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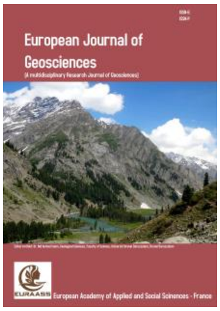

Research Article

2D seismic interpretation of Dun06 projects, Great South Basin, New Zealand

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Abstract

DUN06 seismic survey was done in the northern part of the Great South Basin of New Zealand with a total of 3110km of high resolution 2D seismic data by Pacific Titan in 2006. This study focuses on 2D seismic interpretation using Petrel Software to interpret the horizons or geological boundaries of different formations based on the extracted well tops from Toroa well which was drilled in the area of interest. The primary objectives of this study are to deduce the structural and stratigraphic information as well as the trapping mechanism of petroleum system if any. Possible indications of the presence of hydrocarbon were also sorted out. There are seven horizons having age ranging from upper Cretaceous to Eocene. Also, approximately 160 faults were interpreted; with two different strike directions; northwest and northeast striking. Several time and depth structure maps were generated. Upon inspection of the facies on the cross section of the seismic images, they are assumed to be deltaic or river channel deposits. The whole structural deformation is classified as syn-rift and post-rift deformation. The latter is divided into first, second and third post rift event. The first two horizons marked the first post-rift event with transgression followed by a set of delta and river channel indicating regression and second post-rift event. The reservoir unit is determined to be Paleocene Dannevirke Teurian formation and the Early Eocene Paleocene formation acts as the stratigraphic seal and trap for the reservoir unit.

Keywords:

Great South Basin, 2D seismic interpretation, rifting, facies, New Zealand.

1. Introduction

This study focuses on the 2D seismic interpretation from DUN06 survey done by the Pacific Titan in early 2006, commissioned by the Crown Minerals group of the New Zealand Ministry of Economic Development. DUN06 survey was consisted of 3110km of high resolution seismic data covering the northern part of the Great South Basin. There are several reports on this area particularly done by the OMV New Zealand in 2009 on the development of the sequence stratigraphic framework. This study interpreted different type of facies

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found during the interpretation. Primary objectives of this study are to deduce the structural and stratigraphic information as well as the trapping mechanism of petroleum system if any. According to the OMV Report by Constable et. al. in 2009, there were eleven wells drilled in the Great South Basin and Southern Canterbury Basin between 1976 and 1987. Some of the wells named as Takapu-1A, Tara-1 and Toroa-1. For this study, only Toroa-1 well was used to interpret the formation along with the other valuable data from the well such as checks hot and well tops.

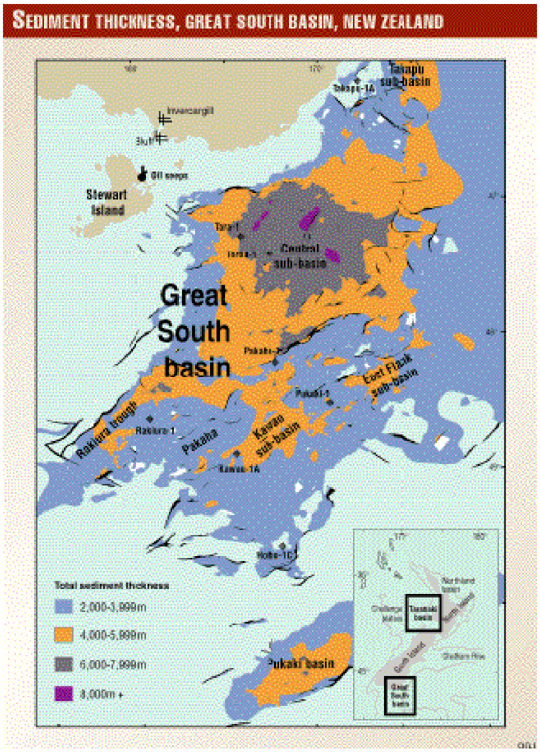

Figure 1: Map of Great South Basin (Pearson, 1998).

2. Geology of the study area

The Great South Basin shown on Figure 1 is located on the south-eastern margin of the emergent New Zealand landmass and covers an area of approximately 100,000 km^2. It is one of a series of sedimentary basins formed by Jurassic and Cretaceous rifting (Sutherland et al, 2001). The Great South Basin formed due to intra-continental extension of the eastern margin of Gondwana during breakup of the supercontinent that resulted in the separation of Australia, Antarctica and Zealandia (Mortimer, 2004). The widespread of rhyolitic and bimodal volcanism at 102 Ma is the earliest evidence of rifting process in Great South Basin.

According to Cook et al (1999), much of the Cretaceous was dominated by fluvial deposition with rivers transporting sediments towards the head of the Bounty Trough. The Bounty Trough is a major submerged feature, a bathymetric depression, of the southwest Pacific Ocean. It is located off the east coast of New Zealand's South Island. The basement terrane underlying the Great South Basin is complex due to accretionary complex and back–arc volcanism associated with the Gondwanan subduction margin shown on Figure 2. It consists of several accreted terranes which are separated by very large-scale faults that variably acted as compressional, transform and normal listric faults throughout the basin history. The basement has been interpreted to control the structural evolution of the Great South Basin. During the Paleocene (65-55 Ma), sea level rise causing the Great South Basin to be submerged.

Different types of deposition were recorded:

1. Marine deposition is found across the basin throughout the Oligocene and Neogene.
2. Terrestrial deposition can only be found at the mouth of Foveaux Strait throughout the Paleogene.

Oligocene onwards, large channel-like features occupied the axis of the basin.

Based on PR 4348 OMV report by Constable et. al., in 2009-2010, there are five main phases in the basin evolution as illustrated in Figure 3.

1. Syn-rift, where deposition occurring during active rifting
2. Post-Rift 1, where sedimentation occurred during the initial thermal subsidence.
3. Post Rift 2 transited from Post Rift 1 with widespread deposition with deltas, slope channels and basin floor fans.
4. Post Rift 3
5. Sedimentation during the syn-orogenic phase

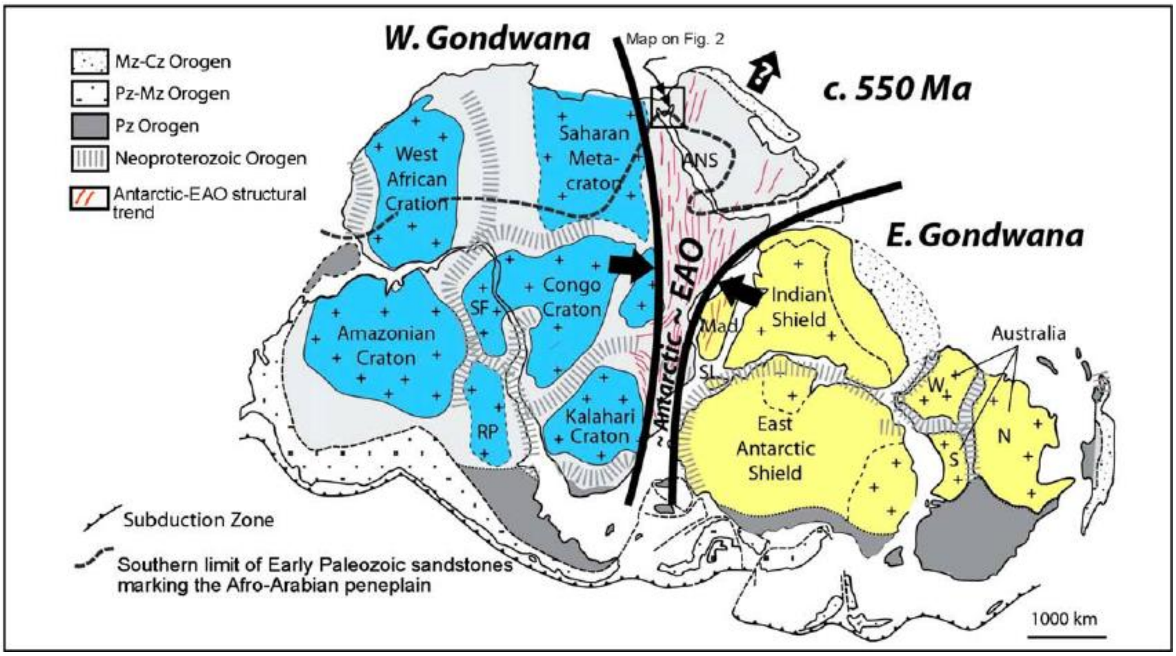

Figure 2: The separation of Gondwana into East and West (after Meert and Lieberman, 2008).

