Basin Analysis and Reservoir Modelling of The Great South Basin as a Template for Exploration in the Niger Delta

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ABSTRACT

Basin analysis and reservoir modelling have been important in interpreting and assessing if the sedimentology and stratigraphy of a basin are suitable for hydrocarbon formation and preservation in commercial and recoverable quantities. As the demand for global energy currently exceeds supply and the gap on course to widen, the oil and gas industry needs to be prepared for what's to come. This presents the importance for the basin analysis and reservoir modelling approach for exploration, development and production for oil and gas in the Niger Delta, which will strengthen the position of the industry for future energy dynamics. The approach involved the interpretation of seismic data of The Great South Basin, New Zealand which covers an area greater than 1000 km. Seismic sequence stratigraphy analysis was conducted and potential sweet spots were identified. Well correlation and petrophysical analysis were conducted to delineate the reservoir and non-reservoir zones. Well data and sequence stratigraphy aided the interpretation of lithologies and their depositional environments. Structural depth and Isopach maps of key horizons were created which aided the construction of paleogeographic maps of those horizons. Play cartoons of the petroleum system analysis of the basin were created. The petroleum system was modelled to give a complete understanding of the basin. A play fairway analysis and a Common Risk Segment Maps (CRS) were conducted to illustrate the possible and lowest risk plays for hydrocarbon storage and extraction. Finally, a prospect volumetric calculation was conducted. The results are promising and there are interesting prospects and plays that show signs of hydrocarbon accumulation. If this concept is applied to the exploration and development of hydrocarbons in the Niger Delta, the industry will be positioned to deal with the future energy dynamics.

Keywords: Basin Analysis, Modelling, Sedimentology, Sequence stratigraphy, Depositional environment, Isopach, Paleogeographic, CRS

INTRODUCTION

The Niger Delta is a well renowned hydrocarbon province with a lot of aging oil and gas fields. It is a landmark geological feature of significant petroleum exploration and production in Nigeria (Whiteman, 1982). It's clear that more exploration efforts need to be done in the region, especially offshore, to fully exploit and maximize the abundance of hydrocarbon still yet to be discovered. Gail Anderson: Wood Mackenzie's Director of Upstream Research recently stated, "there is still plenty of running room in the shallow water Niger Delta". This is after TotalEnergies recent oil discovery at Ntokon in the Niger Delta. The complex relationship between timing of maturation and timing of structuration in the different structural domains creates exploration risk and the need to understand the development of the system (Bellingham *et al.,* 2014). The basin analysis and reservoir modelling approach used for The Great South Basin; New Zealand is a good template for exploration efforts in the Niger Delta.

Overview of The Great South Basin

The Great South Basin is located to the south-eastern coast of the South Island, New Zealand. The water depth is about 300-600 metres deep and it is the largest and deepest sedimentary basin on the Campbell Plateau, encompassing an area about 85,000 km^2 (Figure 1). Exploration began with acquisition of seismic surveys since 1971. Then 8 exploration wells were drilled from 1976 – 1984 but only 5 wells are available for this study

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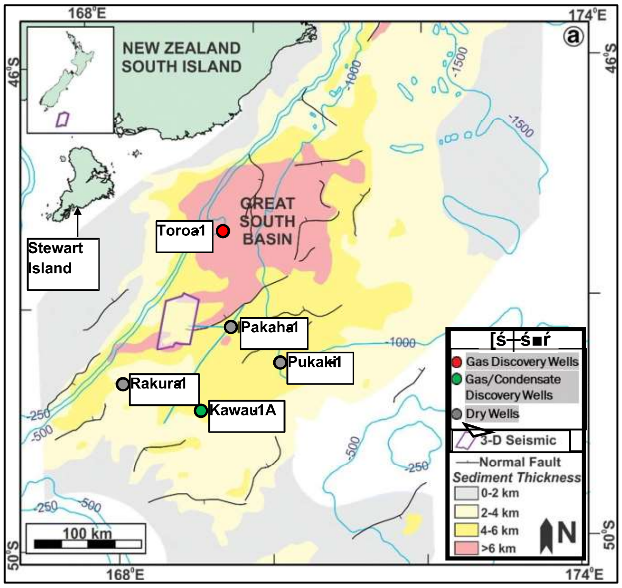


Figure 1: Map of The Great South Basin, New Zealand showing the wells of interest (Modified from Omosanya & Harishidayat, 2019).

