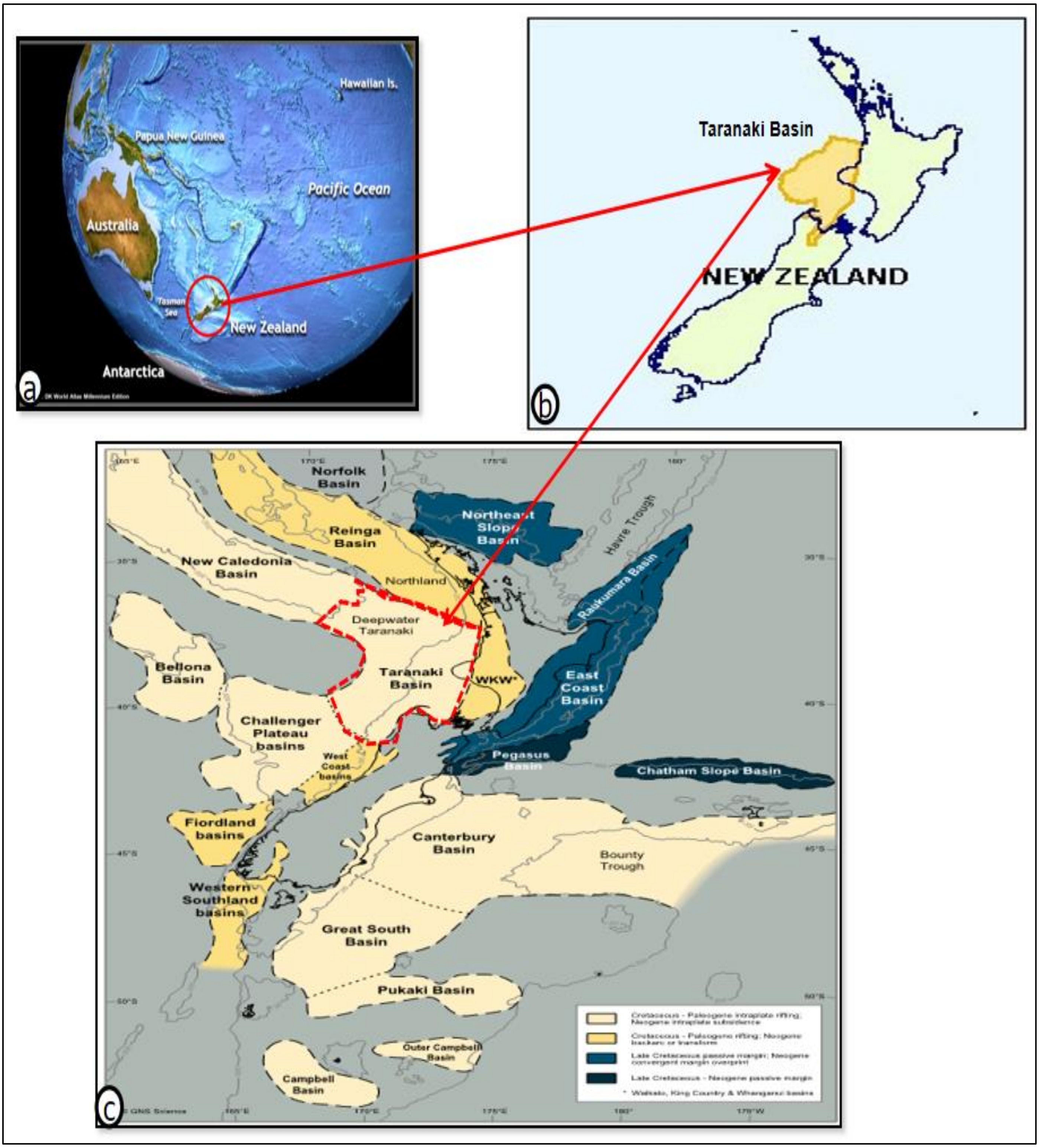

Fig 1 Regional Setting of (a) New Zealand (b) Taranaki Basin (c) Basin Extent
(Source: DK World Atlas)

II. GEOLOGIC SETTING

Taranaki Basin is an extensional sedimentary basin located along the western side of the North Island, New Zealand and was initiated in the late Cretaceous in response to rifting and sea-floor spreading in the Tasman Sea-Lord Howe Rise region [13]. The basin has since experienced multiple phases of subsidence and tectonic activity. It is characterised by diverse depositional environments, from deep marine to coastal plain settings, influenced by tectonic and eustatic processes. The basin's stratigraphic framework is complex, with numerous unconformities and transgressive-regressive sequences that reflect the interplay between sediment supply, sea-level changes, and tectonic movements [13]. The basin is a large sinking block formed by movement between the Australian and Pacific tectonic plates. For the

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past 80 to 100 million years, eroded rocks from the surrounding land have been deposited in the basin as mudstone and sandstone. Taranaki basin contains alternating layers of sandstone, siltstone, mudstone and occasional coal and limestone deposits.

The basin's geology is greatly influenced by the rifting, compression and subduction of the Pacific plate beneath the Australian plate, which gave rise to its complex structural setting, including folds, faults and sedimentation sequences [16]. Taranaki basin is well known for its oil and gas reserves, which can be traced to anticlinal and synclinal structures that serve as important hydrocarbon traps. The oil and gas fields are found within the basin along two main faults: the Taranaki Fault in the east and the offshore Cape Egmont Fault in the west [17, 3]. They may act as pathways for the migration of hydrocarbons and influence trapping mechanisms within the basin.

The Taranaki Basin's primary structure is divided into two regions: (I) the Western stable platform and (II) the Eastern mobile belt [13, 18, 16]. The Western stable platform extends from the Cape Egmont fault zone in the west to near the continental shelf edge. This area is characterised by a broad, simple, and relatively undeformed structure and stratigraphy, ranging from the Late Cretaceous to present-day sediments, which have primarily remained undisturbed since the late Eocene [17]. The Cape Egmont fault zone separates the stable platform and the mobile belt, which trends north to northeast. The Eastern mobile belt includes the Southern Inversion Zone, Central Graben, Manaia Graben, and Northern Graben, trending from north to south and significantly influenced by compressional forces that created features like the Tarata Thrust Zone [13, 19 – 20]. The Taranaki Basin's generalised stratigraphy (Figure 2) comprises several groups with petroleum-bearing formations of varying ages: the Pakawau Group, Kapuni Group, Moa Group, Ngatoro Group, Wai-iti Group, and Rotokare Group, spanning from the Late Cretaceous to the Pleistocene [13].

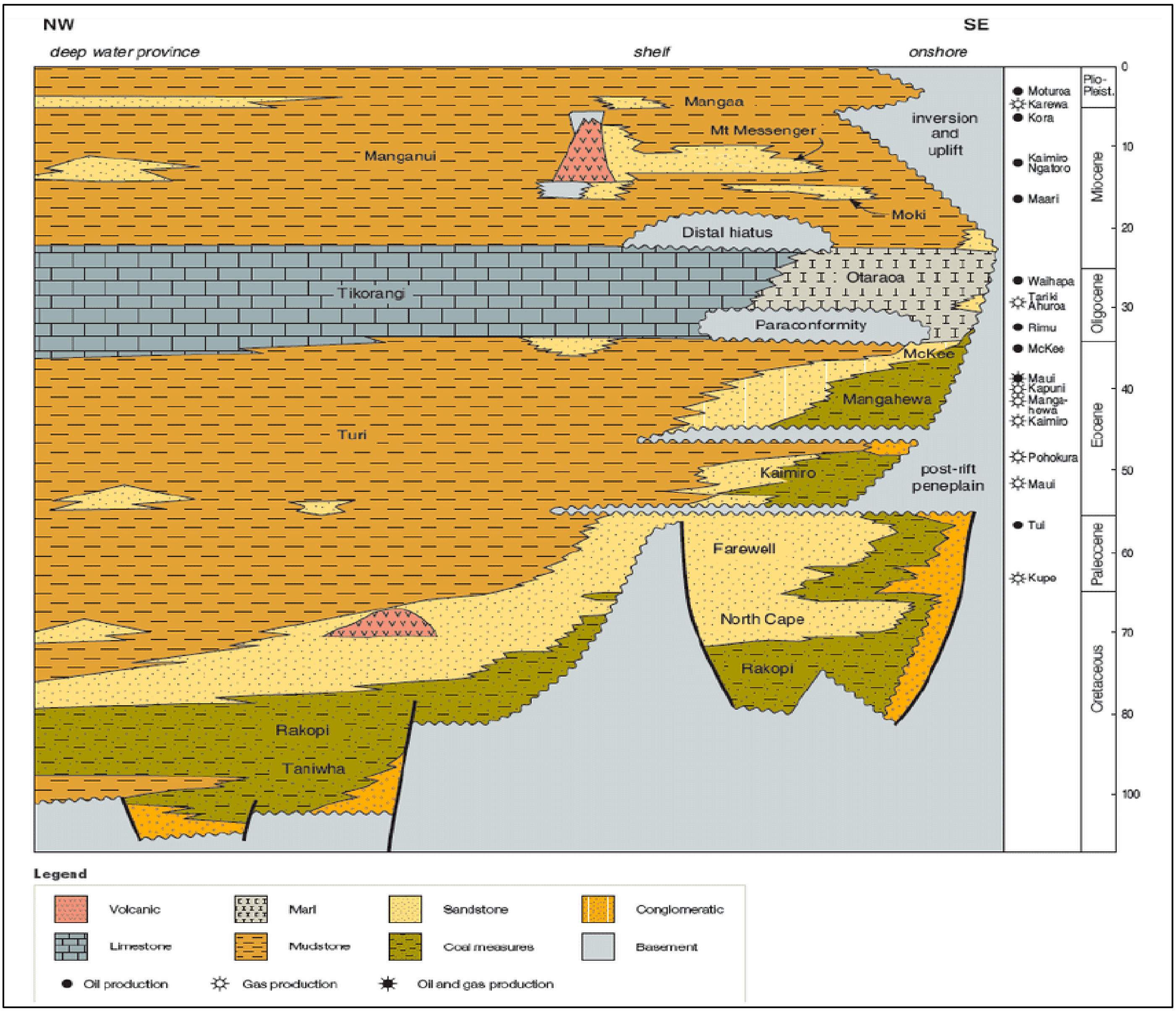

Fig 2 Generalized stratigraphic section of Taranaki Basin New Zealand (Grahame-2015).