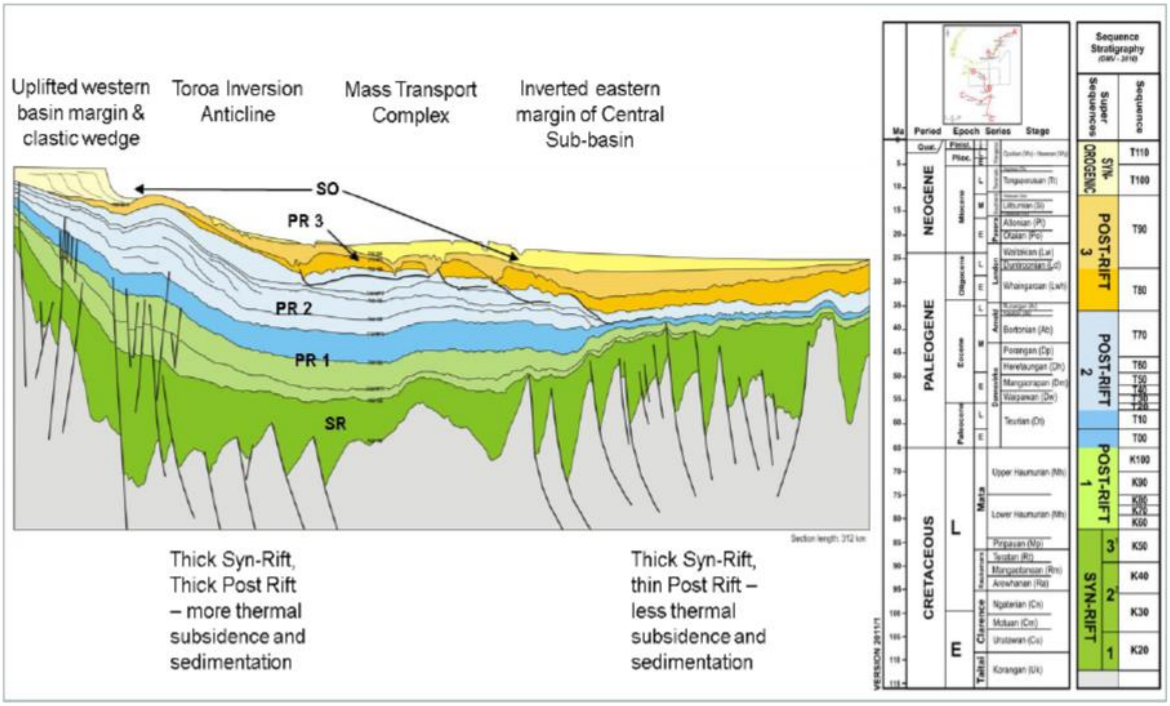

Figure 3: Generalised cross-section from west to east through the basin showing the main stages in the basin evolution (Contable et. al., 2009).

3. Data and methods

3.1 Project data

The seismic data used for this study was based on the acquisition of the DUN06 survey from Dunedin by the Pacific Titan in early 2006, commissioned by the Crown Minerals group of the New Zealand Ministry of Economic Development. DUN06 survey was consisted of 3110km of high resolution seismic data covering the northern part of the Great South Basin with ties to five of the eight wells drilled in the basin shown in Figure 4. Seismic data collection was done by using a 6000m streamer length carrying 480 channels recording for eight seconds was deployed. The collected seismic data was processed with careful selection of the swell noise filter, pre-stack time migration (PTSM), the selected coherency filter used post-stack and use of the radon demultiple technique. These techniques were used for correcting prominent seabed and peg-leg multiples as well as coherent noise trains deriving from shallow, high-density faulting. Another important component of seismic data is the well along with the well top. Toroa well was used as it intersects with three seismic lines from DUN06 survey for better interpretation. The seismic data was loaded into Schlumberger Petrel E&P software and fixing coordinates. Observation of 2D seismic data has been done to find the zero phase and the interval velocities by using well and check shot data from Toroa well drilling report. Well tops were created and used to acquire the position of the interpreted reflective horizons of the seismic lines in Petrel. The checkshots from Toroa well report was then used to convert well tops in depth domain to time domain.

3.2 Velocity modeling

Velocity modeling is a tool in Petrel software that allows domain conversion either from time to depth or vice versa for any item in the software from 2D and 3D seismic data like surfaces, horizons, faults and well data. This allows the conversion of surface map generated in time domain to depth map of the interpreted horizons. Using velocity modelling option, all the time structural maps were then converted to depth.

3.3 Surface and depth map

The interpreted horizons were then used to create a surface map for each of the horizons. These surface maps were then converted to depth map by using velocity modelling which shows variations in depth, possibly due to different types of depositional environment and influx of sediment available for the particular horizons.

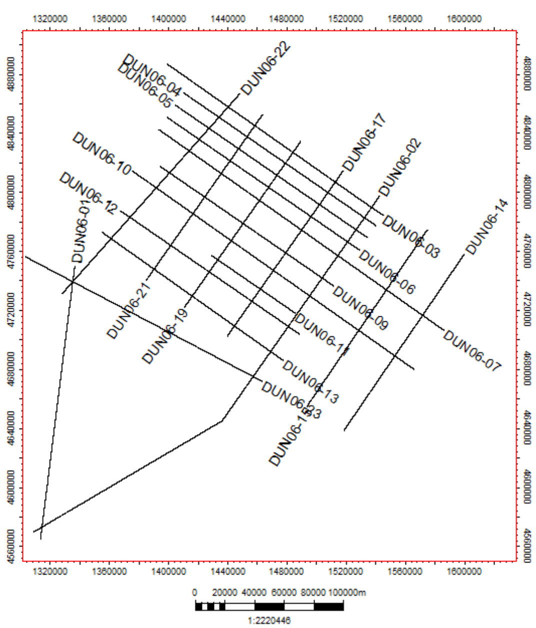

Figure 4: 2D seismic lines from DUN06 survey shows a total of 19 seismic survey lines acquired offshore from Dunedin by the Pacific Titan in early 2006.

4. Results and Discussion

4.1. General interpretation

The interpreted seismic lines display normal polarity convention where low acoustic impedance to high acoustic impedance showed peak in blue coloured. The sea floor reflection exhibits positive contrast displayed as peak which is blue in colour. For well tops correlation, gamma ray logs were used to review the correct layer position for as accurate correlation as possible. Horizons in the subsurface are the seismic events visible in the seismic data. Seismic data consists of mainly 2D and 3D seismic data where both when viewed in cross-section view, the horizons are displayed as reflectors. These reflective events were later used for horizon interpretation.

