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Seismic attributes and analogues to characterize a large fold in the Taranaki Basin

SEISMIC ATTRIBUTES AND ANALOGUES TO CHARACTERIZE A LARGE FOLD IN THE TARANAKI BASIN

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Geological Feature: Fault bend fault or large amplitude fold (possibly monocline)

Seismic Appearance: Large, discontinuous, high variance feature

Alternative Interpretations: Fault, fold

Features with similar appearance: Fault, Fold, Wide straight channel belt (time or horizon slice)

Formation: Rift sequence of Taranaki Basin

Age: Eocene

Location: Taranaki Basin, Western offshore New Zealand

Seismic data: Provided by New Zealand Petroleum and Minerals.

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SUMMARY

The Taranaki Basin lies in the western portion of New Zealand (Figure 1), both onshore and offshore. It is a Cretaceous rift basin that is filled with up to ~10 km thick

deposits from marine to deepwater depositional environments from the Cretaceous (~93ma) to the Neogene (~15ma) (New Zealand Petroleum and Minerals, 2014). This basin underwent important tectonic events that resulted in large scale features such as faults and folds and the deposition of turbidites such as channels and channel belts. These features are easily recognizable in seismic data. When analyzing the offshore 3D Pipeline dataset, we recognized a peculiar fault-like feature with large-scale dimensions (~15 km long and ~1 km wide) within the sequence. The alignment was perpendicular to the direction of deposition in the basin (southeast-northwest) as identified by previous studies, and sub-parallel to the main structures in the area (southwest-northeast). We interpreted the seismic character of the funny looking thing (FLT) likely as 1) a fault, 2) a fold, or 3) a large channel belt within the basin. We utilize seismic attributes such as coherence (Sobel filter), dip, cosine of phase, and curvature to characterize this feature geomorphologically. The geological background of the area and analog settings such as Kane et al. (2010) Camerlo and Benson (2006) and others aided in understanding and distinguishing the nature of this large structure. Conneally et al. (2017) provide the best example of a Miocene monocline similar to the FLT studied. Monocline examples in seismic data are rare to find, and we want to show how to avoid misinterpretations.

GEOLOGICAL BACKGROUND

The rift derived Taranaki Basin depositional systems have been identified and studied by several authors including King and Trasher (1992), Baillie and Uruski (2004), Baur (2012), and most recently, in the Pipeline dataset by La Marca-Molina et al.(2019) and Silver et al.(2019).

Being New Zealand's most prolific petroleum basin to date, much research is available regarding the tectonic history of the region. King (1992; 2000), Baur (2012), and Strogen et al. (2014) presented tectonic insights of the basin during the Eocene-Early Miocene and compiled a map that shows the main structures along the area which are oriented southwest-northeast (Figure 1). This map serves as a guide to understand the nature of the feature of interest.

SEISMIC DATASET

58 We recognized the FLT in a seismic survey named “Pipeline 3D”. This survey was acquired by Todd Exploration in 2013 and covered ~515 of the southern Taranaki Basin (Figure 1). The post-stack time migrated volume was processed in 2015 by Excel Geophysical services. The data has SEG negative polarity and is zero phase. The sample rate is 4 ms, its bin size 25x12.5m and its record length is 6s. The datum projection is NZGD2000.

64 FLT DESCRIPTION

65 The feature consists of a large lineament in map view that goes from south-west to north-east and has a longitude of around 10 km and a width of ~1 km. In Figure 2a, the feature exhibits variable amplitude lineaments within. This amplitude expression is different than the surrounding amplitudes and differs from that of the channels where amplitudes are not that variable and do not show stripes. Another important observation is that overall the direction of deposition of the channelized features in the survey is mostly perpendicular to that of the FLT. In vertical section (Figure 2b), we noticed that the channel-like feature was a large tilted/ folded structure that could be a fault or a fold.

UNDERSTANDING FLT NATURE THROUGH ANALOGS

Seismic analogs are interpretations made on seismic data that are geologically similar to the study data and that have undergone similar events. The Gulf of Mexico and Central Sumatra Basin are examples of rift basins that are comparable to the Taranaki Basin in some aspects. Previous studies in these basins (Fiduk et al. 1997 and Shaw et al. 1997) suggest that the FLT in the Taranaki Basin exhibits a similar seismic expression to the folds that they described. Ji and Long (2006) pointed out that asymmetric inclined folds produce straight, discontinuous, dipping reflections potentially misinterpreted as thrusting faults or shear zones. Moreover, Reilly et al. (2015) explored the relationships between faults and changes in unit thickness associated with syn-rift events in the Taranaki Basin, and Conneally et al. (2017) gives us a better geological context for the interpretation north to the study area (monoclines or fault propagation fold). Based on that, we decided to use seismic attributes to help in the definition of the feature geometry.