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III. MATERIALS AND METHOD

This study employs a multidisciplinary approach, integrating various datasets made available by the American Association of Petroleum Geologists (AAPG) and analytical techniques. The data used for this study include 215 2-D seismic lines, nine wells with well-log suites, geochemical data, a check-shot survey, and a surface geologic map.

Basin analysis involved a literature review of the basin, encompassing the tectonic framework, stratigraphy, structures and the Petroleum system of the Taranaki basin (Figure 3). The well-log interpretation was carried out using the available well logs from which reservoir tops were mapped and correlated across the wells in the northwest-southeast direction. A seismic-to-well tie was done using the generated synthetic seismogram. Well-log sequence stratigraphic Interpretation was done using the Depositional Sequence Model IV to identify genetic sequences and their corresponding system tracts. Seismic facies analysis was carried out based on reflection parameters: reflection amplitudes, reflection geometry and continuity of reflection [21 – 22] along key seismic traverses to identify the seismic facies indicative of exploration play facies.

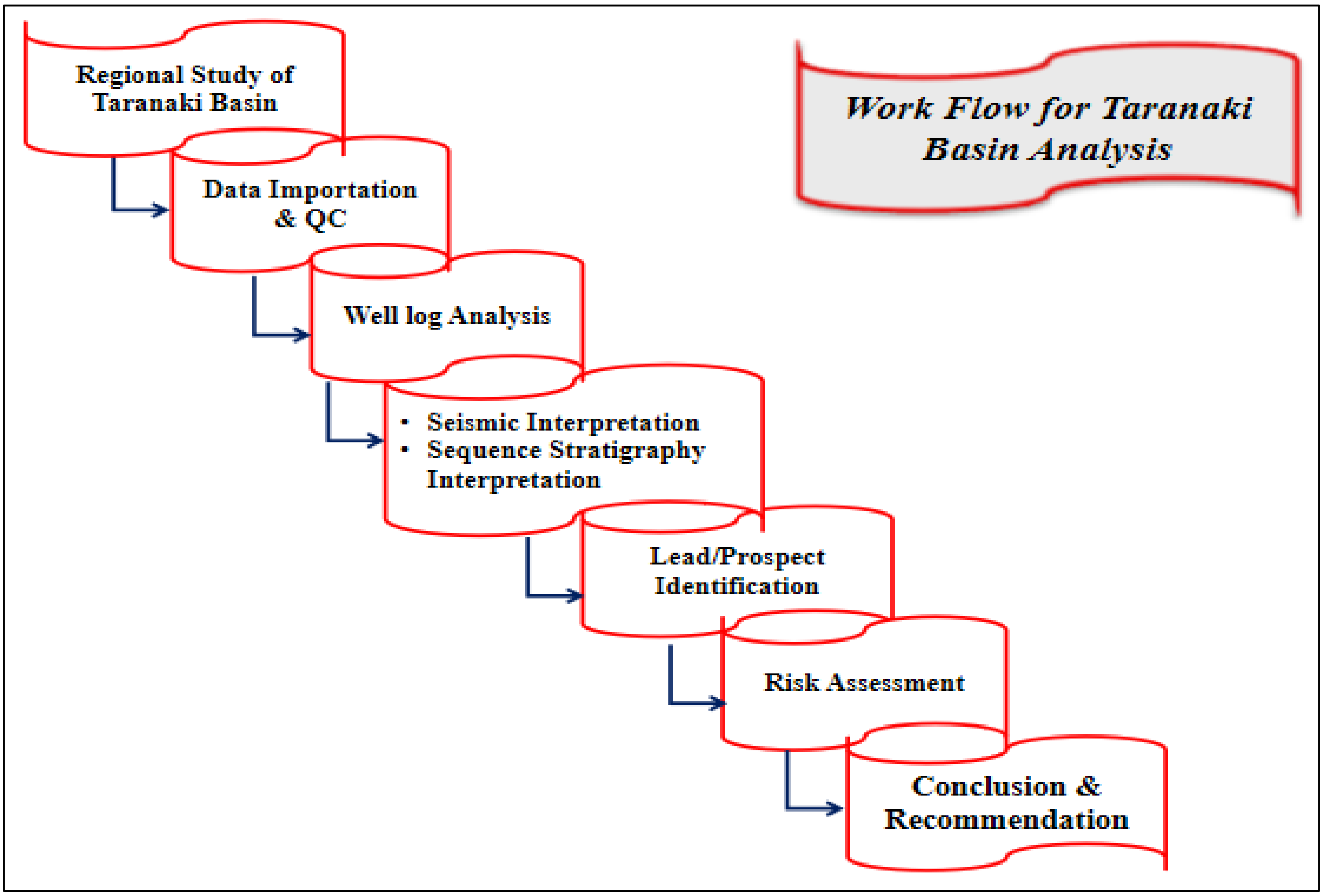

Fig 3 Methodology Workflow

Seismic structural interpretation was also done on the seismic sections to generate a seismic time map, depth maps, fault planes, and isochore maps. The petroleum play maps were generated and superimposed to identify the play sweet spot consisting of the prospective zones. Volumetric calculation is beyond the scope of this research.

IV. RESULTS AND DISCUSSION

From the well logs, the lithostratigraphy was interpreted by correlating it from the formation tops across the wells, thereby determining the lateral extents of the elements of our petroleum system in the field (Figure 4). The well logs also aided in stratigraphic sequence generation and interpretation, which was done using the depositional sequence model IV. As such, the sequences were defined by SBs (sequence boundaries (unconformities). This resulted in two genetic sequences designated SEQ 1 and SEQ 2 and their relative system tracts. From the interpretation, the source and seal rocks were determined to be the shales of the HSTs and the TSTs, while the reservoirs are the sand units of the HSTs and the LSTs (Figures 5 and 6).

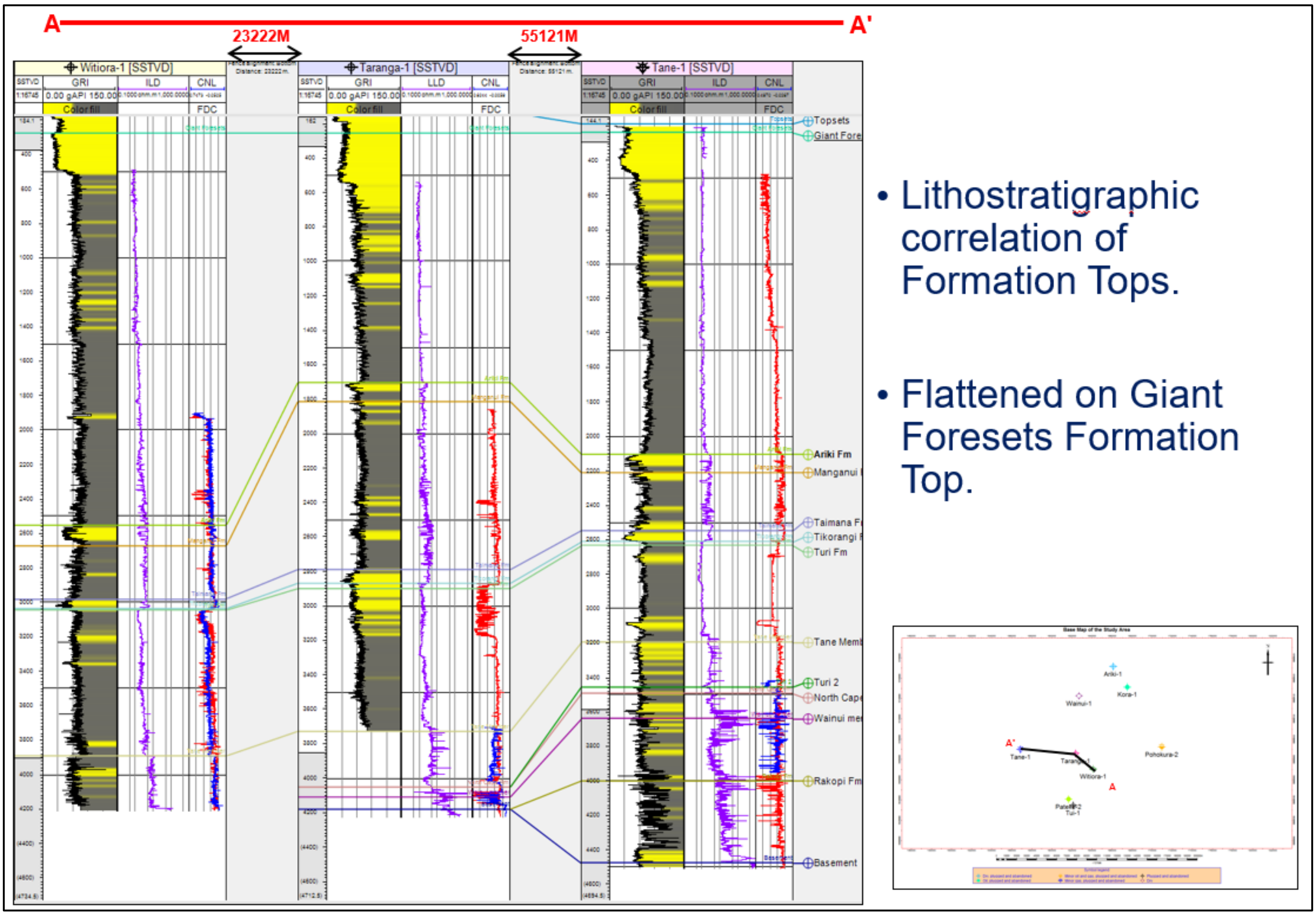

Fig 4 Lithostratigraphic Correlation between Witiora-1, Taranga-1 and Tane-1 Wells.

