Seismic geomorphology of deep-water channel systems in the southern Taranaki Basin

Clayton Silver, Karelia La Marca-Molina, Dr. Heather Bedle, University of Oklahoma*

Summary

Interpretation of three-dimensional reflection seismic data to characterize channels is an effective way to understand the evolution of complex channel systems. Two surveys from the Taranaki Basin were used to observe and characterize the evolution of mid to late Miocene channel complexes along a prograding continental shelf-slope. Architectural elements of deep-water channel systems reveal a systematic change as the system progresses from a proximal shelf-slope environment to a more distal, weakly confined system.

Introduction

In this region of the southern Taranaki Basin, channel complexes range from 250 meters to one kilometer width and range from high to low sinuosity and from deeply-incised to laterally stacking, revealing a complex depositional system. As the Taranaki Basin is New Zealand's most prolific petroleum basin to date, much research has been done regarding the tectonic history of the region. The observed siliciclastic deep-water channels were formed in response to basin subsidence and uplift in the hinterland. Potential petroleum reservoir and seal rocks also exist in this region, having been deposited basin-ward of the developing shelf.

To better understand the reservoir potential in this relatively unexplored part of the basin, two recent seismic acquisitions are being studied. The Pipeline and Hector three dimensional seismic datasets were integrated with two available wells: The Pukeko-1 and the Hector-1 (Figure 1). A suite of attributes was generated to aid in identifying architectural elements along with interpreting the geometry of the channel complexes.

Linking the sequence boundaries between datasets is crucial for stratigraphic interpretation. This was accomplished through interpreting 2-D seismic lines that intersect both datasets, as the two 3-D surveys are 8 kilometers apart at their closest point. The Hector 3D data set was acquired in 2005 and the Pipeline data set was acquired in 2013. Formation tops and interpreted sequence boundaries were picked from well data and integrated into the seismic data to match seismic reflections in order to help build a depositional model for the region.

Taranaki Basin

Geologic Setting

The Taranaki Basin off the western coast of New Zealand is a cretaceous rift basin that formed in response to the breakup of Gondwanaland and the opening of the Tasman Sea. Rifting ceased in the Paleocene, and the basin was a passive margin through the Eocene. In the mid-Oligocene, the Pacific Plate began subducting beneath the Australian Plate, which marked a large increase in subsidence in the Taranaki Basin. In the mid-Miocene, a pronounced regressive shelf-slope system was established and progradation began (King and Thrasher, 1996). During this time of progradation, low order sea level changes occurred. Hinterland uplift combined with subsidence created a series of high stand tracts and low stand tracts. As sea level fell series of channel complexes were formed oriented southeast to northwest transporting eroded sediment from the uplifted hinterland to the basin. Evidence for heavy reworking of deposited sediments during highstands by ocean-bottom currents into large-scale sediment waves has also been presented (Kroeger, 2019).

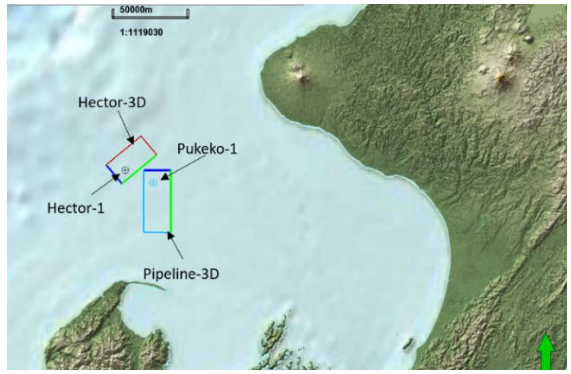


Figure 1: Map view of the study area. The seismic volumes are outlined along with the locations of the Hector-1 and Pukeko-1 wells.

The basin consists of Cretaceous through Neogene sediments and range up to 10 km thick. In the late Miocene through the Pleistocene, large scale progradation of the shelf-slope occurred, depositing what is informally known as the Giant Forset Formation (GFF). The GFF is characterized by large, continuous clinoforms easily visible in seismic data. In our study area, the Pukeko-1 well encounters the GFF, and the formation is interpreted to be approximately 1 km thick. The GFF are predominately mud-rich lithologies (Hansen and Kamp, 2001). Heavy channel incision occurred during regressive system tracts (RST) and lowstand system tracts (LST) in the Pipeline survey area as eroded sediment from the recent uplift is transported from the southeast basinward to the northwest.