In determining which seismic amplitude, whether peaks or troughs represent the correct lithology, the first changes in amplitude reflect changes in lithology. In this case, signal from water (less dense) to surface (dense) produces peak and therefore also changes from sand to shale produce peak and shale to sand produce trough. Picking the reflections carefully is necessary to have consistent amplitudes extracted from the seismic data for horizon interpretation.

Horizons in the subsurface represent the event in geological time scale in the Great South Basin. The main well used for this project is Toroa well with well tops. The well tops are markers in picking the reflectors as in seismic line the horizons are displayed as reflectors. Toroa well contains 7 well tops. These well tops were then correlated with the reflectors of the seismic data or through well tie to establish geology from well data to seismic data. Toroa well intersects with 3 seismic lines from DUN06 seismic survey; DUN06-01, DUN06-22 and DUN06-23. The interpretations were first done on seismic line 23P and then this created markers on every seismic line that intersect with the previously interpreted lines. Quality control of the horizon interpretations were carried out to find mistie and corrected for a better interpretation. So far, 7 horizons were interpreted using 2D seismic lines as shown on Figure 5.

4.2. Sequence Stratigraphic Interpretation

During the interpretation of the 2D seismic cross sections, there were several seismic facies found that later helped to interpret the DUN06 survey area of Great South Basin, New Zealand. The 7 horizons interpreted following the reference from sequence stratigraphic framework by Constable et al. (2009). The sequences are explained below.

4.2.1. Syn-rift Supersequences

The first facies identified was half graben shown on Figure 6 below the deepest section below the interpreted horizon called Senonian

Raukumara Teratan Formation. A series of half graben was noticed which are bounded by normal faults on Figure 6. Seismic facies of relatively high amplitude and continuity are overlying the half-grabens, inferred to represent delta plains. As time passes by, the half-grabens had been filled up, accommodation space was low and connectivity between the grabens was greatly improved. The interpretation of syn-rift sequences to be in fluvial and lacustrine environments as many of the half grabens are deep, isolated depocentres up to 3-4 km deep; an ideal condition for lacustrine anoxia. This interpretation is also supported by Constable et. al. (2009).

4.2.2. Post-Rift 1

After rifting occurred, sedimentation in the area increases rapidly and this can be seen with the interpreted horizons; Senonian Raukumara Teratan and Maastrichtian Mata Haumarian on top of a series of faults specifically half grabens. On top of the rifting, the seismic data shown on Figure 6 shows an almost uniform of amplitude suggesting the first post rifting of the area. The first post-rift marks the beginning of the thermal subsidence phase and records an overall transgression after syn-rift sequences. The accommodation space plays a vital role in controlling the amount of deposition at that time. Interpretation of post-rift 1 to be in in fluvial, estuarine of a shallow bathyal marine as indicated by the depth map generated in Figure 11 with small difference in elevation of the area. The deposition of the sediments in both horizons could be derived from the erosion of the horst structure during the rifting process.

Post-Rift 1 consists of these two horizons:

i) Senonian-Raukumara-Teratan (924.5m thick)

This interval has hydrocarbon potential with sandstones and siltstones with minor shale and limestone. The sandstones have two different characteristics with one is light coloured, very poorly sorted, very fine to coarse grains and sub-angular to sub-rounded. The other is dark brown in colour and varied from siltstone to medium grain in size but more rounded (Hunt International Petroleum, 1977).

4.2.3 Post-Rift 2.

Maastrichtian-Mata-Haumurian (744.6m thick)

This zone is predominantly sandstones and siltstones with minor shale breaks and some poorly developed limestones. The sandstones are well cemented with calcite, kaolinite and silica, sub-angular and very poorly sorted (Hunt International Petroleum, 1977).

The widespread of lowstand deposition with deltas, river channels and basin floor fans indicated the transition of Post-Rift 2 as shown on Figure 7 and Figure 8. Post-Rift 2 ranges in age from Paleocene/Dannervirke to Early Eocene/Paleocene Dannevirke (DT). It is interpreted that relative sea level fall, regression cause less accommodation space for the sediments from the coast to be deposited to the deep marine environment to form deltas and various river channels. The sag phase is identified where a series of deltas are present. This event is marked by the depth map on Figure 12 and Figure 13 shows a transition in depth from coastal belt to abyssal plain.

Post-Rift 2 consist of these intervals:

i) Paleocene-Dannevirke-Teurian (1035.4m thick)

This thick Teurian stage is predominantly sandstones with minor limestone and abundant siltstones and some intercalated shale. The sand varies from sub-rounded, poorly sorted argillaceous to sub-angular to sub-rounded and loosely to very well cemented, (Hunt International Petroleum, 1977).

ii) Early Eocene-Paleocene-Dannevirke Waipawan (100.6m thick)

This interval is predominantly light to medium grey clay, shales and some silts (Hunt International Petroleum, 1977).

iii) Early Eocene-Dannevirke-Heretaungan (765.7m thick)

This zone is comprised of massive argillaceous sand beds with intercalated silts, limestones, clay, shale and silt beds. The sands are sub rounded and very poorly sorted, (Hunt International Petroleum, 1977).

iv) Mid Eocene-Dannevirke-Porangan (76.4m thick)

The thickness of this horizon is unknown due to the fact that no samples were collected until 791.8m. The lithology of this horizon was predominantly light to medium grey siltstones and clays. Some fine grained sandstone lenses were observed along with some gravels, (Hunt International Petroleum, 1977).

v) Mid early Eocene-Dannevirke-Porangan-Heretaungan (76.4m thick)

Predominant with intercalated sandstone, siltstones and marls. These sediments are moderately sorted and becomes poorly sorted at the base of the interval and sub rounded to rounded, (Hunt International Petroleum, 1977).