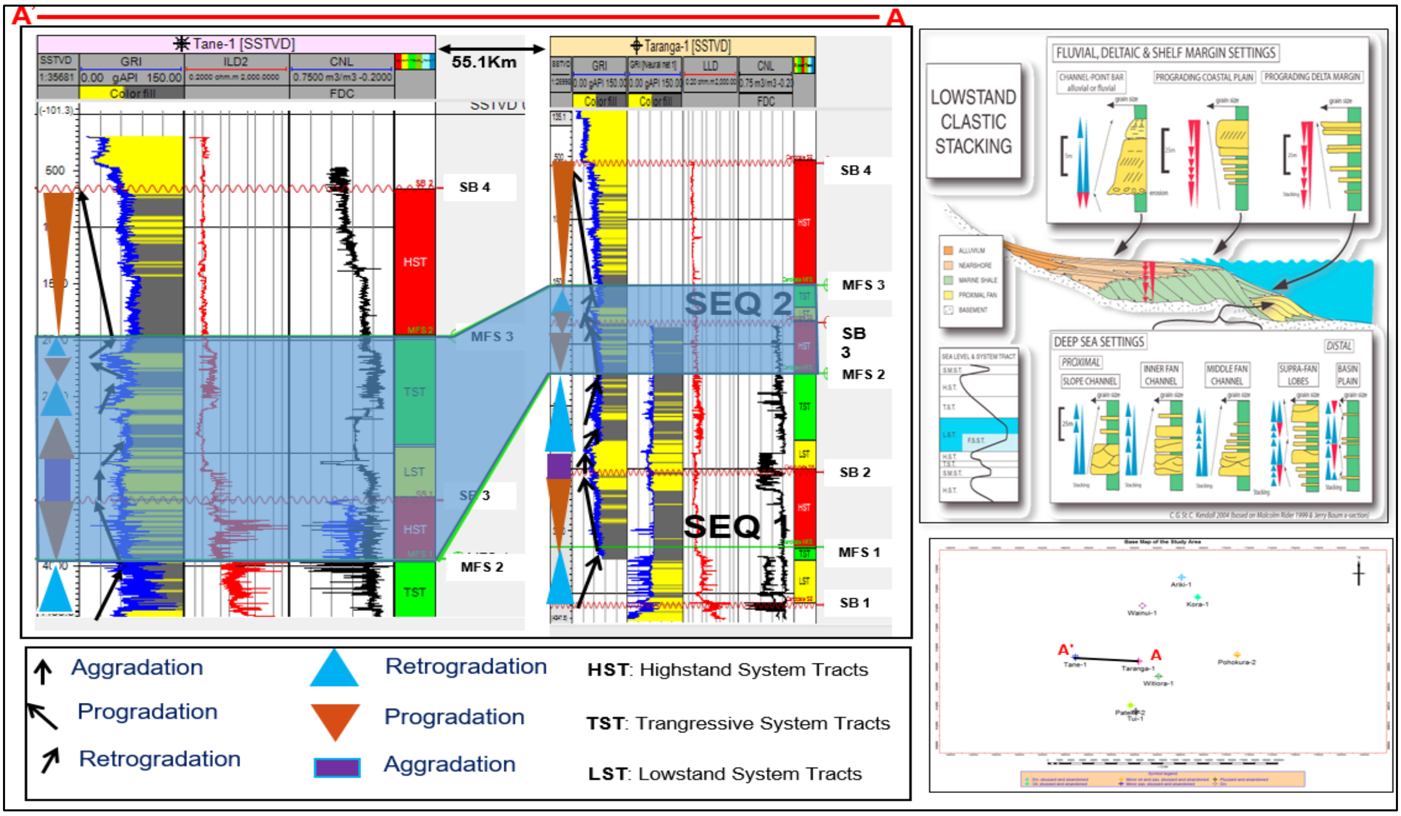

Fig 5 Sequence Stratigraphic Interpretation using Depositional Sequence Model IV

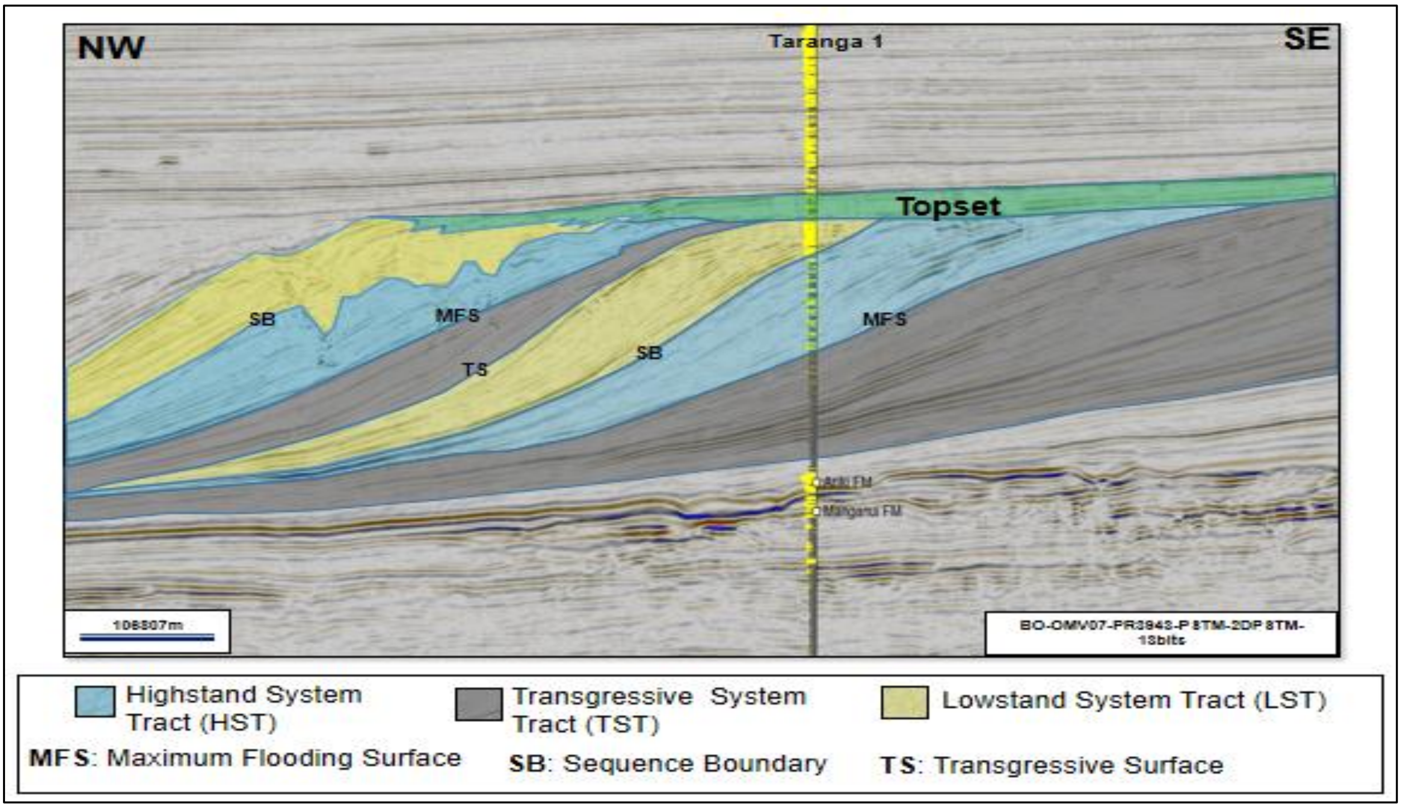

Fig 6 Seismic sequence stratigraphy of the Giant Foresets on BO-ST03-401-8bits 2D seismic reflection line.

The dissimilarities between the measurement domains of the seismic data and the well logs make seismic-to-well tie an essential step in the workflow highlighted in the methodology section. This was also done to determine the seismic responses of the rock units. The top of Turi FM was determined to be a trough (Figure 7).