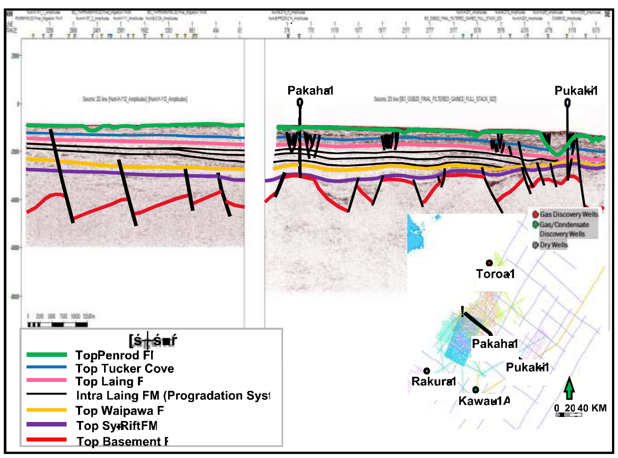


Figure 2: Interpreted regional seismic line of The Great South Basin, New Zealand.

(Sahoo *et al.,* 2014). The region had indicators of hydrocarbon presence due to oil seeps at Stewart Island (Figure 1), flat spots and gas chimneys on seismic. These were all key in analysing the petroleum system in the basin.

METHODOLOGY

It is essential to understand the geological setting and history of the area of interest. It is important to create a tectono-stratigraphic diagram (Figure 3). It illustrates the sedimentary and tectonic evolution of the basin simultaneously.

During syn-rift phase of the late Cretaceous, the basin was filled with conglomerate, sandstone, mudstone & coal called Hoiho Group (Killops *et al.* 1997). The basin continued subsidence and was filled with sediments supplied from the northwest to southeast which can be observed from seismic cross-section. It illustrates progradation of down-lap (top set, fore set & bottom set).

In the late Palaeocene, the marine transgression climaxed with the deposition of organic-rich shales called Waipawa Formation (Nicolo *et al.* 2007, Killops *et al.* 2000, Morley *et al.* 2017).

During the Eocene, the fluvio-deltaic systems were deposited along the paleo-shoreface located to the northwest. This can be observed from seismic characteristic of progradation systems. In addition, the basin floor was deposited across the basin in front of delta systems (Killops *et al.* 1997). In the Oligocene, the basin continued its subsidence and low rate of sediment supply resulting in the depositional of mudstone, marl, and carbonate sediments predominantly (Cook *et al.* 1999).

At the end of Paleogene, the rapid uplift of the southern Alps and hinterland to the west led to deposition of thin Neogene regressive sediments (Uruski *et al.* 2007).

Understanding the tectono-stratigraphic history of the basin gives insight on the characteristics and properties to expect when analysing the seismic, petrophysical and well data.

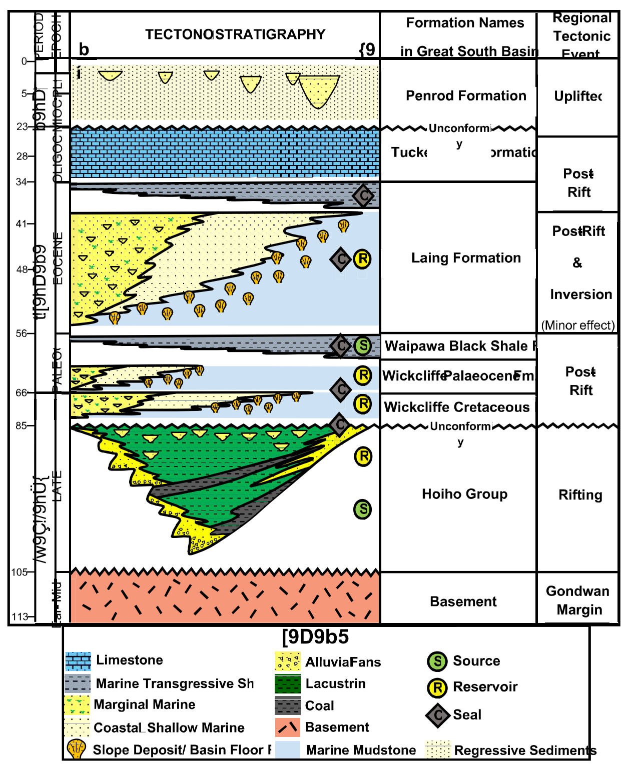


Figure 3: Tectono-Stratigraphy of The Great South Basin.