4.2.3. Seismic facies identified on DUN06 seismic lines

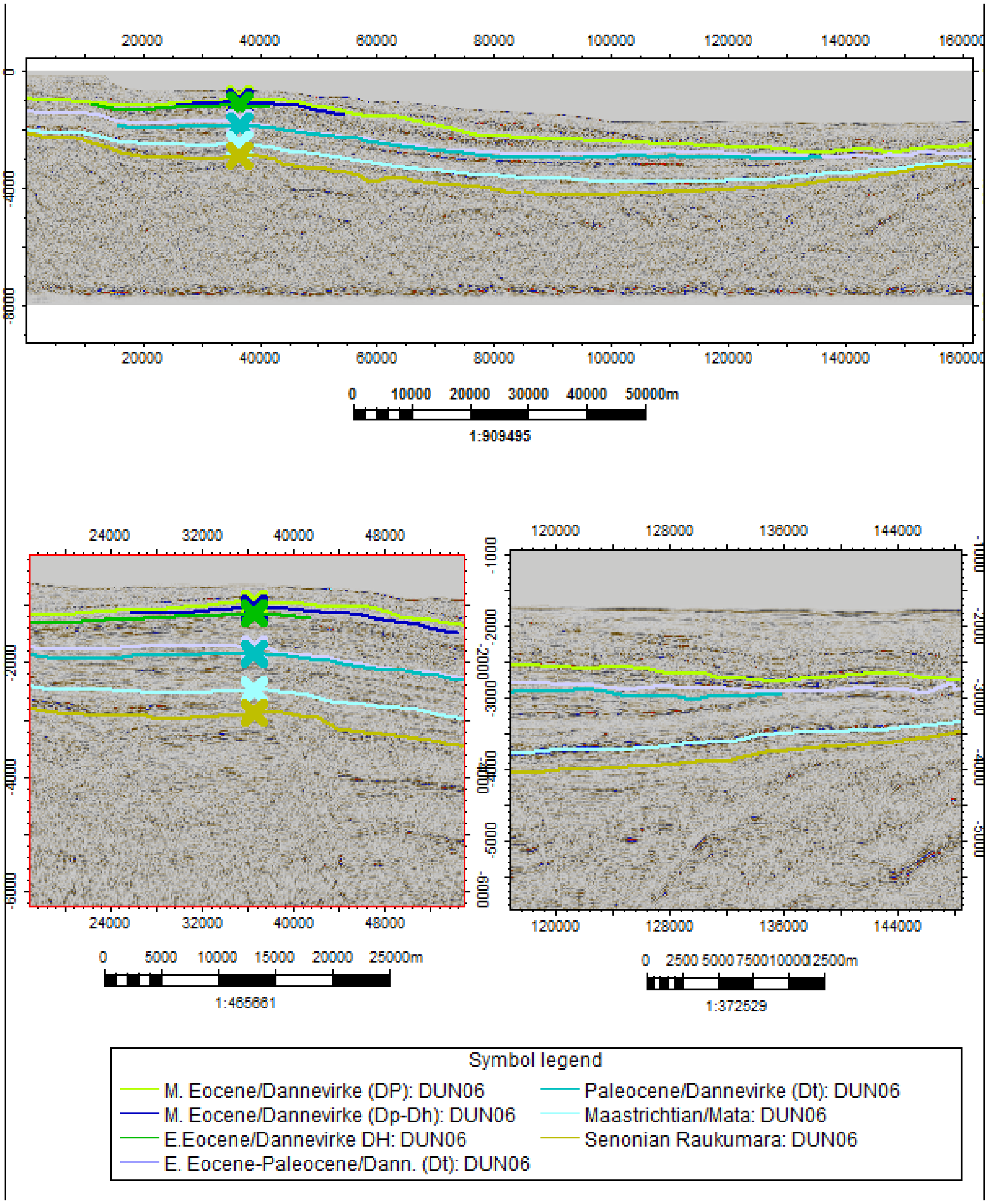

Figure 5: Generalised cross section view of the seismic line shows coastal belt on the west and basin on eastward.

a) Half Graben

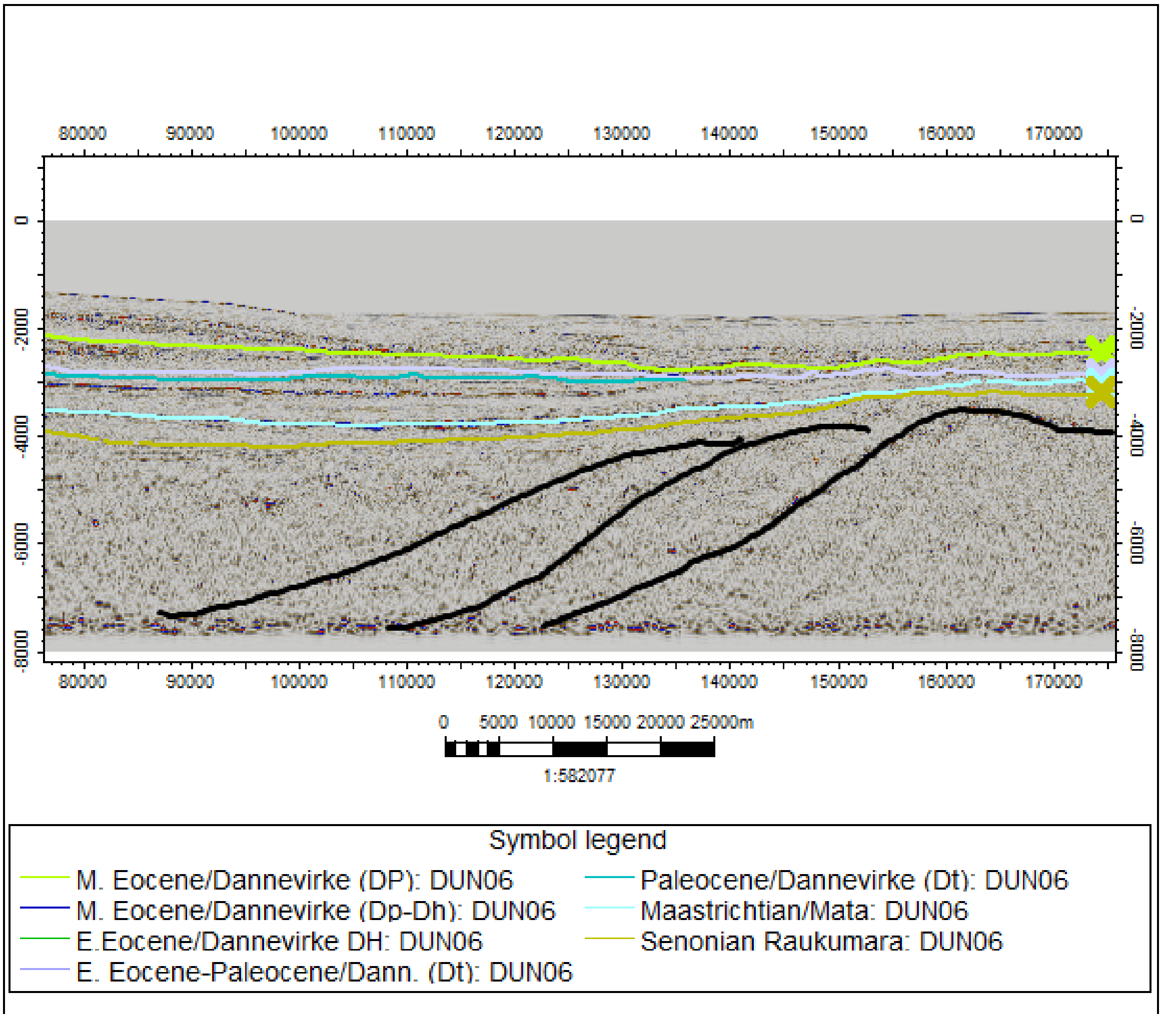

Figure 6: Half Graben under Senonian Raukumara indicating rifting event.

b) Delta and river channel

At the continental shelf edge, there are evidences of delta building process or progradation of delta. Also, a paleo-river channel was found in the DUN06-13which indicates fluvial environment of deposition.