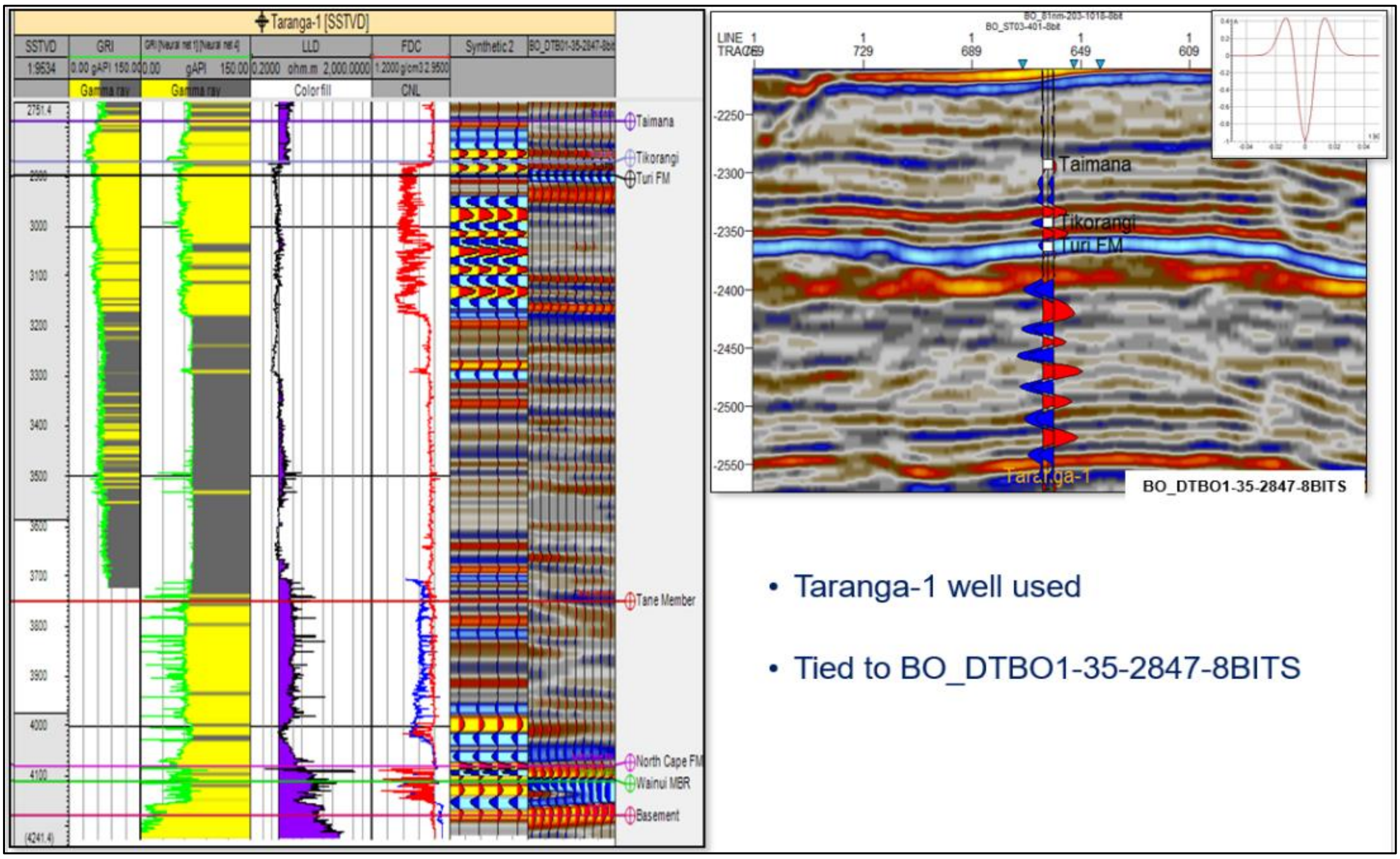

Fig 7 Seismic to Well Tie: Generated Synthetics and tied to BO_DTBO1-35-2847-8BITS

From seismic facies interpretation, eight seismic facies were identified on dip sections based on seismic reflection parameters such as amplitude, continuity and geometry. They include Low amplitude discontinuous, shingled to chaotic (Bl), Convergent low amplitude and thinning at Paleo-basin margin (Ctl), Low amplitude convergent (Cbl), High and low amplitude convergent (Cbhl), High amplitude convergent (Cbh), High amplitude discontinuous, shingled to chaotic (Bh), High and low amplitude discontinuous, shingled to chaotic (Bhl), Continuous high and low amplitude (D) (Figures 8 and 9).