Petrophysics

The identification of reservoir and non-reservoir zones were identified which narrows down the area of interest. Figure 4 shows one of the wells analysed: Kawau-1A, and it turned out to be a 461 Bcf gas condensate discovery (Uruski *et al.,* 2007).

The available data for the petrophysical analysis was of good quality where majority of the wells had gamma ray, caliper, deep & shallow resistivity, neutron, and density. This allowed for a petrophysical evaluation to help determine the integrity of the basin facies.

The neutron density x-plot was how the clay point was picked, because the clay rich facies shown by the purple data cloud, sits in-between the 60-80% part of the line (figure 4). This was the basis for calculating VClay. Water saturation was calculated using the Simandoux model because the basin lacks clean sands and instead more clayey fluvial and deltaic sands.

The calculated porosity values for each formation and zone were plotted against depth. From this cross plot the cut off depth for reservoir effectiveness could be determined; with bad RE = <10% at 3102m, average RE between 10-12%, and good RE >12% ay 2900m.

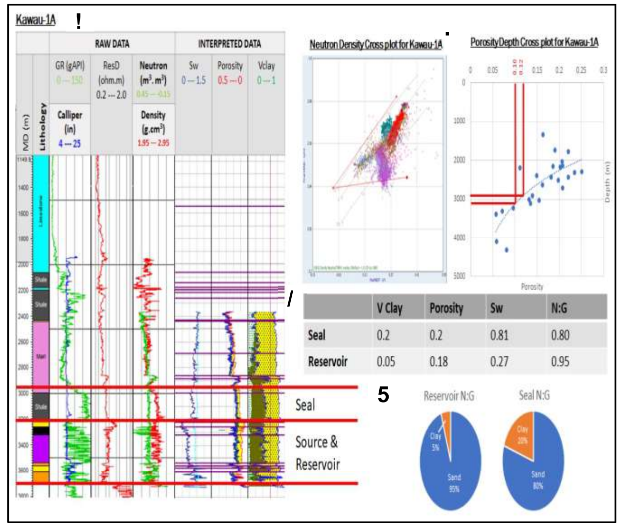
The cutoff parameters were 1 for VClay and 0 for porosity for the whole well to be considered when analyzing net-to-gross (N:G) and reservoir rather than just the potential reservoir sections. It means it includes all the dirty rocks/ high clay content rocks. This enabled a facies scheme to be made, which was reinforced with information from literature and mud cutting record from the well reports, and this was used during compiling the palaeogeography and petroleum plays.

The seal formation is determined as a shale with low permeability and a high capillary entry pressure and allows for any accumulating hydrocarbons to be trapped in the right setting. Also, as shown in the table (Figure 4), the high-water saturation in the proposed seal rock indicates it contains little hydrocarbon and could be water wet, another factor in being a good seal.

The reservoir and source formations were determined as sandstone with interbedded sections of mud and coals, the coals acting as a hydrocarbon source and sands as reservoirs. These sands are considered as potential reservoirs due to hydrocarbon shows, as well as high net to gross (low clay content) indicating a good reservoir quality.

Well Correlation

To start putting the various pieces of geological and petrophysical data together and start seeing a broader



	V Clay	Porosity	Sw	N:G
Seal	0.2	0.2	0.81	0.80
Reservoir	0.05	0.18	0.27	0.95

Figure 4: **(A)** Petrophysical log of Kawau 1A **(B)** Neutron Density cross plot and porosity depth cross plot. **(C)** Table highlighting reservoir and seal properties. **(D)** Pie Chart illustrating reservoir and seal properties.

picture of what is occurring in the basin regionally, a well correlation was conducted (Figure 5). The wells show mainly marginal marine and shelf facies and display two main unconformities: late Oligocene to early Miocene (Tucker Cover Limestone Formation, Top progradation) and late Paleocene to early Miocene (Wickcliffe Formation, Top syn-rift).