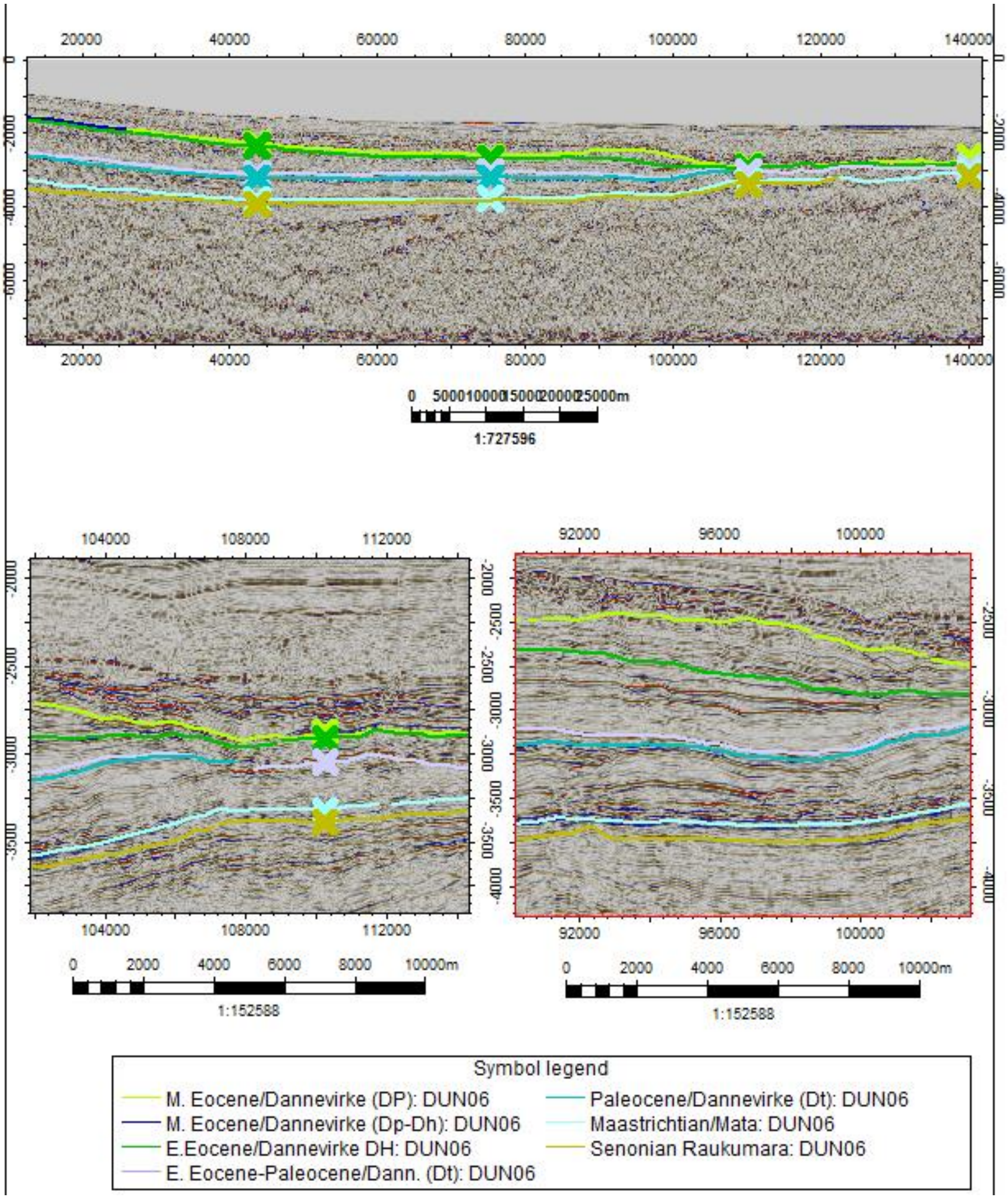

Figure 7: Delta and river channel can be found on this seismic line (DUN06-13).

c) *Basin floor fan*

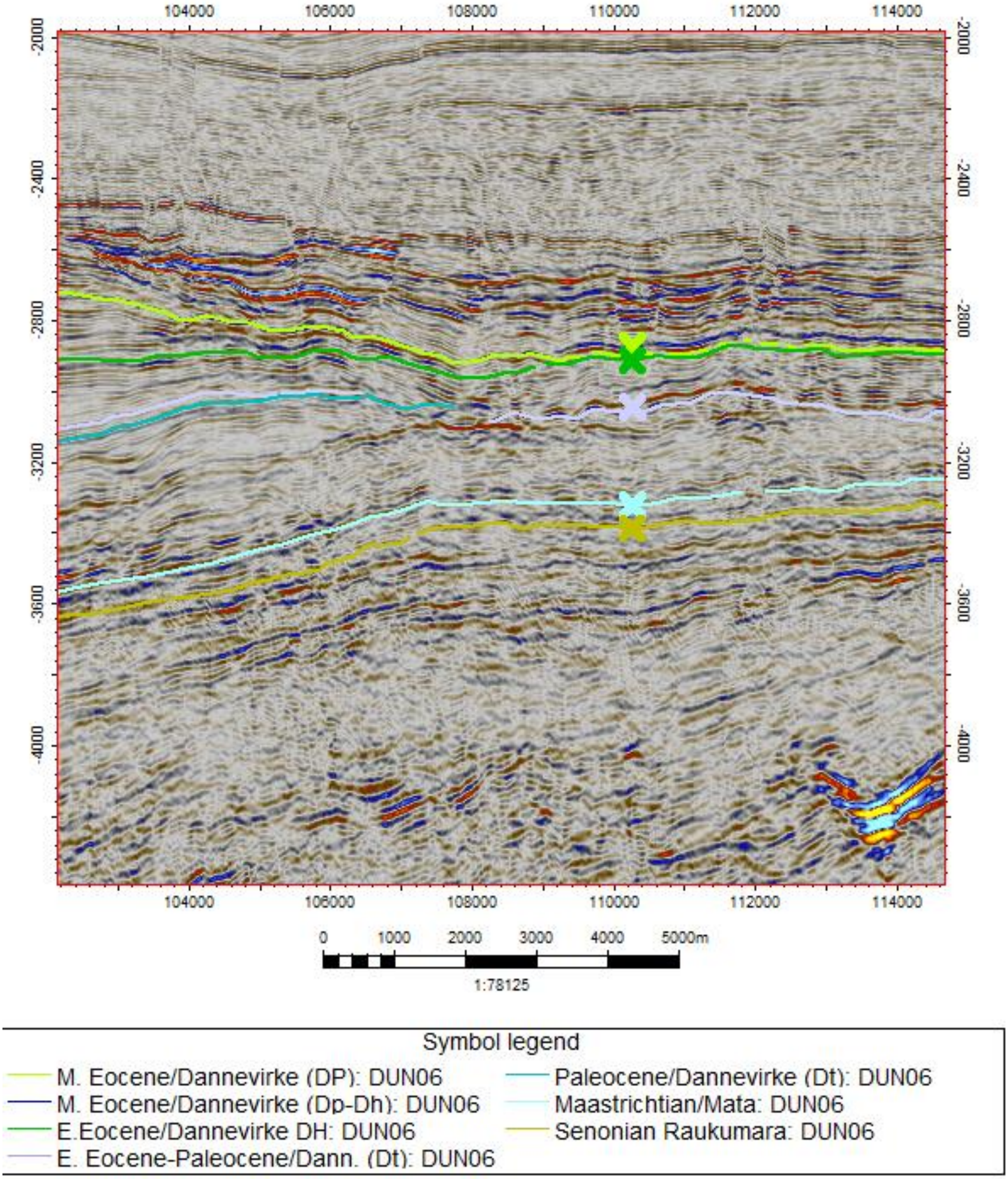

Figure 8: Seismic line (DUN06-13) shows basin floor fan facies where it consists of sediments deposited from the submarine canyon in figure 10.