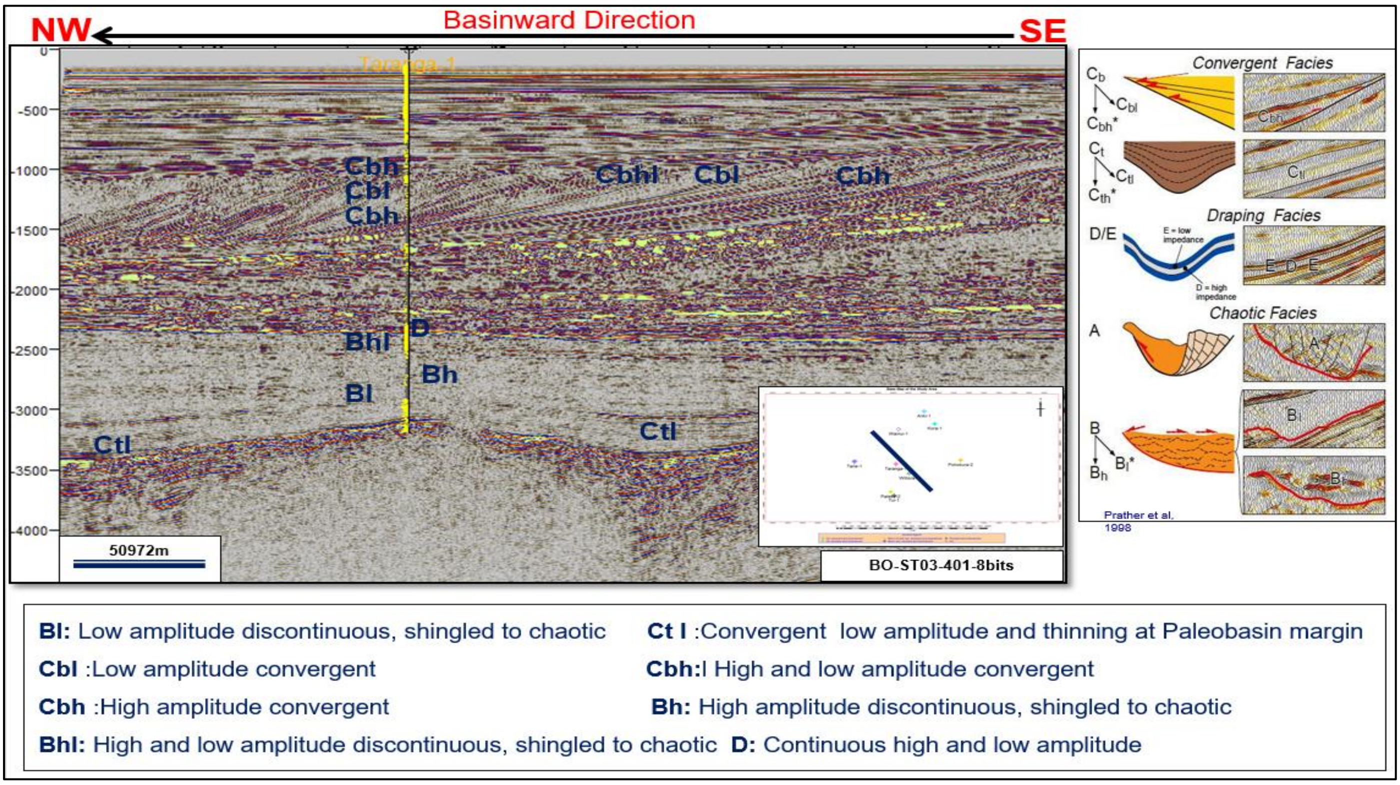

Fig 8 Seismic Facies on Dip Sections on BO-ST03-401-8bits Seismic line

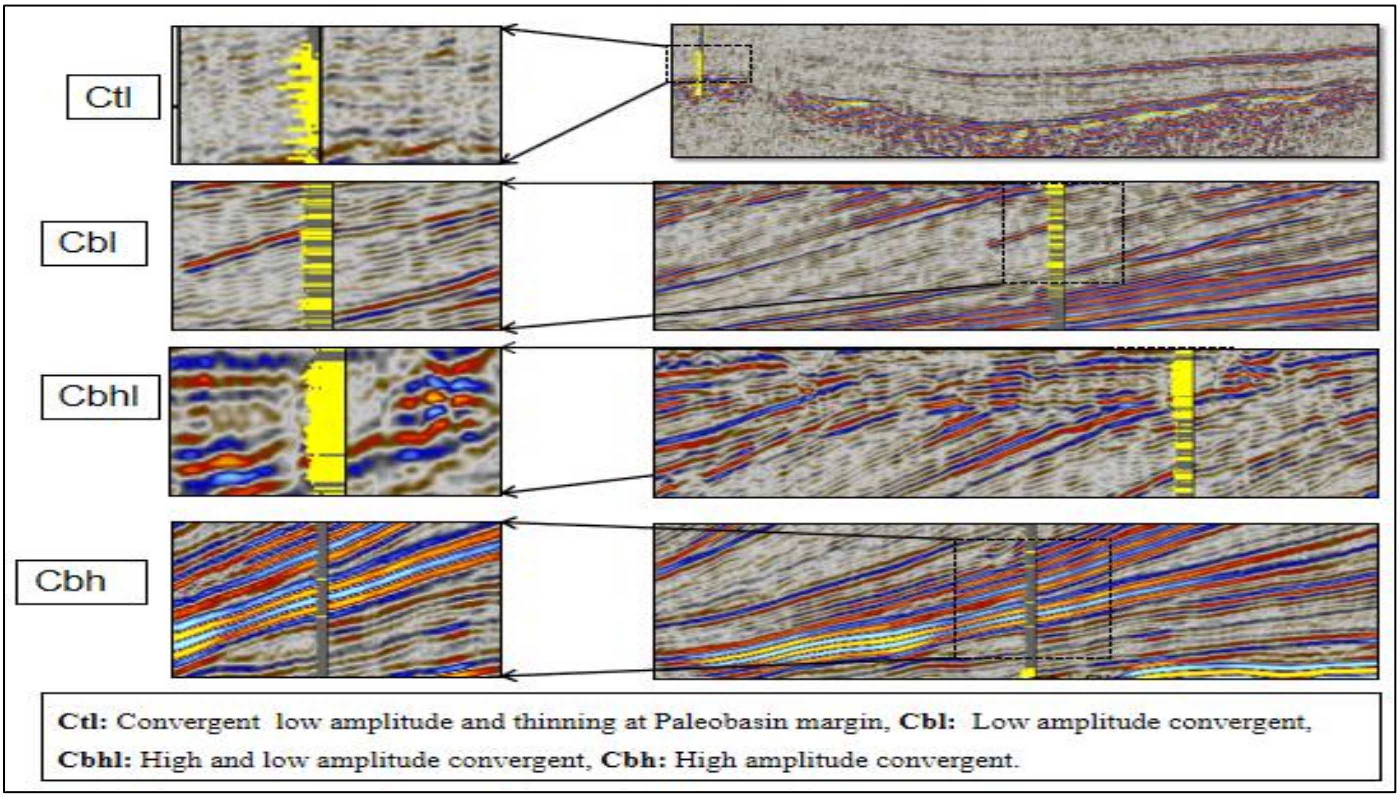

Fig. 9a: Enlarged sections from Figure 8 showing the interpreted seismic facies

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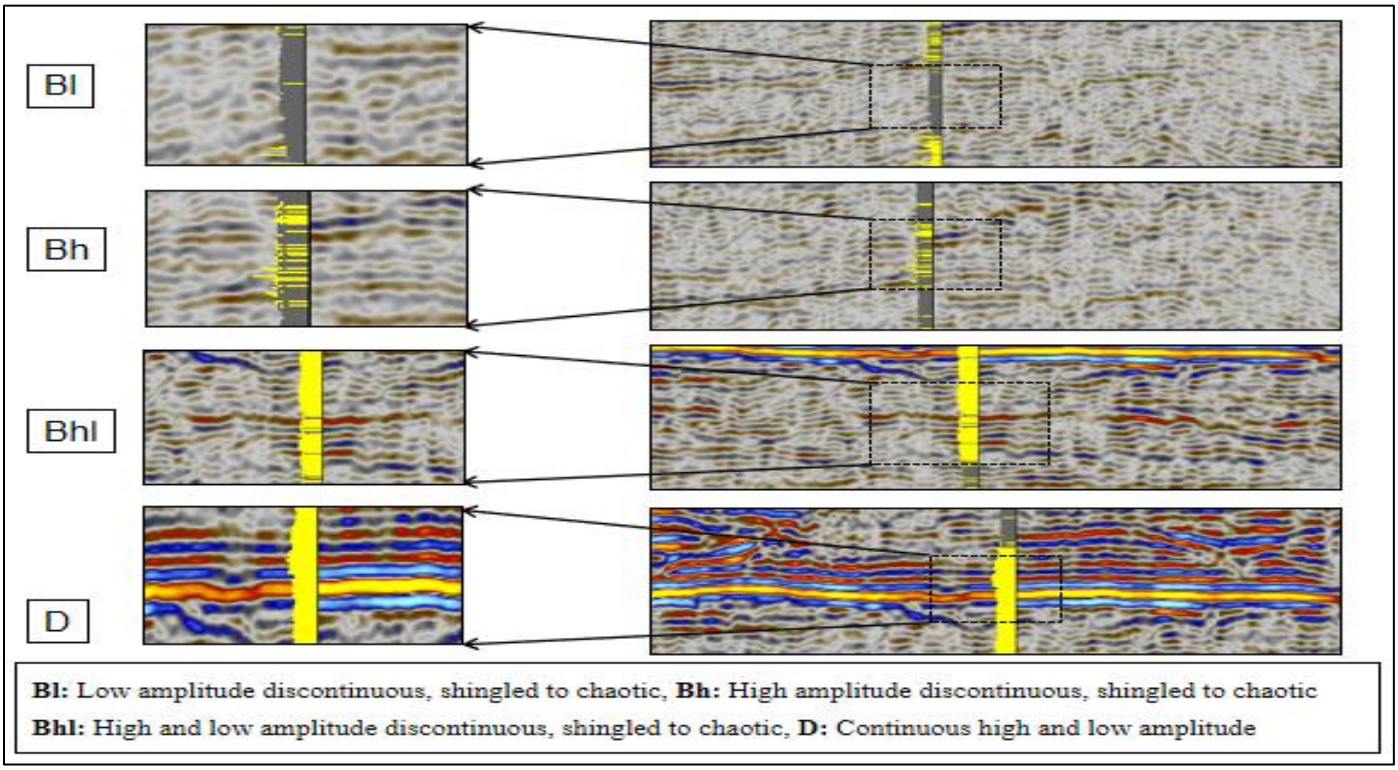

Fig. 9b: Enlarged sections from Figure 8 showing the interpreted seismic facies

Figure 10a shows the result of the detailed seismic facies analysis obtained by combining the interpretations from the sequence stratigraphy and the facie analysis. Figure 10b shows the reservoir percentages of these facies. D, Bhl and Cbhl correspond to the LST sands; their reservoir percentages are higher, with D having the highest percentage.

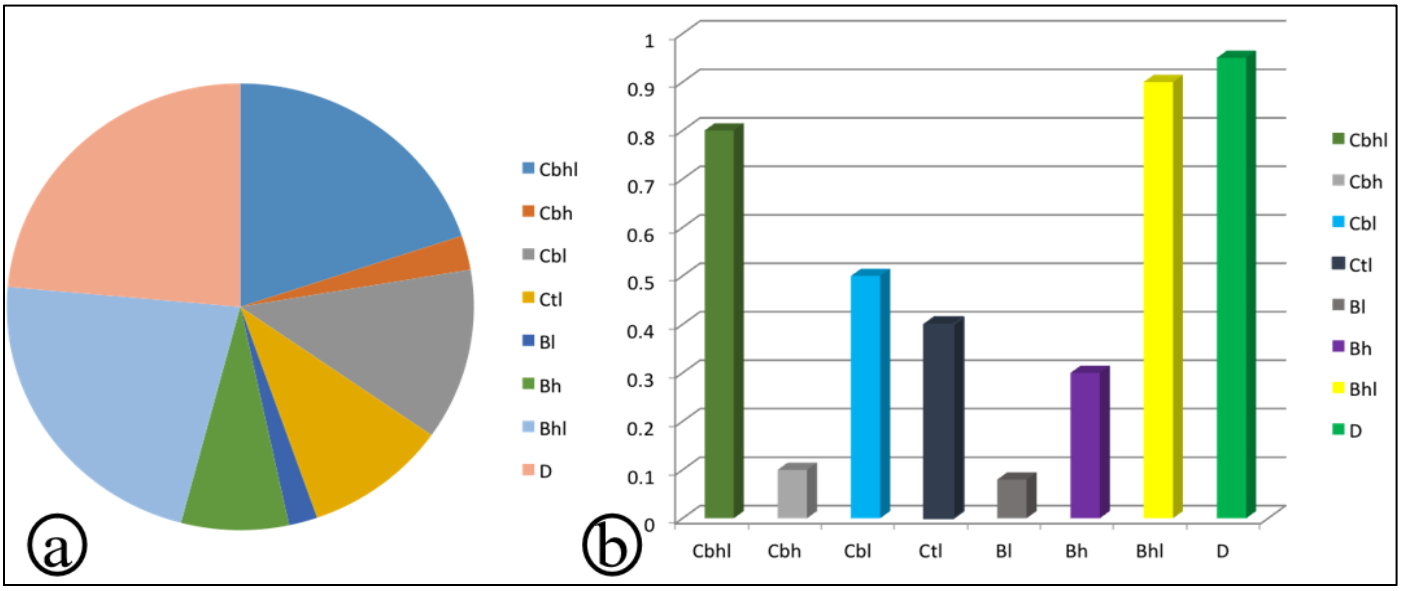

Fig. 10: a) Seismic Facies Interpretation. b) Reservoir Percentage and ranking of the seismic facies.

A chrono-lithostratigraphic model was generated on the 2D interpretation window (Figure 11). Stratigraphic correlation across the seismic sections revealed a volcanic intrusion toward the southeast of the field. The structural framework interpretation indicates the presence of faults that may have played critical roles as either conduits (migration pathways) or hydrocarbon traps. These faults and horizons were interpreted on the seismic sections. These horizons were used to generate time-domain and depth-domain surface maps (Figures 12 and 14). The depth domain surface maps were generated from the time domain surface maps using a third-order polynomial look-up function (Figure 13). Time and depth structure maps of the mapped horizons highlight the closure and trap mechanism for the targets. These depth surface maps reveal the leads and prospects present and other petroleum system elements, such as the seal/trap mechanisms essential for trap viability and hydrocarbon accumulation.