Seismic Data

Seismic geomorphology of the southern Taranaki Basin

Two three-dimensional seismic datasets in the southern Taranaki Basin were used to create a depositional model for mid to late Miocene channel complexes (Figure 1). The area of the Pipeline-3D dataset is approximately 515 km^2. This was acquired in 2013 and processed in 2015. This dataset has SEG negative polarity and is zero phase. Kirchhoff anisotropy PSTM has also been applied during processing, and the data has a 4-millisecond sample rate and a record length of 6 seconds.

The second survey analyzed was the Hector-3D seismic survey. This survey was acquired in 2005 to image a local structural trap for hydrocarbon exploration in the southern Taranaki Basin. The marine survey was acquired with an eight-streamer survey vessel with two alternating sources. The full fold area of the survey is 434 km^2 and has a bin size of 6.25 m x 25 m. Like the Pipeline-3D dataset, Hector-3D has a 4-millisecond sample interval, 6 second record length, SEG negative polarity and is zero phase.

Methods

Seismic Interpretation

Seismic interpretation of the deep-water channel complexes was done in a step-wise manner. First, sequence boundaries were identified. Sequence boundaries in this study followed the description given Hansen and Kamp (2007) in their study of the GFF in the Northern Taranaki Basin. Sequence boundaries were identified by the following:

- Bold, high amplitude reflectors across the survey
- Onlap of strata on a lower sequence boundary
- Erosional truncation of reflectors
- Slumps or fans – these commonly occur during lowstand conditions and overly the lower sequence boundary.

A sequence boundary above our interval of interest was mapped in both datasets. Next, each seismic volume was flattened on the interpreted sequence boundary. This was done to remove structural effects and to provide a more accurate representation of the stratagraphical relationships between the reflectors. It is important to keep in mind the dip of the paleo-seafloor will still have an effect, albeit not as severe. The master valleys and overbanks (Kolla et al, 2007) were then interpreted for the more prominent channel complexes. This was accomplished using inline, crossline, arbitrary lines, and time-slices. With the locations and three-dimensional geometry of the master valleys known, the internal architecture of each mapped channel was interpreted.

Attributes

A subset of attributes was selected for calculation based on their ability to aid in channel architecture identification and interpretation shown in previous studies and to efficiently interpret the results. All attributes were calculated on flattened datasets in order to help identify internal structures of the channel complexes not easily visible in the amplitude data. Coherency-based attributes have been shown to excel at highlighting subtle discontinuities in the data (Marfurt et al, 1998), and so energy ratio similarity (ERS) was calculated (Figure 2C). Most-positive (k1) and most-negative (k2) curvature along with spectral decomposition and sweetness were applied to the data. Most-positive curvature anomalies represent anticlinal features such as channel banks and/or levees. Most-negative curvature anomalies represent synclinal features such as the base of a channel which is not easily seen in amplitude data (Marfurt et al, 2007). Spectral decomposition is commonly chosen for channel interpretation and is calculated by transforming the seismic data to the frequency domain via a continuous wavelet transform, and individual frequency cubes are the result. These cubes are then corendered utilizing the red-green-blue (RGB) color scheme. Sweetness is derived from instantaneous attributes by dividing the reflection strength by the square root of instantaneous frequency. This attribute was calculated as it has been used to highlight sand-rich lithologies in the Taranaki Basin.

Results

Pipeline-3D

The architecture of the channel systems present in the Pipeline-3D dataset have characteristics of a confined channel system. On average, the master valleys range from 500m to 2000m in width and are deeply incised into progradational clinoforms. Well-developed levees are also present in the Pipeline dataset. An example of these features is presented in Figures 3B-C. The internal architecture of channels varies throughout the survey and the master valleys becomes somewhat ambiguous in the northwestern corner of the survey. Co-rendered curvature attributes in Figure 2D reveal connectivity between channel complexes indicated a complex, interconnected channel systems.

Hector-3D

Channel complexes in the more distal Hector-3D dataset are typically less incised and poorly constrained. Lateral migration of channel complexes is common relative to the Pipeline survey. ERS and spectral decomposition time slices reveal curvilinear anomalies oriented perpendicular to the flow direction (Figure 2 B-C). These represent channel-overbank sediment waves (Posamentier, 2003) which are related to overspill and flow stripping from the channel.