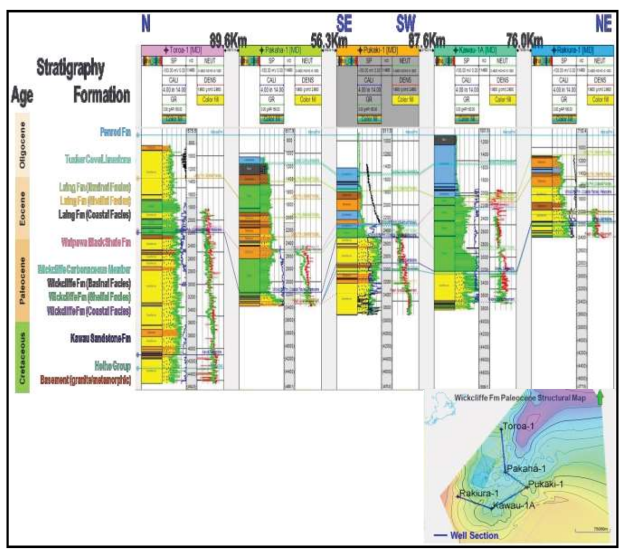


Figure 5: Stratigraphical well section (orientation N-S-NE), flattened using Penrod Fm marker; the wells included are: Toroa-1, Pakaha-1, Pukaki-1, Kawau-1A, Rakiura1. It displays Lithology, GR/CALI, Depth (MD) and NUE/DENS logs.

Seismic Sequence Stratigraphy

Seismic sequence stratigraphy was conducted to interpret and identify mega-sequences in The Great South Basin. It aided the interpretation of strata and depositional facies from the seismic data (Steel et al., 1995). This method is very important as it can directly detect hydrocarbon accumulations in the seismic section using seismic geometries (Amedjoe & Adjovu, 2013. Each line has been interpreted in detail to aid the understanding of the basin history as well as highlight potential sweet spots. Figure 6 is highlighting the major mega sequences and the following lines go into the smaller scale 3rd order sequences. In addition to the seismic sequence, five wells are integrated to define and interpret the lithologies and depositional environments.

Figure 6 illustrates a detailed interpretation of the northwest region of the basin, highlighting the various seismic geometries, reflections, and seismic facies. It illustrates the delta top and therefore the more proximal part of the basin. Interpretation indicates that the delta is prograding from the northwest to the southeast.

Figure 8 demonstrates a more eastward section and therefore a more distal section of the basin. A more eastward seismic image showing the distal region of the lowstand delta. Turbidite slope and basin floor fans can be identified, and they all have bright amplitude reflectors. The bright reflectors could indicate the presence of fluids.

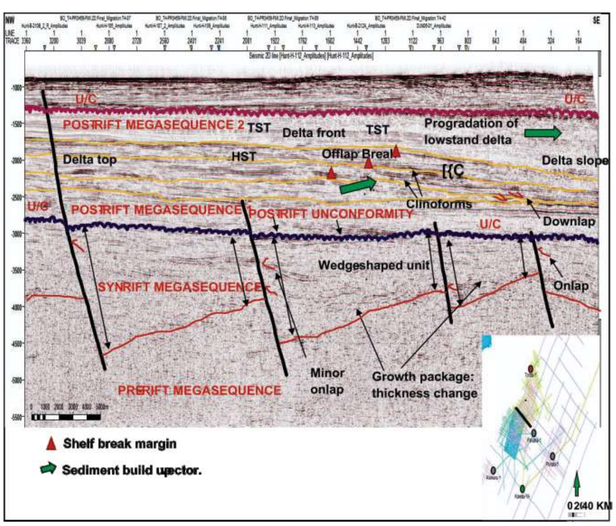


Figure 6: Seismic section illustrating a prograding delta from the northwest to southeast.