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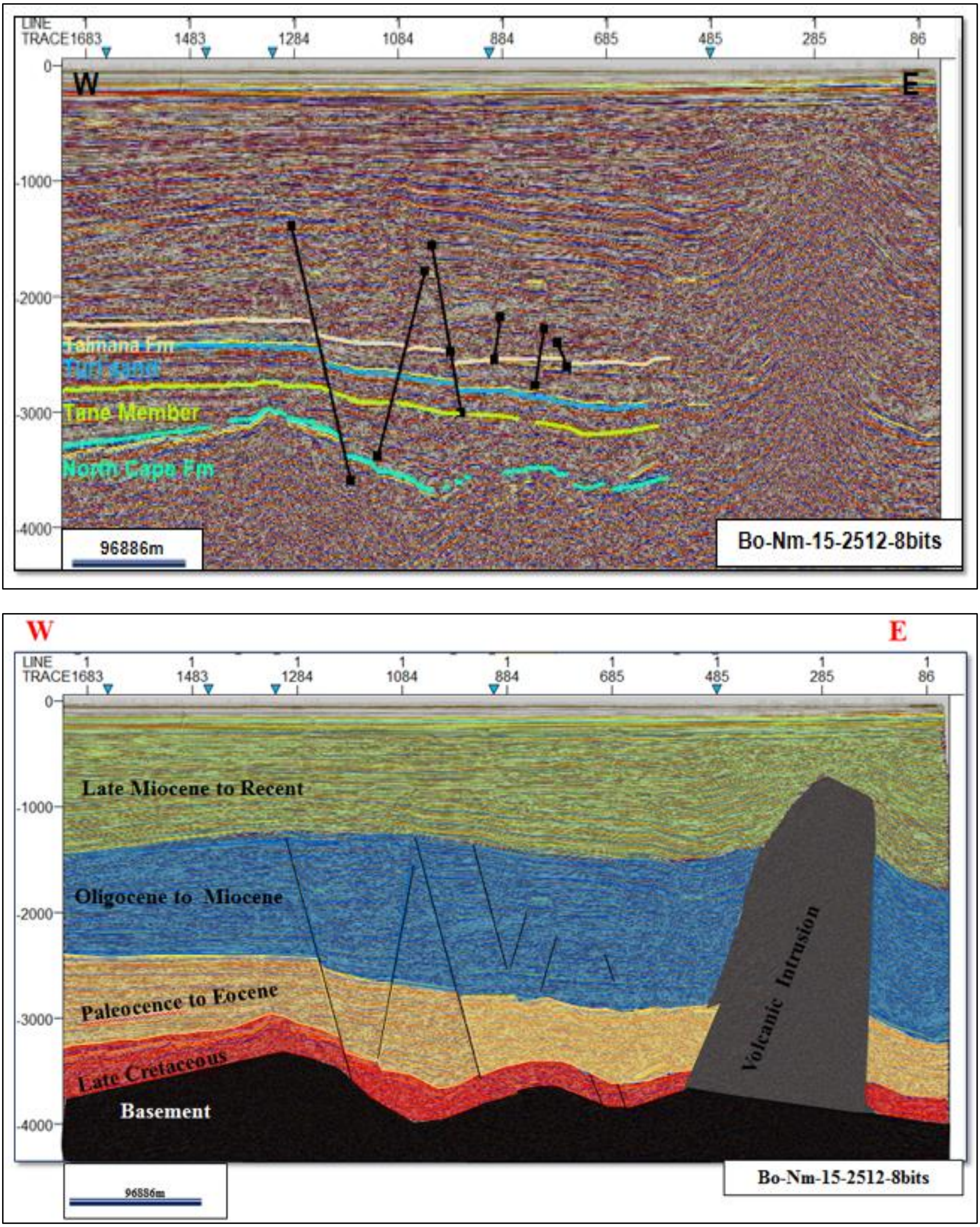

Fig. 11: Bo-Nm-15-2512-8bits Seismic line showing (a) interpreted faults and horizons, and (b) age model.

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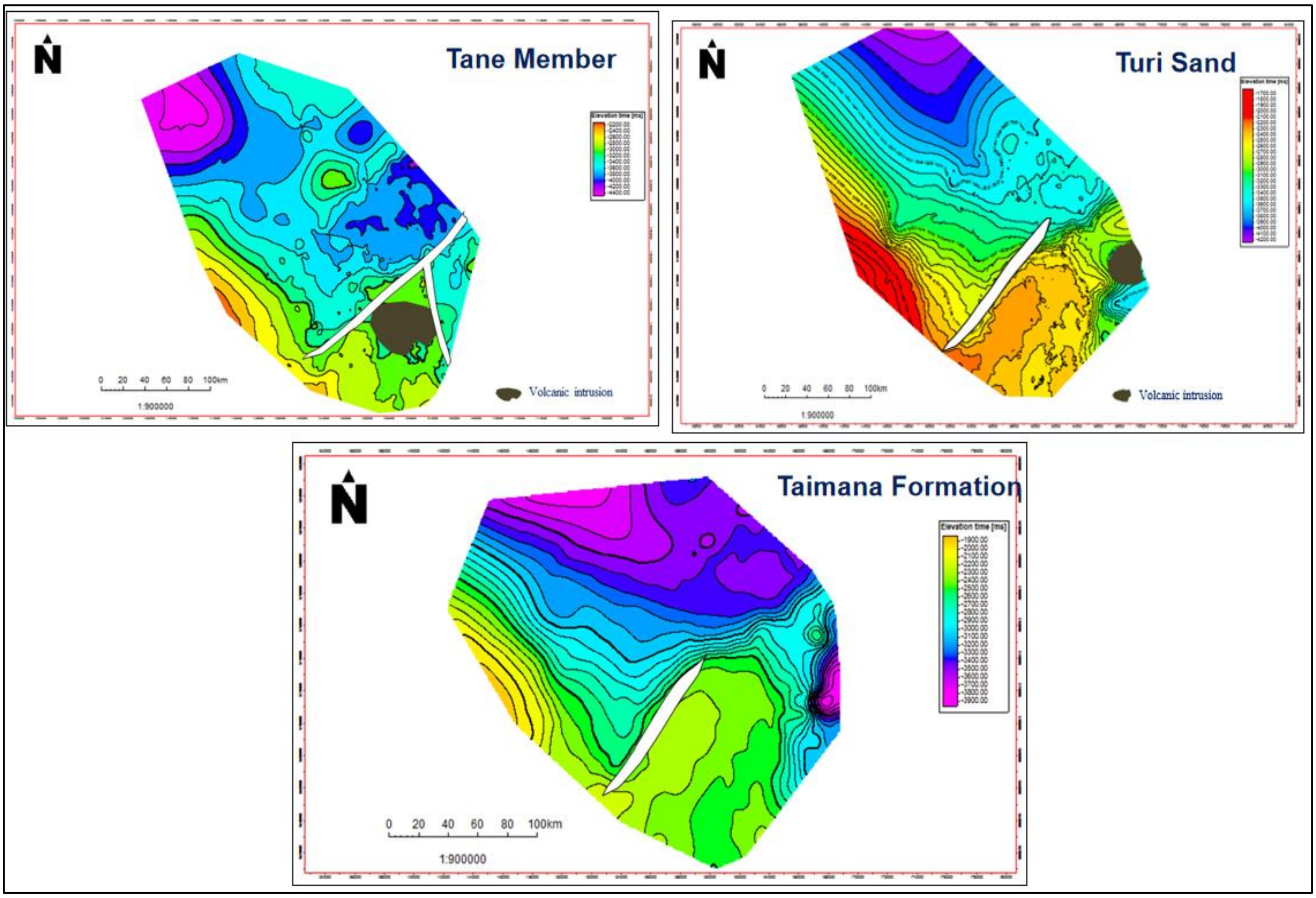