d) *Plume*

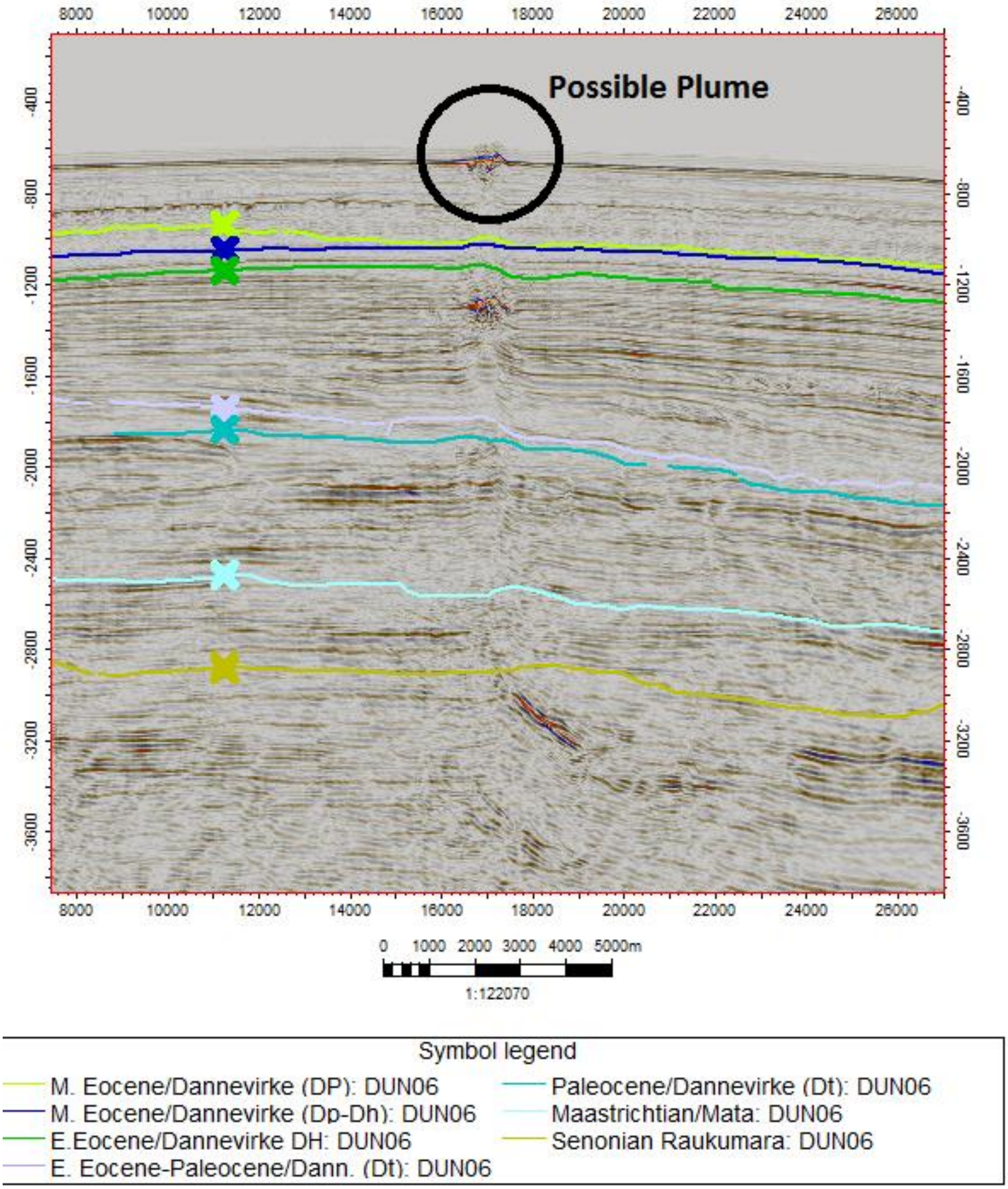

Figure 9: Possible plume identified on seismic line DUN06-22 indicating a possibility that the studied area to be an active margin.

The evidence of gas chimneys as interpreted in this seismic package is indicated by the rising effect from the lower density of gases compared to its surrounding. From Figure 9, it shows that the gas chimney body rises through the fault line from the basement to the seabed.

e) Submarine canyon

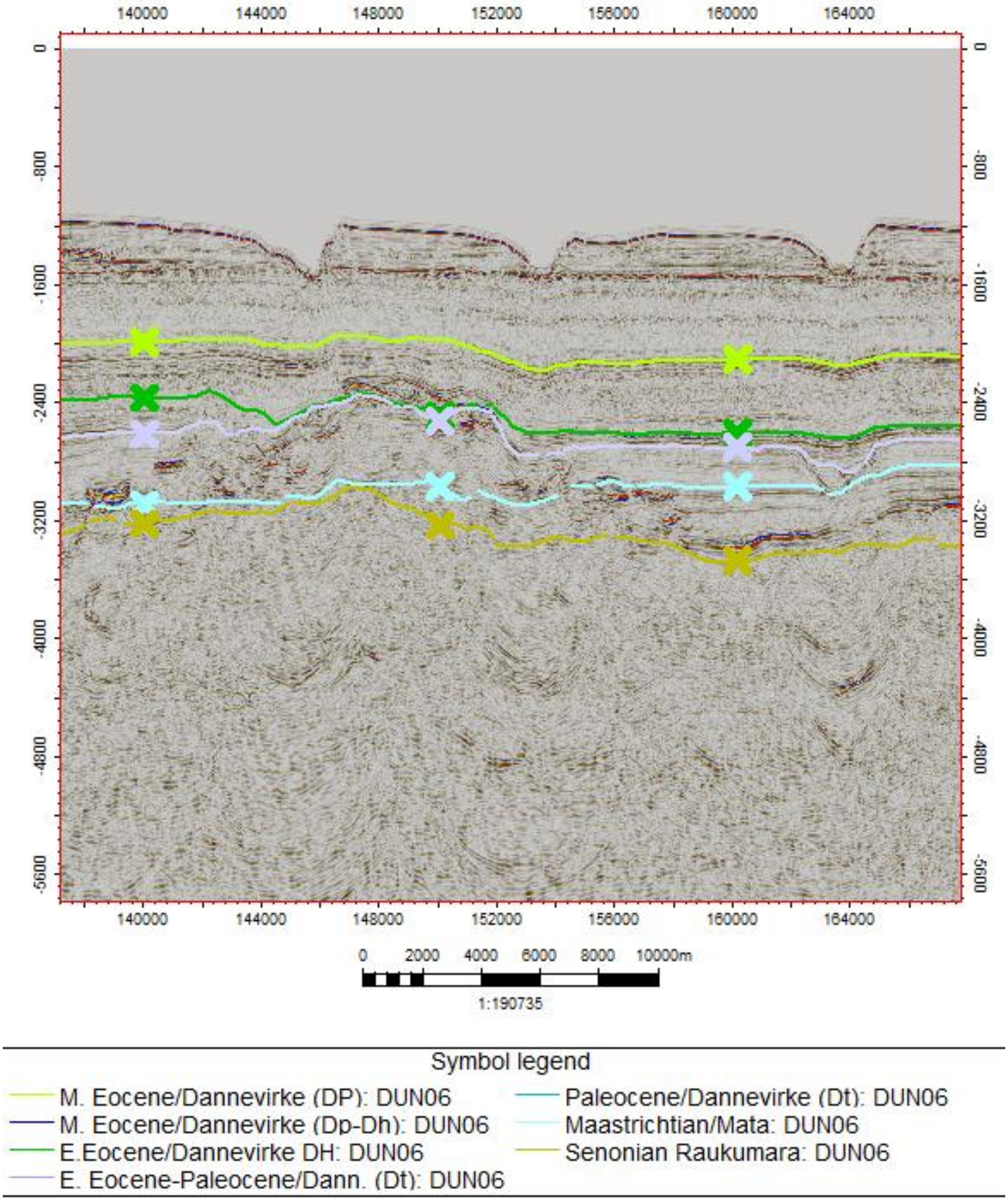

Figure 10: Submarine canyons on DUN06-13 possibly an indicator that the studied area to be an active margin. They are more common on steep slopes found on active margin compared to ones found on passive margin. It is evident with very steep and subject to erosion by slumping (Harris, 2011).