Structural depth and Isopach Maps

The seismic interpretation was mainly done on 2D seismic lines which covered the entire area of the basin. There are five major mappings based on the mega sequences and

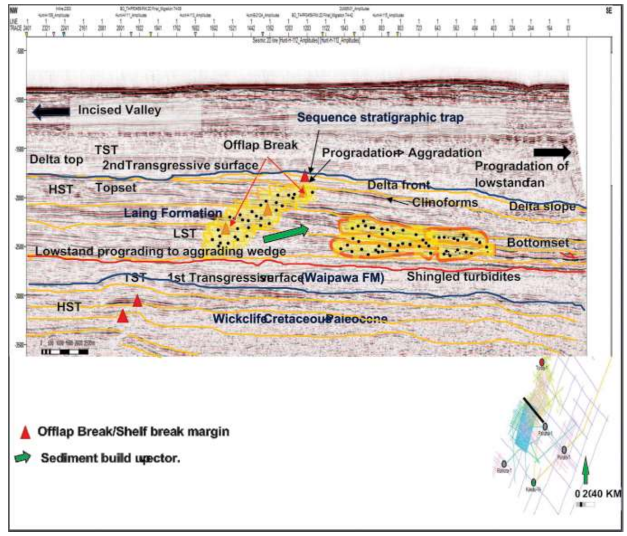


Figure 7: Zoomed in section of the seismic shown in figure 6 displaying several seismic facies and system tracts.

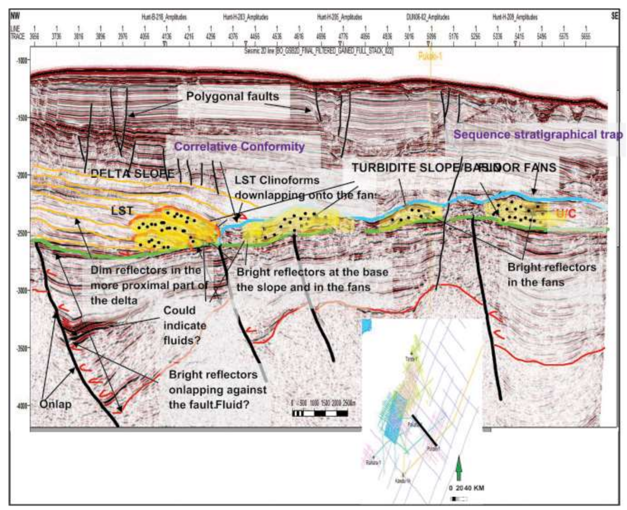


Figure 8: Seismic section showing the more distal and basinward area of the basin, towards the southeast.

these key horizons are related to key petroleum systems: sources, reservoir & seal. Structure maps (figure 9) and isopach maps (figure 10) were constructed to further paint the picture of the geometry and nomenclature of the basin. The two figures display two of the key horizons which illustrate major events that play a key role in the petroleum system. These maps further show the behaviour of the delta and therefore the basin.

Petroleum System Analysis

Further building on the structure and isopach maps, paleogeographic maps were built for the five key horizons that were related to the petroleum system (figure 11).

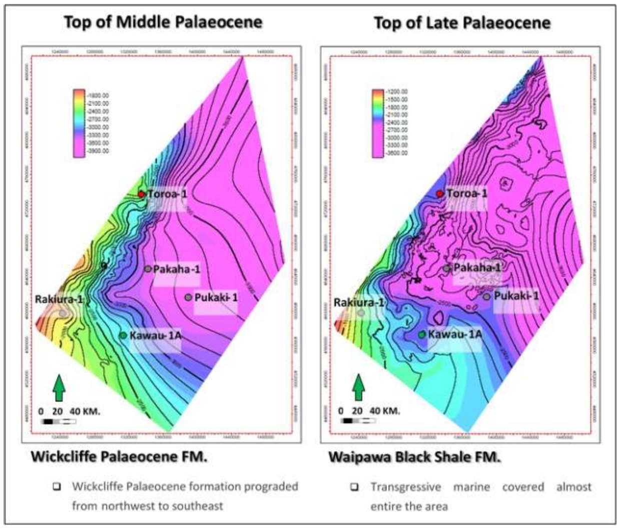


Figure 9: Structural maps of two key horizons. The Waipawa overlays the Wickcliffe.

