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

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Abstract
The Taranaki Basin lies in the western portion of New Zealand, onshore and offshore. It is a Cretaceous rift basin that is filled with up to approximately 10 km thick deposits from marine to deepwater depositional environments from the Cretaceous (approximately 93 ma) to the Neogene (approximately 15 ma). 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 easily are recognizable in seismic data. When analyzing the offshore 3D Pipeline data set, we recognized a peculiar fault-like feature with large-scale dimensions (approximately 15 km long and approximately 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 subparallel 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 use seismic attributes such as coherence (Sobel filter), dip, cosine of phase, and curvature to characterize this feature geomorphologically. The geologic background of the area and analog settings aided in understanding and distinguishing the nature of this large structure. Monocline examples in seismic data are rare to find, and we want to show how to avoid misinterpretations.

Geologic background
The rift-derived Taranaki Basin depositional systems have been identified and studied by several authors including King and Thrasher (1992), Baillie and Uruski (2004), Baur (2012), and most recently, in the Pipeline data set 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 (New Zealand Petroleum and Minerals, 2014). King and Thrasher (1992), King (2000), Baur (2012), and Strogen et al. (2014) present tectonic insights of the basin during the Eocene–Early Miocene and compile 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 data set
We recognized the funny-looking thing (FLT) in a seismic survey named “Pipeline 3D.” This survey was acquired by Todd Exploration in 2013 and covered approximately 515 of the southern Taranaki Basin (Figure 1). The poststack time-migrated volume was processed in 2015 by Excel Geophysical services. The data have SEG negative polarity and are of zero phase. The sample rate is 4 ms, its bin size 25 × 12.5 m, and its record length is 6 s. The datum projection is NZGD2000.

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FLT description

The feature consists of a large lineament in map view that goes from southwest to northeast, and it has a longitude of approximately 10 km and a width of approximately 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 (Kane et al. (2010), Camerlo and Benson (2006), and others). 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; 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) point out that asymmetric inclined folds produce straight, discontinuous, dipping reflections potentially misinterpreted as thrusting faults or shear zones. Moreover, Reilly et al. (2015) explore the relationships between faults and changes in unit thickness associated with syn-rift events in the Taranaki Basin, and Conneally et al. (2017) give us a better geologic context for the interpretation north of 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

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

We applied geometric seismic attributes, including coherence, dip, and curvature, to better define the nature of the feature. Figure 3 shows the cosine of the phase attribute. Normally, the presence of a fault shows disruptions or discontinuities in the seismic reflectors, but in this region, discontinuities along the reflectors are not observed (Figure 3b),

Figure 1. Map of the Taranaki Basin that shows the main faults, sediment thickness, wells, and localities. Location of the 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 out by the yellow arrows and the funny-looking thing (FLT) with a green arrow. Vertical slice A-A’ is indicated with a fuchsia line. (b) Amplitude vertical slice perpendicular to the FLT (the light yellow square). The reflectors show apparent continuity. Horizon A used afterward is indicated in yellow.
which leads us to think that we may be in presence of a fold instead.

The coherence attribute (Gersztenkorn and Marfurt, 1999) helps to distinguish faults due to low coherency values that represent discontinuities. Figure 4a shows the response of the coherence attribute in our FLT feature. Overall, high coherence values dominate. The subtle changes observed are interpreted as low-coherence features that possibly are caused by lithology changes and not to main structures. These observations suggest the interpretation of a fold instead of a fault. In this case, if we were 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 in the north of the survey area interpreted as channel belts. Recent studies (Silver et al., 2019) 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.

The 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 often is 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.

The curvature attribute (Chopra and Marfurt, 2007) helps to identify structures and changes in shapes (geomorphology). Figure 5 displays a corendered image of two attributes: the cosine of the phase and curvature, which provides the final support to our interpretation. The extended positive curvature response shown in red reflects a wide area with positive relief typical of a large antiform. Additionally, the negative curvature exhibits a similar wide aerial extension that corresponds to the synform of the large interpreted fold. Considering the continuity of the reflectors and the gradual change in shape from concave down to concave up, we interpret the feature as a monocline.

Remarks and recommendations

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

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Data and materials availability

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

References


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Figure 4. (a) Horizon slice of coherence (Sobel filter) where the FLT shows low values of coherence. The channels follow a direction perpendicular to the feature of interest. (b) The dip magnitude in the horizon slice shows in blue the constant value of approximately 325 in dip azimuth, which corresponds to a dip orientation of north-northwest (Strike west-southwest-east-northeast). The fold limb is approximately 1 km wide.

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


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