4.3. Structural interpretation

The general structure of the basin on Figure 7 can be subdivided between the western and the eastern side of the basin. Based on the seismic cross section of the area as shown on Figure 7, the western and central parts are characterized by a thick post rift and possibly thick syn-rift indicating high thermal subsidence and sedimentation rates. Sleep & Snell (1976) considered that thermal expansion of the lithosphere causes uplift and erosion; subsequently, the lithosphere returns to thermal equilibrium, cools and subsides by thermal contraction. Thick post-rift is evident with the intervals between the interpreted horizons are significantly thicker from the eastern side. Thermal subsidence of the rift occurs when conductive cooling of the mantle causes the lithospheric to be thickening and resulted in decreased elevation. The eastern side has a thin post rift section indicating less thermal subsidence and sedimentation rates.

The difference in height between the western and the eastern margin of the basin indicated the coastal belt on the west and deep marine environment such as shelf-bathyal to the east. This is shown prominently in almost all of the seismic lines except DUN06-19 and DUN06-21 due to the orientation of the seismic survey indicated a flat structure possible at or near the abyssal plain of the basin.

Identification of submarine canyon on Figure 10 along with plume on Figure 9 indicated the area to be an active margin. The formation of submarine canyon could be the result of slumping and mass wasting of the continental slope of the area (Harris, 2011) and this is evident as most of DUN06 survey area showed a substantial amount of mass wasting instead of prominent faults in a large number.

4.3.1 Fault interpretation

Faults were interpreted when a change of continuity of strata or horizon due to abrupt termination. Since this is a 2D data, fault interpretation is limited to the orientation of lines and the spaces between them. Since DUN06 survey has covered 3110 KM of area, the grid is widely spaced with respect to the distance between the seismic lines and the faults. This problem is an example of spatial sampling where attention to every detail is needed given the limited quantity and quality of the seismic data. The average distance between the seismic lines reached up to 10 km, which resulted in a different physical structure of seismic images from one and another. This posed the problem of tying the identified faults from line to line and when viewed in 3D window, the interpreted fault should become fault polygons which represent the specific type of fault for example hanging wall or foot wall. Instead, the untied faults become fault sticks, a set of vertical lines that only indicate the faults slope. Approximately 160 normal and listric faults were interpreted with northeast and northwest striking as shown on Figure 14.

4.3.2. Depth map

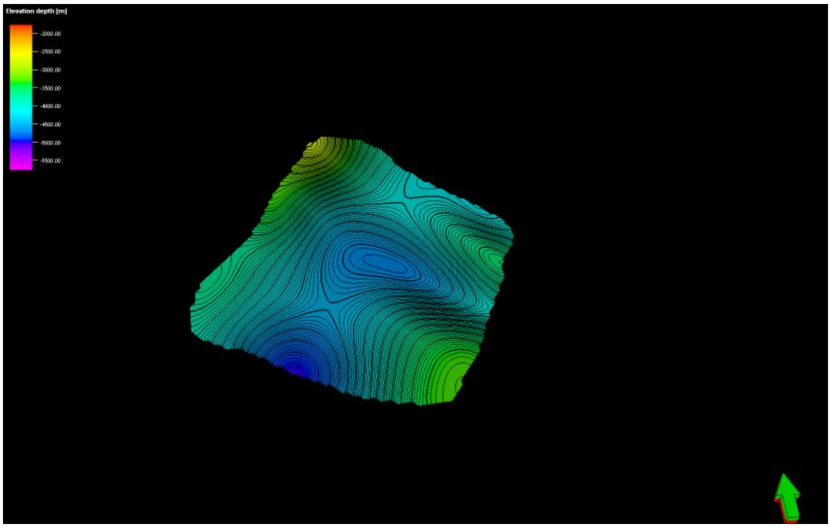

Figure 11: Depth map of Senonian Raukumara that mostly shows the same elevation as this interpreted horizon is on top of the series of half graben in Figure 6.

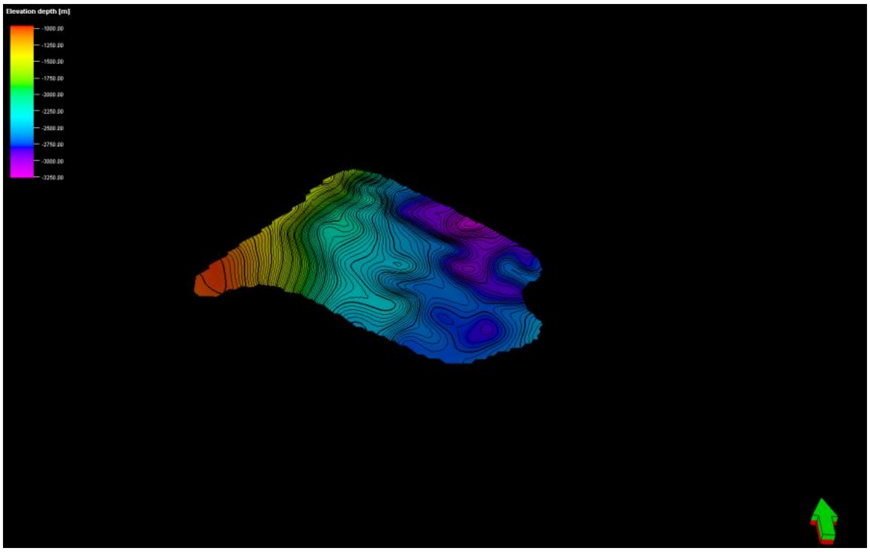

Figure 12: Depth map of Early Eocene Dannevirke DH showed a relative difference in terms of depth elevation possibly indicating a thermal subsidence on the western part of the area.

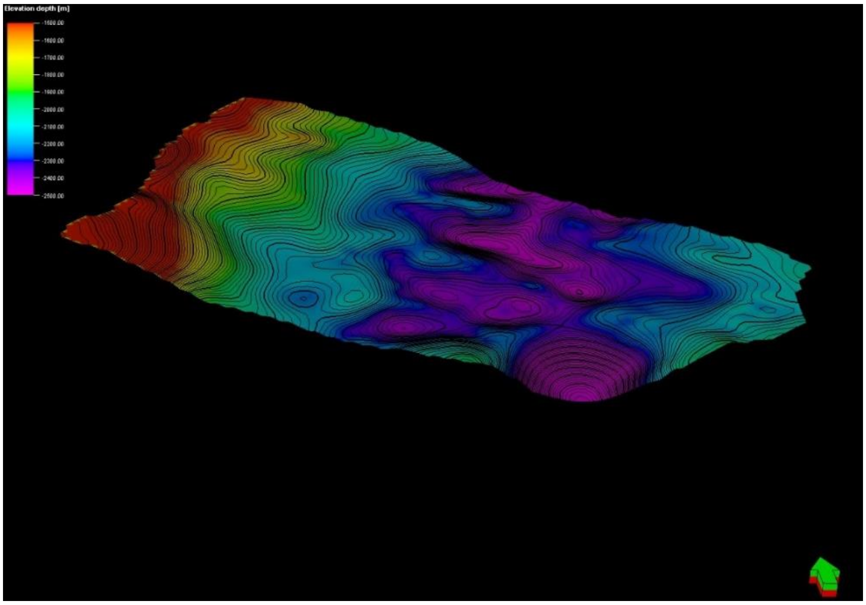

Figure 13: Mid Early Eocene Dannevirke Porangan Heratuangan shows the transition from coastal belt to abyssal plain.