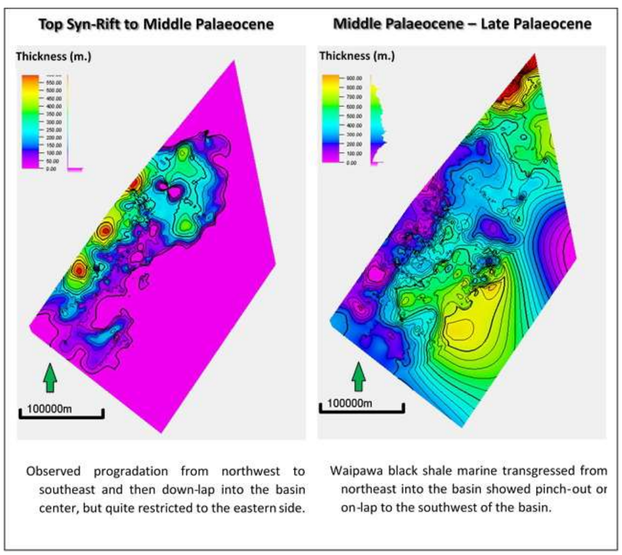


Figure 10: Isopach map of the Wickcliffe and the Waipawa Formations.

These are based of 2D seismic interpretation, structural depth maps and isopach maps. However, the boundaries of progradation facies are relied based on structural mapping, isopach and seismic horizons.

Constructing paleogeographic maps for the key horizons simplified the building of the petroleum system of The Great South basin (figure 12). This was another step in investigating where the oil and gas could be accumulated. From the petroleum system, three plays were identified and analysed.

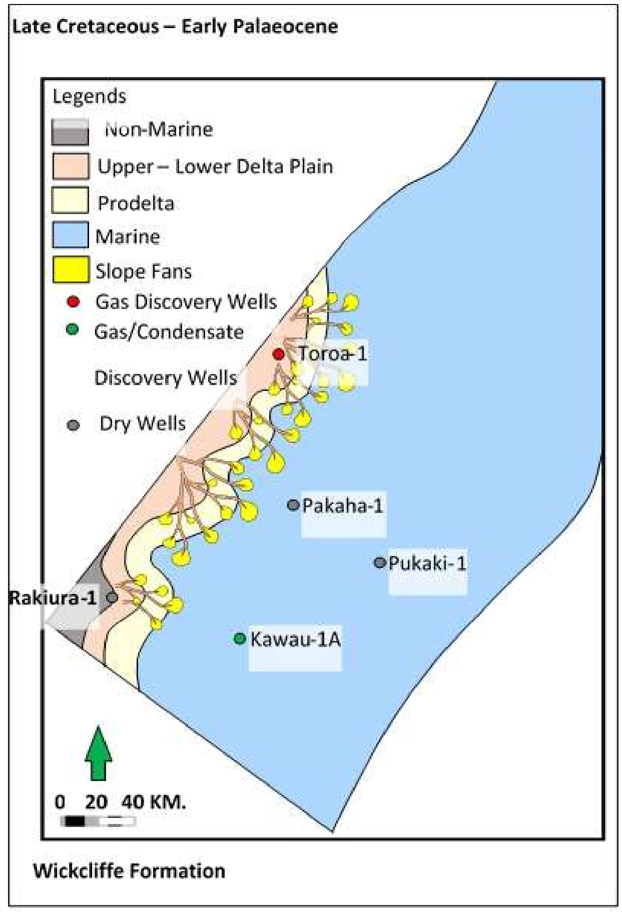


Figure 11: Paleogeographic map of the prograding delta; Wickcliffe Formation.

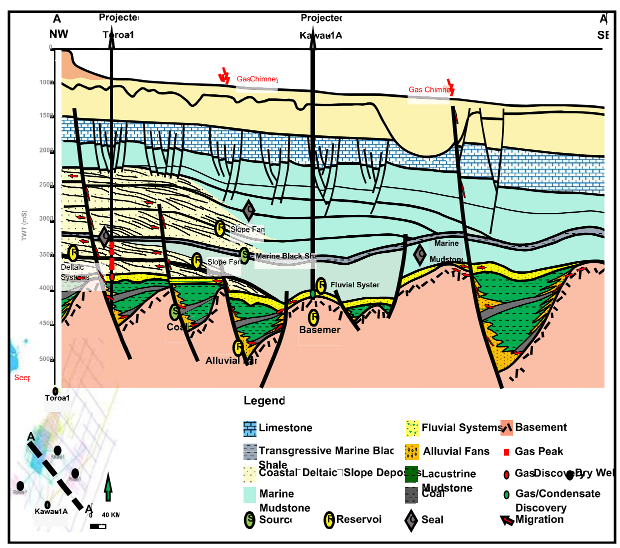


Figure 12: Play cartoon of petroleum system analysis of The Great South Basin.