APPEARANCE ON SEISMIC DATA: DEFINITION BY SEISMIC ATTRIBUTES

88 The FLT seismic expression is characterized by a long and discontinuous
89 alignment in plain view (time or horizon slice) that exhibits a curved shape in a vertical
90 view where reflectors seem to be continuous (Figure 2).

91 We applied geometrical seismic attributes, including coherence, dip, and
92 curvature, to better define the nature of the feature. Figure 3 shows the cosine of phase
93 attribute. Normally, the presence of a fault shows disruptions or discontinuities in the
94 seismic reflectors, but in this region, discontinuities along the reflectors are not
95 observed (Figure 3b) which leads us to think we may be in presence of a fold instead.

96 The coherence attribute (Gersztenkorn and Marfurt, 1999) helps to distinguish
97 faults due to low coherency values that represent discontinuities. Figure 4a shows the
98 response of the coherence attribute in our FLT feature. Overall high coherence values
99 dominate. The subtle changes observed are interpreted as low coherence features that
100 are possibly caused by lithology changes and not to main structures. These
101 observations suggest the interpretation of a fold instead of fault. In this case, if we were
102 to make interpretations based just on coherence attribute, we would be prone to

misinterpret the FLT as a channel (Figure 4a) because there are similar features in size and seismic expression north in the survey interpreted as channel belts. Recent studies (Silver et al. 2018) revealed the presence of large channels in the Pipeline area that can reach widths of almost 1 km and appear in a southeast-northwest orientation. Still, their depositional trend is perpendicular to that of the feature studied.

Dip azimuth attribute allows us to infer the apparent dip direction of the reflectors. Figure 4b shows a constant dip along the feature with a north-northwest trend. Usually, in folds, the dip values display subtle changes along the limb, but if there is an abrupt change in dip values, then it is often interpreted as a fault. Based on the constant values of azimuth dip observed, we interpret the FLT to be a monoclinal fold with a large limb around 1 km wide.

Curvature attribute (Chopra and Marfurt, 2007) helps to identify structures and changes in shapes (geomorphology). Figure 5 displays a co-rendered image of two attributes: cosine of phase and curvature, which provides the final support to our interpretation. The extended positive curvature response shown in red color reflects a

118 wide area with positive relief typical of a large antiform. Additionally, the negative
119 curvature exhibits a similar wide aerial extension that corresponds to the synform of the
120 large interpreted fold. Considering the continuity of the reflectors and the gradual
121 change in shape from concave down to concave up, we interpret the feature as a
122 monocline.

123 ## REMARKS AND RECOMMENDATIONS

124 In this study, we used a multiattribute approach that includes the dip azimuth
125 attribute to define the geometry of the structure and cosine of phase to highlight the
126 continuity of the reflectors. The curvature attribute proves to be useful for distinguishing
127 faults from folds. We recommend being aware of the parametrization for the calculation
128 of these attributes. After analyzing the regional structure of the area and analogs in
129 addition to seismic attribute responses, we interpret the FLT as a regional monoclinal
130 fold. To fully characterize the evolution of this fold, we suggest the use of proper
131 structural methods that extends beyond this study scope.