Fig. 12: Surfaces generated in Time domain

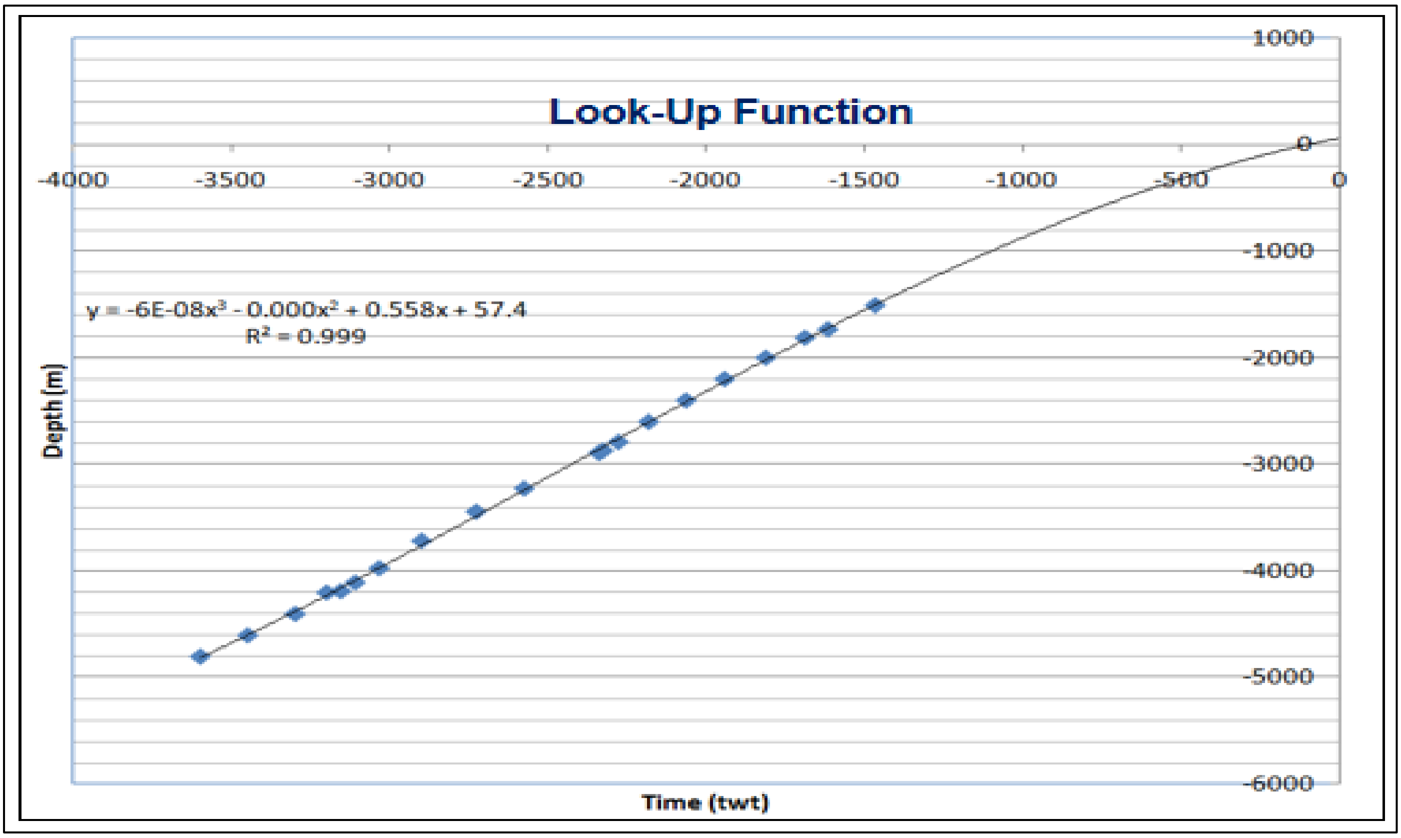

Fig 13 Third-order polynomial look-up function used for the depth conversion

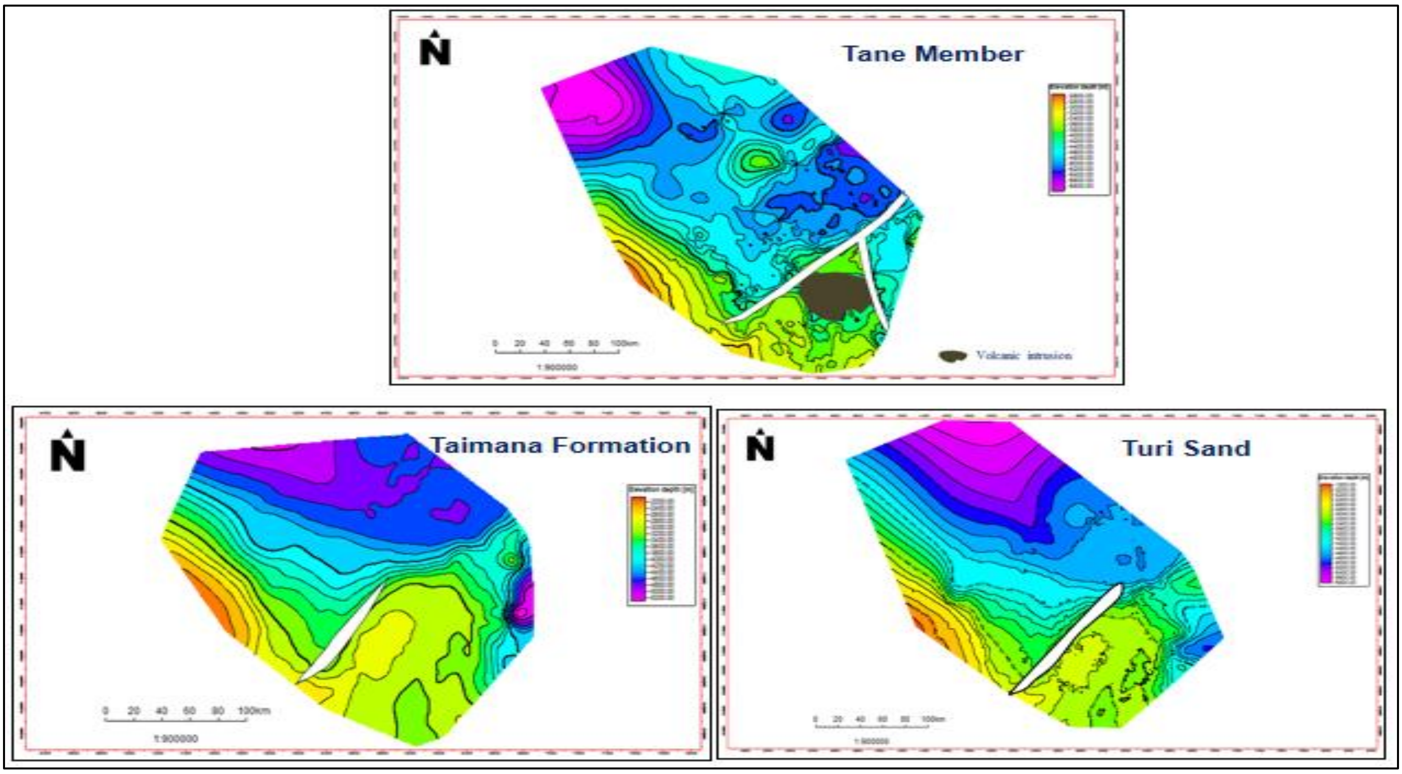

Fig. 14: Surfaces Generated in Depth Domain

A play fairway analysis was carried out on each of these depth surfaces that were generated to show where all the petroleum elements are in place. The source rock, the Rakopi rock, and the reservoir rocks, as shown from the maps, are laterally extensive. The seal was also seen to be laterally extensive. The migration pathway is interpreted to be up-dip along faults. Finally, the traps are structural (faults) and stratigraphic (pinch out). These elements were present simultaneously, so we have a functioning petroleum system (Figure 15).

Figure 16 shows the play sweet spot. This is a point or area where all the play elements overlap after all the depth surfaces have been stacked vertically. The absence of this play spot shows a failed petroleum system, so hydrocarbons cannot accumulate and remain trapped.

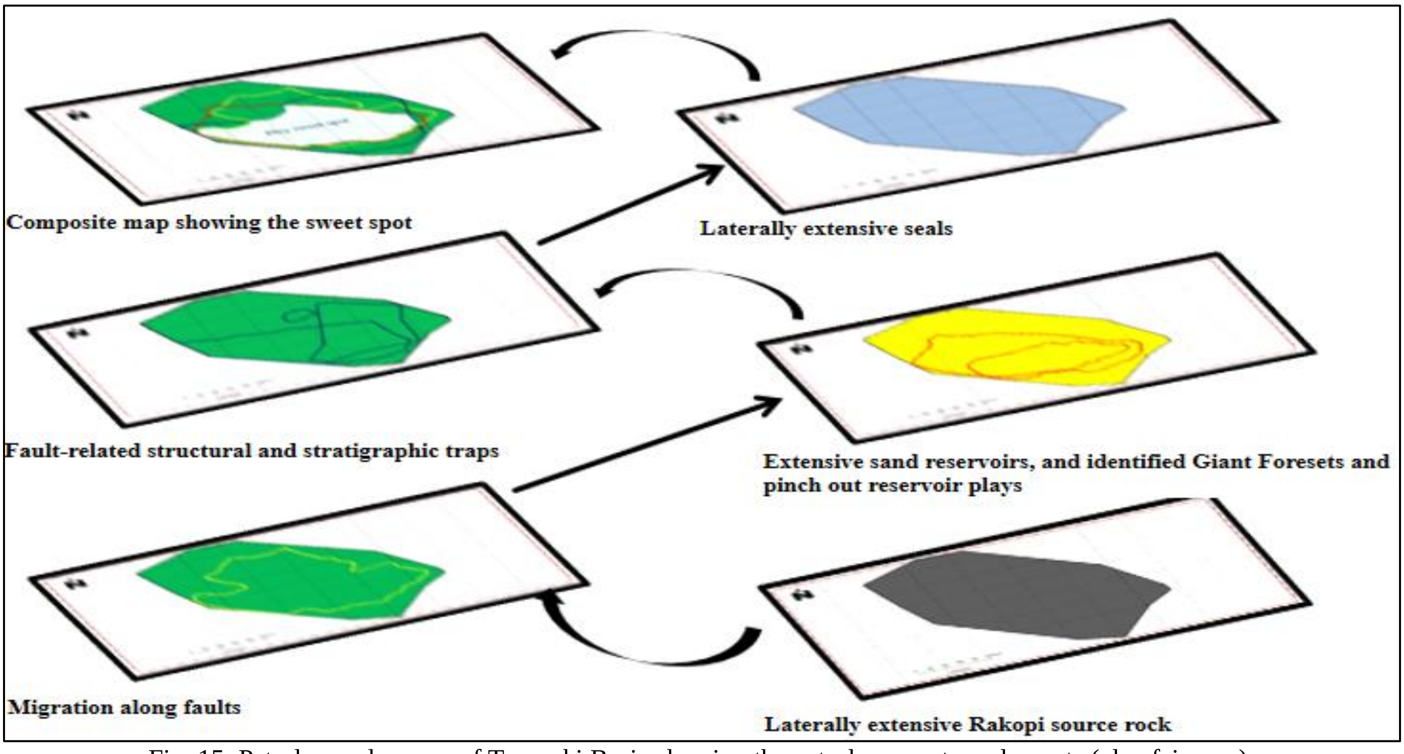

Fig. 15: Petroleum play map of Taranaki Basin showing the petroleum system elements (play fair way)