Conclusions

The channel complexes in GFF in the Pipeline-3D survey match the characteristics of those in a confined system caused by a shallow gradient shelf-slope system, illustrated in Sprague’s proposed model (Figure 3). During the massive progradation that took place during the deposition of the

GFF, these channels would have formed in response to falling sea levels after a high stand period and transported a large amount of sediment to the starved, subsiding basin. Due to the steep prograding shelf slope, the channels eroded into the slope as sediment bypassed forming the master valleys. The internal structure of the channels exhibits major cuts, as indicated in Figure 4C by the green arrows. These cuts represent the lateral migration of channels within the master valley over time. Near the edge of the survey in the northwest corner, the channel system begins to meander. This change in behavior is likely caused by a change in the shelf-slope gradient. As the gradient flattens out, the transportation energy will decrease, resulting in the formation of gentle meanders. The depth of the master valley also decreases towards the northwest as the system likely doesn't have enough energy to erode down into the shelf. However, this could also be caused by a change in lithology that is more resistant to erosion.

The channels present in the Hector-3D dataset illustrate the trend of decreasing system confinement observed in Pipeline, and the system appears weakly confined. Channel complexes are characterized by sinuous behavior and channel fill mounding, which is caused by differential compaction of sand-filled channels overlaid by clay-rich muds. The channels also have a prominent feature not shown in the Pipeline-3D dataset: distinguished levee overbank sediment waves. Time slices of spectral decomposition clearly illuminate these features (Figure 2C). These provide further evidence that the channels are less confined and more prone to breaching their banks.

Future Work

Further analysis on the Hector-3D dataset will be done. A stronger link between time-equivalent channel complexes in the two datasets will be done in order to make more in depth observations of changes in the depositional environment as the channels become more distal in Hector. More channels will be mapped out to provide more accurate interpretations as time-slices fail to illustrate dipping events perfectly, even after flattening.

The detailed analysis of these channels will allow for the creation of a predictive model of what is out deeper in this relatively unexplored portion of the Taranaki Basin. As the channels progress basinward, we expect to find the deposition of large sheet sand or fans in response to the transported sediment coming out of suspension. The location of these sands would be crucial to know for exploration purposes as they can have high reservoir potential.

Acknowledgments

We would like to thank New Zealand Petroleum and Minerals for providing the seismic and well data for this study. We also would like to thank Schlumberger for the Petrel licenses that allow us to strengthen our knowledge of the subsurface.