4.3.4. Fault

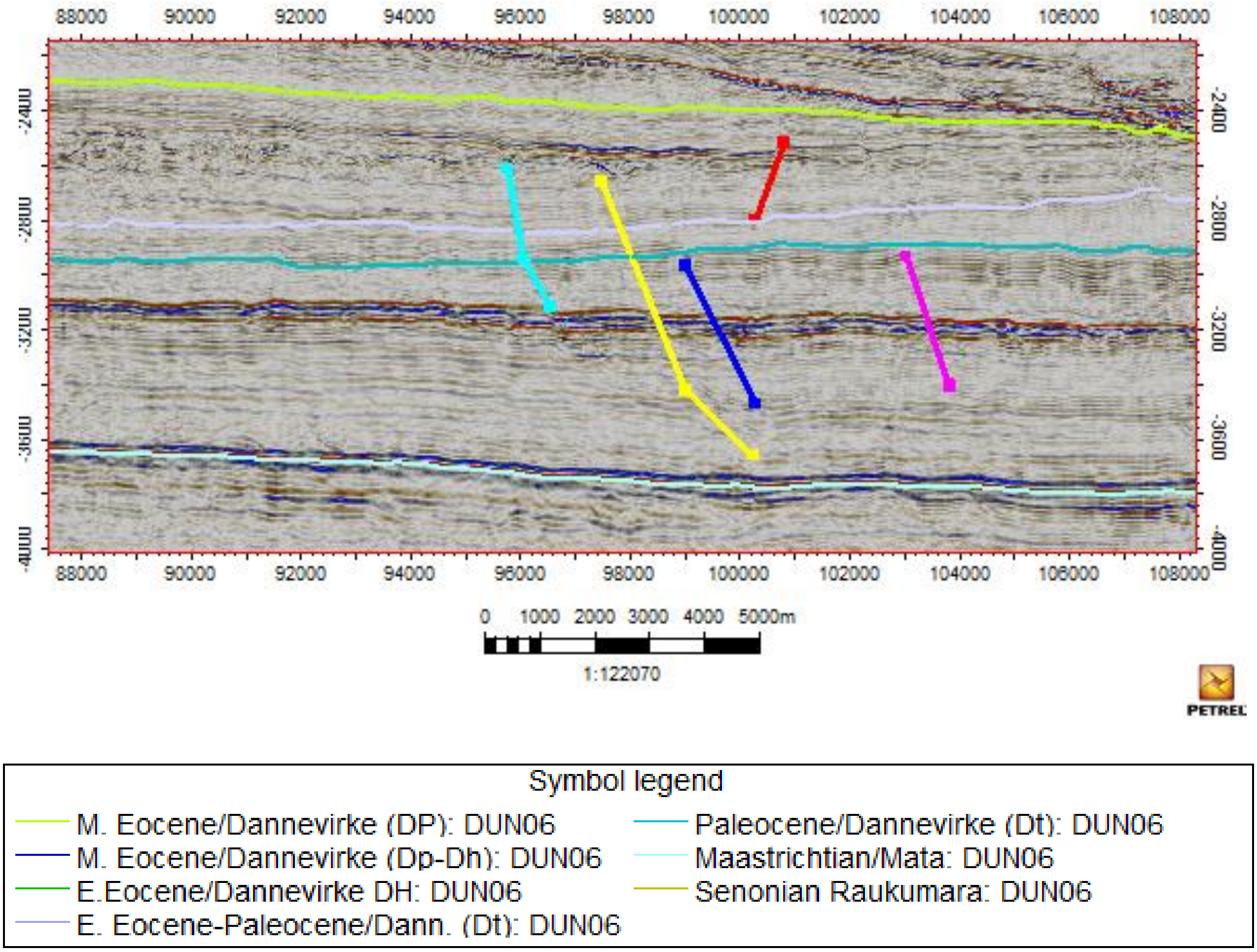

Figure 14: Normal and Listric faults can be found throughout the survey area with most of the faults are dipping southeast and southwest.

4.4. Implication of Petroleum System

The potential petroleum system suggested is based on my seismic interpretation, lithology of each formation from the well report and facies identified in DUN06 seismic survey.

4.4.1. Source rock

Potential source rock for the area is Senonian Raukumara as this formation is interpreted to contain coarse grain sediments deposited from erosion process on horsts during the formation of half graben. It is an ideal source rock due to deep location of the half grabens which reached up to 3-4km deep; an ideal condition for lacustrine anoxia.

4.4.2. Reservoir

The main reservoir unit for DUN06 survey area is the Paleocene Dannevirke Teurian Formation with the general lithology consists of massive sands and minor silts with a total thickness of 1035.4m. Lateral connectivity of the of the reservoir is not continuous due to distributary mouth bar system in the delta. The formation reservoir unit is interpreted to be deposited during the active deltaic progradation and the reservoir quality decrease with basinward as indicated by ***figure 5***. According to Cook et al (1999), the Toroa Dome found during the drilling of Toroa well is 100km long by 50km wide and has a vertical closure of 250m.

4.4.3. Trapping structures

The normal and listric faults could act as structural trapping mechanisms however during the interpretation of the DUN06 survey area, there is minimal amount of faults found at the reservoir formation as most of the reservoir formation consists of mass transport complex.

4.4.4. Seal

The seal unit for DUN06 survey area is early Eocene-Paleocene Dannevirke Waipawan with a total thickness of 100 m consisting of clay, shales and silts. This formation is interpreted due to transgressive event in the early Eocene where sea level rises transported fine clastics sediments towards the coast. This is evident with the lateral connectivity of the seal unit across the area from the basin towards the coast. The unit rocks also act as stratigraphic trap to prevent the migration of the hydrocarbons.

5. Conclusions

Interpretations of 2D seismic reflection profiles of DUN06 conform to the whole deposition interpretation of Great South Basin by Constable et al (2010). Major conclusions of this study are:

A total of 7 horizons as well as 160 faults were identified across the whole 19 seismic profiles from DUN06 survey. These interpreted horizons range from the late Mesozoic era to Cenozoic Era as oppose to PR3450, a preliminary interpretation and structural modelling report by Crown Minerals which interpreted horizons from Cretaceous to Paleocene Era only. Toroa well is used along with its well top to act as markers for correlating and interpreting all the horizons.

Identified seismic facies such as delta, river channel, submarine canyons and plumes helped stratigraphic and structural interpretation of DUN06 survey area.

Subsequent interpretation based on the interpreted horizons, faults and the seismic profile shows that DUN06 survey area are further supported with the basin development and sequence stratigraphic framework that was proposed by Mitchum (1977). It was proposed that the area experienced syn-rift supersequences and followed by three post rift events and lastly syn-orogenic event. In this report, the horizons are within the syn-rift and the two post rift events only.

Structural interpretation showed the 160 faults interpreted to be normal faults with northeast and northwest striking. In regards with the petroleum system, Senonian Raukumara Formation is deemed to be the potential source rock unit due to deep location of the half grabens which reached up to 3-4km deep; an ideal condition for lacustrine anoxia. The Paleocene Dannevirke Terurian would the reservoir unit with a total of 1035.4m thickness consisting of massive sandstone with minor silt. The Eocene Paleocene Dannevirke Waipawan acts as the seal and trap.

It is proposed that further studies would utilize other wells drilled such as Tara and Pakaha well for better horizon interpretation. Also, a further petrophysical studies on the petroleum system is needed to determine the viability to drill more wells for hydrocarbon.

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