132

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189 LIST OF FIGURES

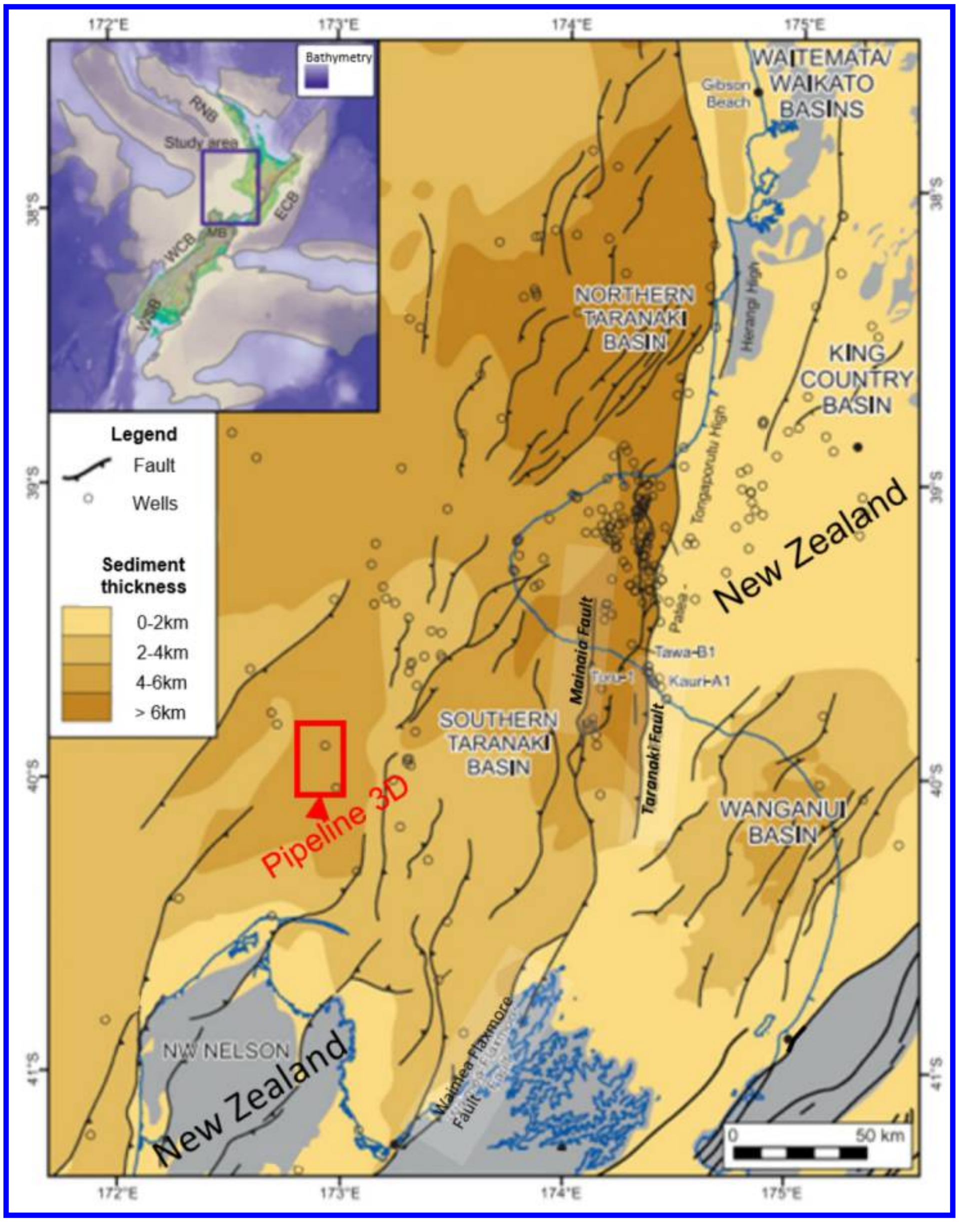
Figure 1. Map of the Taranaki Basin that shows main faults, sediment thickness, wells, and localities. Location of Pipeline 3D- seismic volume indicated with a red square within the area. Modified after New Zealand Petroleum and Minerals (2014) and Strogen et al. (2014).

Figure 2. a) Amplitude time slice at 2000 ms showing channels pointed by yellow arrows and the FLT with a green arrow. Vertical slice A-A' is indicated with a fuchsia line. b) Amplitude vertical slice perpendicular to the FLT (light yellow square). Reflectors show apparent continuity. Horizon A used after is indicated in Yellow.

Figure 3. a) Cross-section B-B' of the cosine of phase helps to enhance imaging the continuity of reflectors and defining the shape of a possible fold. Horizon A is indicated in yellow at around 2500 ms. The area of the FLT is marked with a light-yellow square. b) Zoom in on figure "a" to show the continuity of the reflectors evidenced with the use of the cosine of phase attribute. c) Horizon slice (Horizon A) of the cosine of phase volume attribute highlights differences between channels and the FLT. d) Time slice at 2000ms of cosine of phase. B-B' cross-section location shown in fuchsia.

Figure 4. a) Horizon slice of coherence (sobel filter) where the FLT shows low values of coherence. Channels follow a direction perpendicular to the interest feature. b) Dip magnitude in horizon slice shows in blue color constant value of ~325 in dip azimuth which corresponds to a dip orientation of NNW. (Strike WSW-ENE). Fold limb is ~ 1km wide.

Figure 5. 3D view of curvature co-rendered with the cosine of phase. The structure appears to be a fold because of the continuity of its reflectors and gradual change from positive (concave down shape) shown in red color to negative curvature (concave up geometry) seen in blue color.