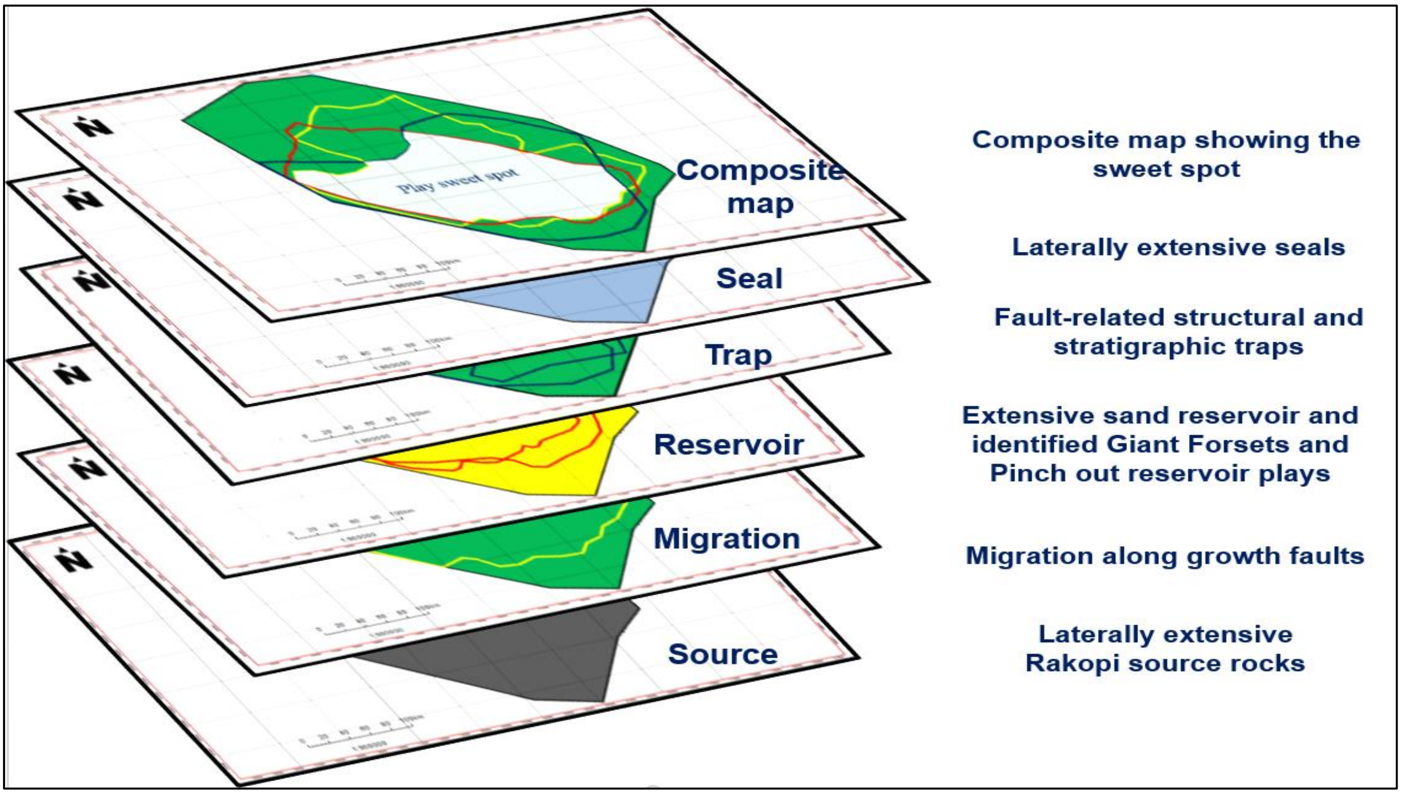

Fig. 16: Petroleum play map of Taranaki Basin showing sweet spot

The risk factors encountered from the interpretation include fault-dependent gas chimneys, prominent chimneys, fluid migration pathways, seal compromise features, faulting of the Taimana seal, and lateral continuity of the fault networks (Figure 17). The above factors, in one way or another, affect the geologic success in the field.

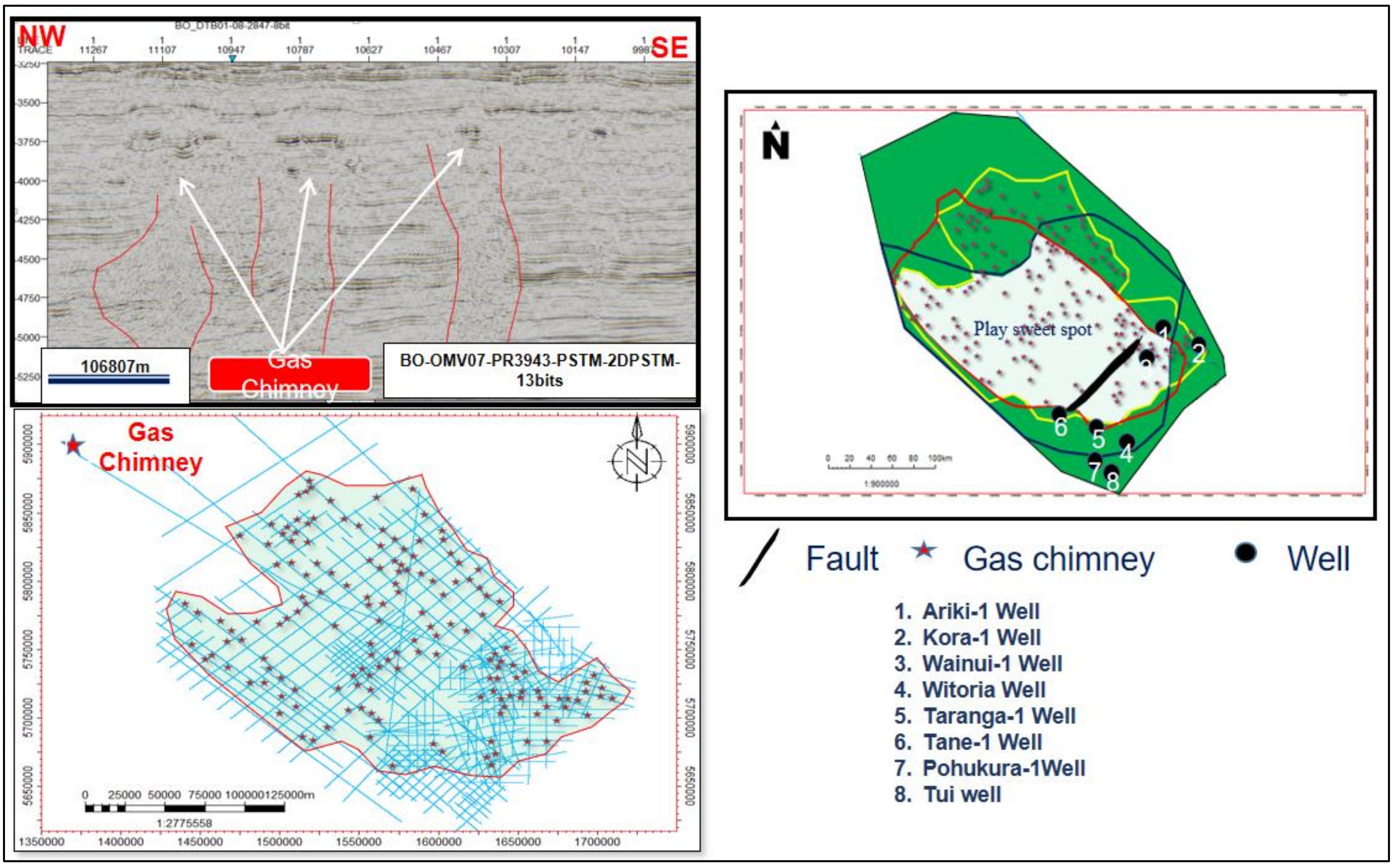

Fig 17: Risk and risk assessment map of the study area.

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Table 1: Geologic chance of success for the plays and prospect

S/N	Petroleum System Element	Assigned Confidence Value
1	**Taranaki Play-1: Late Cretaceous**	
	Source (Rakopi Fm., Wainui Member)	1.0`
	Reservoir (North Cape, Tane Member)	0.8
	Trap (3-way closure and stratigraphic pinch-out)	0.5
	Seal (Turi Fm.)	0.95
	Timing between maturation and trap formation	1.0
	Play Chance of Success	**0.42**
2	**Taranaki Play-2: Paleocene - Eocene**	
	Source (Rakopi Fm., Wainui Member)	1.0`
	Reservoir (Turi Sand)	0.85
	Trap (3-way closure, stratigraphic trap and Anticlinal Trap)	0.5
	Seal (Taimanai Fm.)	0.8
	Timing between maturation and trap formation	1.0
	Play Chance of Success	**0.34**
3	**Taranaki Play-1: Oligocene - Miocene**	
	Source (Rakopi Fm., Wainui Member)	1.0`
	Reservoir (Tikorangi Fm.)	0.7
	Trap (3-way closure, stratigraphic trap and Anticlinal Trap)	0.5
	Seal (Manganui Fm.)	0.8
	Timing between maturation and trap formation	1.0
	Play Chance of Success	**0.28**
4	**Taranaki Prospect: Cretaceous**	
	Source (Rakopi Fm., Wainui Member)	1.0
	Reservoir (Tane Member)	0.8
	Trap (stratigraphic trap and structural trap)	0.9
	Seal (Turi Fm.)	0.95
	Timing between maturation and trap formation	1.0
	Play Chance of Success	**0.68**

V. CONCLUSION

Integration of multiple datasets resulted in the identification of three Plays and one Prospect; Taranaki Play-1 is Late Cretaceous with a 42% Play Chance of Success, Taranaki Play-2 is Paleocene – Eocene with 34% Play Chance of Success, Taranaki Play-3 is Oligocene – Miocene with 28% Play Chance of Success, the Prospect is the Cretaceous Tane Member with Geologic Chance of Success of 68%. Four reservoirs, two primary source rocks, one regional seal and inter-reservoir seals, and down-to-basin and local faults acting as migration pathways and traps have been identified. Two Genetic Sequences were identified with their associated Systems Tracts. The LSTs and HSTs are potential reservoirs; the shales of TSTs and HSTs constitute the source/seal units.

The integrated basin analysis and hydrocarbon potential assessment of the Taranaki Basin represents a critical step towards unlocking the full resource potential of this region. By leveraging advanced geological and geophysical techniques, this research contributes to the scientific understanding of the basin's evolution and provides valuable insights for exploring and exploiting its hydrocarbon resources. It is a cornerstone study for academia and the petroleum industry, guiding future exploration endeavours in New Zealand's offshore and onshore environments. Moreover, integrating seismic facies analysis with sequence stratigraphy offers a robust tool for delineating potential hydrocarbon-bearing zones, thereby reducing exploration risk and aiding in the efficient reassessment of existing prospective zones and future exploration efforts.

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