Petroleum System Modelling

The Basin Petroleum System Modelling helps to answer key questions such as Is the seal effective at a specific location? When did the source rock start generating? Are the source rocks mature?

This project was focused only in the 1D and 2D models (figure 14). The Petroleum Systems 1D models properties through geological time require input data at one well location or proposed well, its result will be timing of petroleum systems elements at a well location (no spatial variation). For this workflow Kawau-1A was selected due to its significant HC shows and it reached the basement.

The 2D Petroleum Systems generates a more accurate model of maturation as lateral effects along the cross-section will be considered, including fluid movements (HC generation timing, location, type, and expulsion). The selected cross section is consisting of a composite of 2D seismic lines intersecting the wells Pakaha-1 and Pukaki-1, oriented NW-SE.

The input for the modelling process includes the following data; The facies, which in the petroleum system modelling (PSM) process denotes a range of petrophysical properties and reservoir or source characteristics assigned to the different strata of the model. It includes lithology and source rock property information on TOC content and distribution, kerogen type and petroleum generation kinetics.

To calculate the hydrocarbon potential of source rocks, it required the original source rock parameters; TOC and HI values at the time of deposition.

There are three factors controlling the temperature and heat transfer within a basin and it involves the boundary conditions necessary to define a basin model: Paleo Water Depth (PWD): The water depth of the basin during deposition of sediments through geologic time. Sediment-Water Interface Temperature (SWIT): The temperature of the interface between sediment and water (derived from PWD) through time. It is the upper temperature condition. Heat Flow (HF): The amount of heat through the basin.

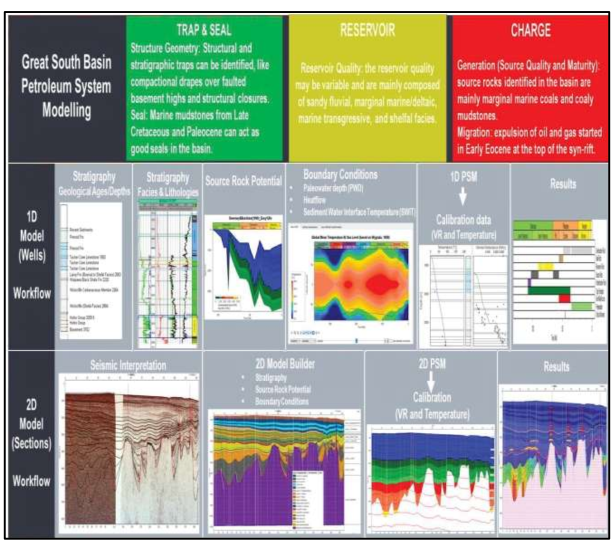


Figure 13: Workflow of the Petroleum System modelling.

Play Fairway Analysis and Common Risk Segment Maps

Once the petroleum system has been modelled, the results are factored into the thought process when constructing the play fairway analysis (figure 14). To make an effective and accurate analysis, common risk segment maps (CRS) must be built (figure 15). The CRS maps thoroughly screen each component of a petroleum system in a specific play and indicate the likelihood of that play being successful.

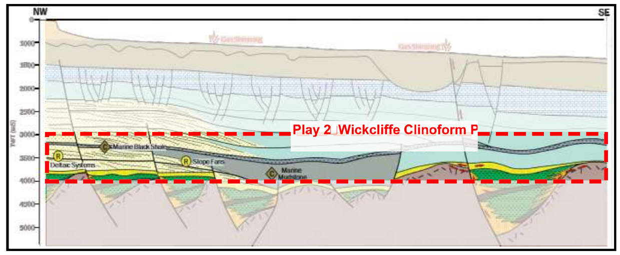


Figure 14: Play of the prograding deltas of the Wickcliffe Formation.