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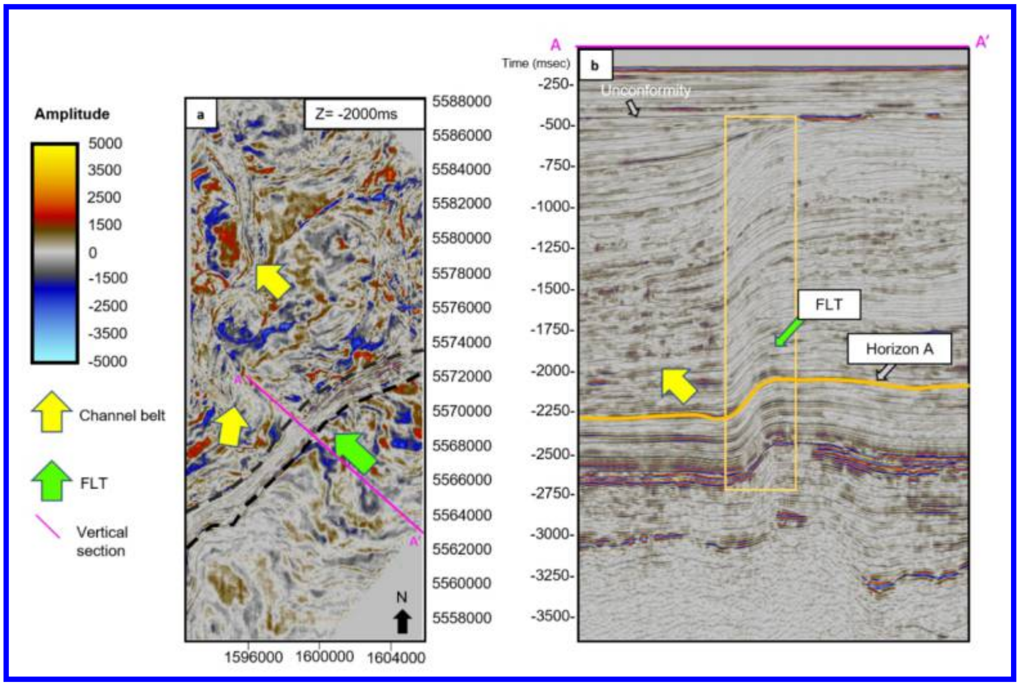

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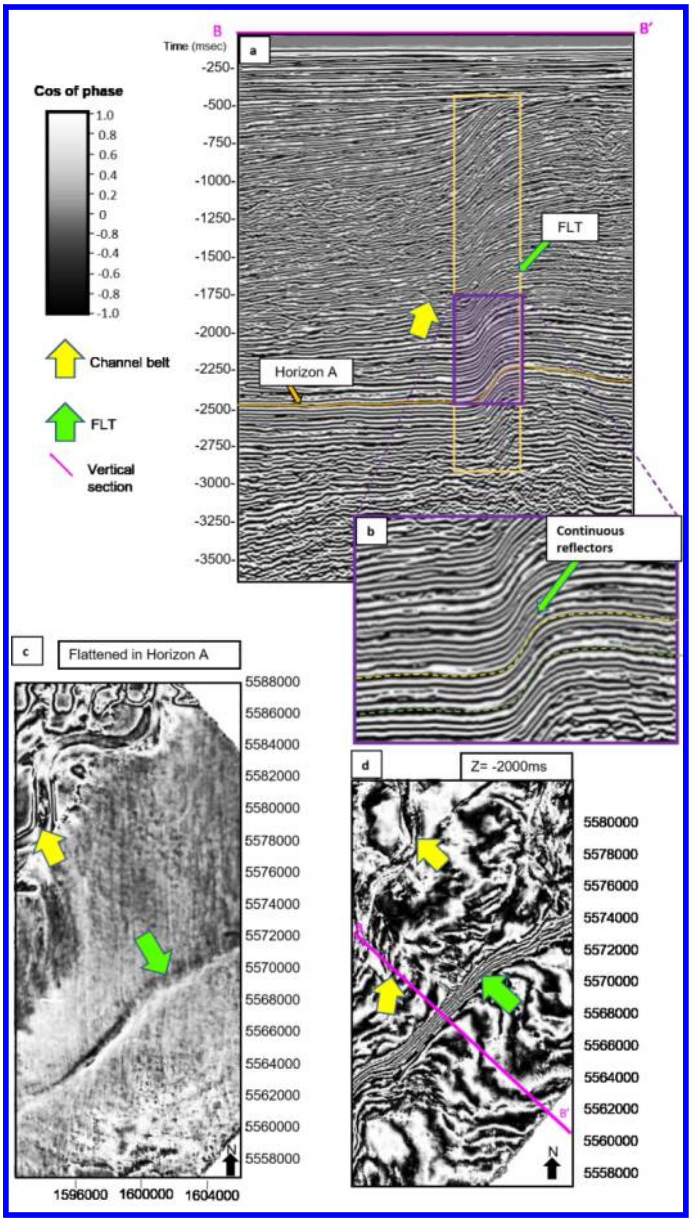