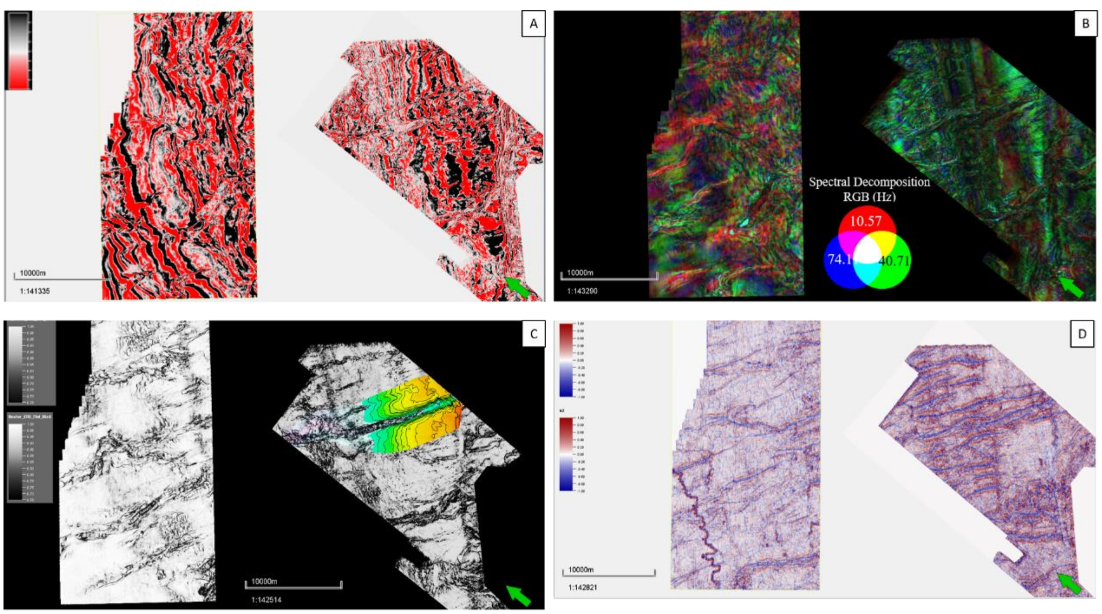


Figure 2: Map view displaying the attributes generated to enhance channel visualization and interpretation. The Pipeline-3D (right) timeslice is at -1224 ms TWT and the Hector-3D (left) timeslice is at -1512 ms TWT. (A) Time slice of the amplitude. (B) Spectral decomposition visualized using a RGB blend of three frequency cubes. Note the increased resolution of channel features in both volumes. (C) Energy ratio similarity time slice with interpreted channel complex surface displayed in TWT. (D) k1 and k2 co-rendered. Red linear anomalies corespond to channel edges and blue linear anomalies correspond to the base of the channel. A curvilinear computational artifact treneding N-S is present in the Hector-3D dataset.

Seismic geomorphology of the southern Taranaki Basin

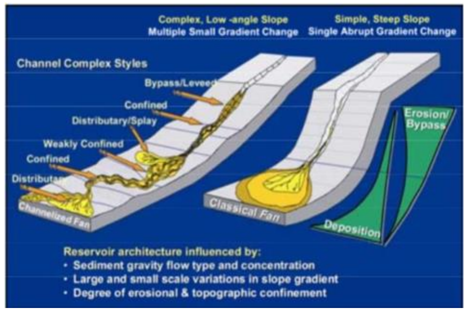
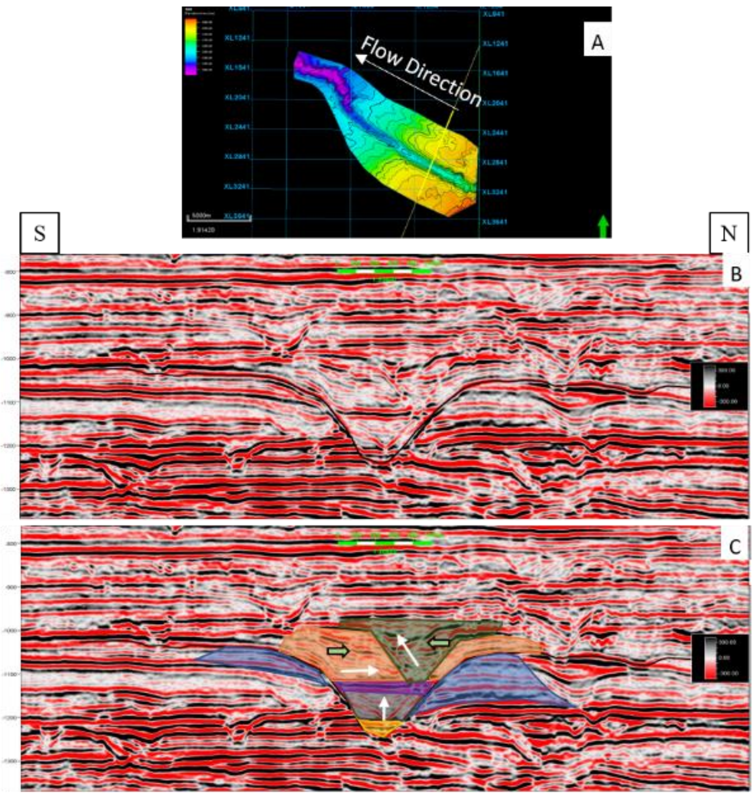


Figure 3: Deep-water channel models modified after Sprague et al (2003).



Blue – Master overbank
Gold – Basal channel deposit
Grey – Aggregational fill
Orange – secondary overbanks
Green – final channel complex
Purple – High-order sequence boundary
White Arrows – Channel complex migration
Green Arrows – Major cuts

Figure 4: (A) Interpreted horizon picked for a master valley in the Pipeline-3D dataset. Paleo-flow direction is from the southeast to the northwest. (B) Arbitrary line seismic section displaying the interpreted channel complex. The location is shown in (A) by the yellow line.. (C) Displays the interpretation of the channel complex along with the identification of architectural elements