Toroa-1 well proved significant gas peaks from the Wickcliffe Palaeocene to Cretaceous. This suggests reservoir potential, charge, and seal, but trap configuration is considered as a significant risk. There are no closures or related fault, but a stratigraphic trap can be considered. The source rock is the syn rift coals, the reservoir is the delta, and the seal is the regional shale bed.

Play type 2 (the Wickcliffe Clinoform play) is situated above the syn-rift coal kitchen. The CCRS map shows a low risk result corresponding to reservoirs, their

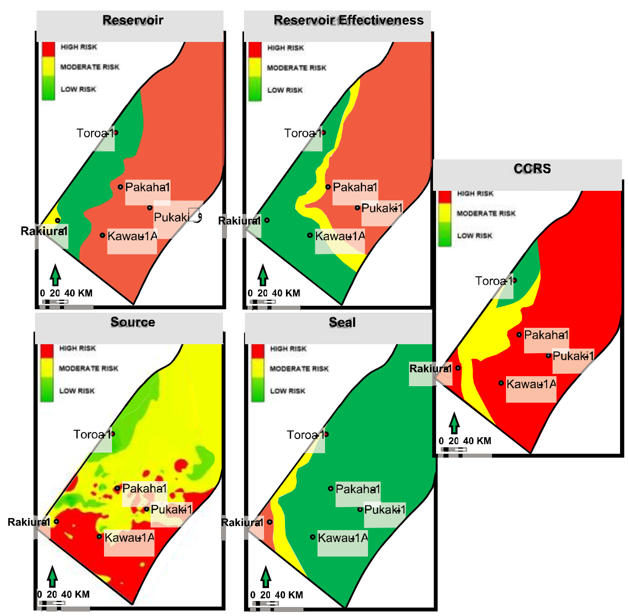


Figure 15: Common risk segment maps for Play 2; prograding deltas of the Wickcliffe formation.

effectiveness, source, and seal CRS maps (figure 15). However, as mentioned earlier Toroa-1 appraised a significant gas peak from the Wickliffe Palaeocene to Late Cretaceous. This could mean trapping configuration will be needed to be considered because it is still considered to be a high-risk parameter. As such, stratigraphic traps need to be investigated for future any exploration wells.

RESULTS

From this detailed approach to explore for hydrocarbons, it is safe to say it is a thorough process to reduce risks and exposure. This process birthed the identification of 10 prospects within the basin. High risk plays were filtered out due to the very thorough CRS maps and petroleum system modelling. Volumetrics were carried out and the prospects are very promising. The petroleum modelling highlighted the source rocks that were not mature enough to be viable options and therefore removing the risk and uncertainty.

The Upper source rock (Waipawa Black Shale) is in the immature window at present day. The lower source rock (Hoiho Group) back 66 Ma it was first buried into the early oil window and with continued burial it reached the main oil window at 56 Ma which correlates to the 140-160 degrees Celsius isolines, and just now at present day it is in the wet gas window.

The Great South Basin displays a defined petroleum system. This is further backed up by the oil and gas shows in wells Toroa-1 and Pakaha-1, and gas condensate shows in Kawau-1A. Further exploration in the area is on the horizon.

CONCLUSION

The success of the approach which led to the identification of prospects and leads in the Great South Basin shows it is a useful template for exploration in the Niger Delta. The Niger Delta is a well-studied and mature basin so it has a solid foundation in which this approach can be built on. Taking advantage of this approach will reduce the risk and uncertainty when exploring for hydrocarbons. The geology and stratigraphy of The Great South Basin and the Niger Delta have some similarities with the thick shale overlain by prograding delta facies. The approach can be applied to various kinds of regions and basins. The help of well data can not be understated. If there are nearby wells around the area of exploration, it is worth getting analogue data. The Great south Basin has been underexplored for 50 years; with this approach the basin is a more attractive prospect. The offshore region of the Niger Delta still needs to be explored more as this is where the huge accumulations are. Bellingham et al., (2014) wrote a paper titled: The Deepwater Niger Delta: An Underexplored World-Class Petroleum Province. Almost ten years later, the title is still relevant. This paper will hopefully urge operators to consider more exploration efforts. Finding these accumulations will put the Niger Delta in a suitable position to deal with the future energy dynamics.

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