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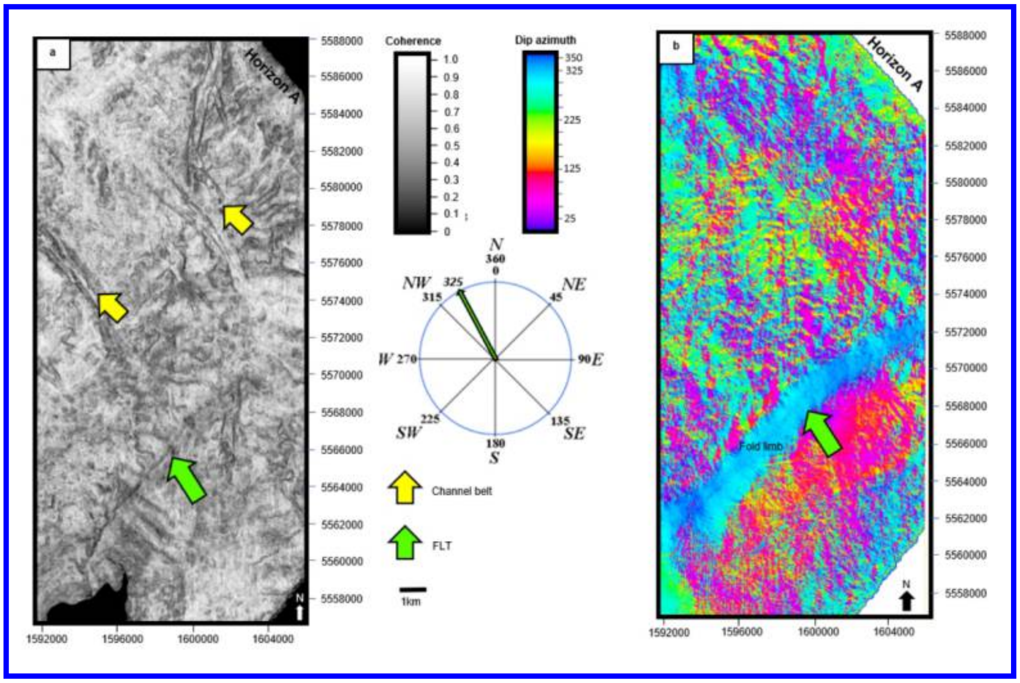

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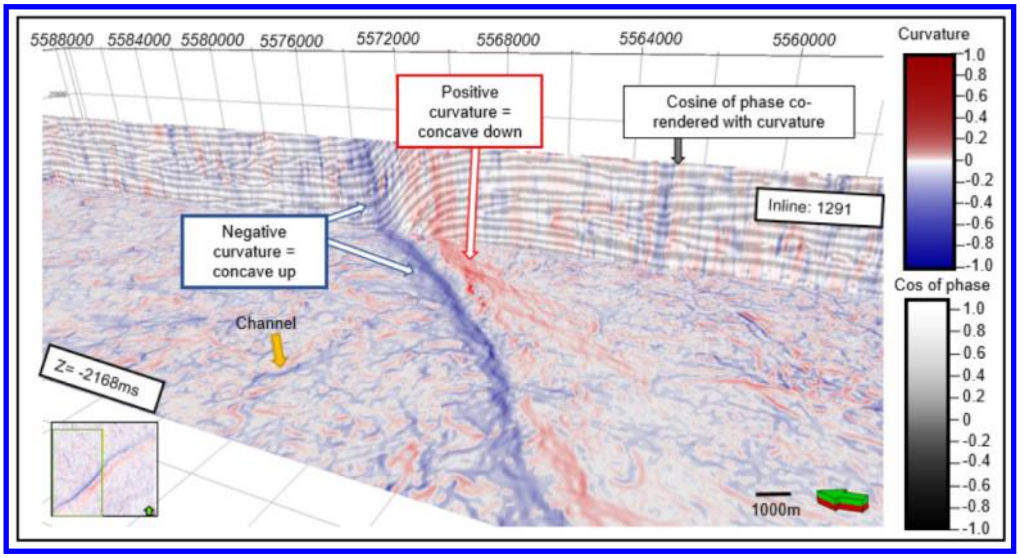

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DATA AND MATERIALS AVAILABILITY

Data associated with this research are available and can be obtained by contacting the corresponding author.