Structural Balancing vs Horizon Flattening on Seismic Data: Example from Extensional Tectonic Setting

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Abstract: Two techniques which are structural balancing and horizon flattening have been applied in this work to verify and validate the seismic interpretation performed on a few extracted 2D seismic cross-sections. Both techniques are useful to provide a mean of understanding what had happened or at least to imagine what had happened during the time of deposition for each of the interpreted horizons. Structural balancing technique is somehow more difficult, time-consuming and requires other information such as rocks' densities before it can be practiced. Horizon flattening, on the other hand is a straight-forward technique available in most interpretation software. Comparing the results from both techniques had shown us that structural balancing, despite its difficulties and time-consuming had provided a more geologically sound interpretation. It allows the interpreters to understand and imagine the relationship of faulting with sedimentation at a particular time. However, horizon flattening only provides a general overview on the morphology and environment of deposition for the flattened horizons. Despite all, both techniques require a familiarity with the interpretation and structural software and what is important is an interpreter who can make his or her interpretation geologically acceptable and logic.

Keywords: Structural Balancing, Horizon Flattening, Seismic Interpretation, Structural Reconstruction, Seismic

1. Introduction

Interpreting a seismic cross-section may vary differently from each of us. Geologists, geophysicists, petroleum engineers and others are potential users of seismic data and they may interpret seismic data according to their objectives of the projects. It is a common practice for a geoscientist to conduct stratigraphic and structural interpretation on the seismic data, be it a 2D or 3D seismic dataset. Seismic data is not 100% convincing if it is to stand alone. Thus, availability of wells data and core plugs or core logs will be very beneficial to validate interpretation performed on the seismic data. However, petroleum-industry seismic data that are commonly donated to research groups in universities or research centers do not necessarily come along with wells and core data. For the

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purpose of interpreting the stratigraphic and structural context based on only seismic data, application of structural balancing and horizon flattening will provide a mean of justification for the interpretation done. This paper is aim to compare the advantages and disadvantages gathered from structural balancing and horizon flattening techniques. We have applied these two techniques to rectify the seismic interpretation done on the data from extensional tectonic setting in the Central Luconia Province, offshore Sarawak, Malaysia.

2. Methodology

Seismic interpretation has been performed on few extracted seismic cross-sections. Cross-section balancing and horizon flattening are conducted on the interpreted cross-sections to validate the interpretation, as well as reveals the features at the particular time of depositions. Below are the detailed descriptions for the methods practiced in this research.

A. Seismic Interpretation

Interpretation of seismic data began with creation of synthetic seismogram, as an aid to compliment geological information from well data in depth with the geophysical information from the seismic data in time. Check shot and sonic logs from two wells were used to provide time to depth relationship. Standard procedures for synthetic seismogram creation have been followed. Three statistical wavelets were tested, with 30Hz, 40Hz and 45Hz dominant frequency, zero phasing and standard SEG polarity conversion. Statistical wavelet of 40Hz give the best result for the creation of synthetic seismogram, thus was used in this research. Seismic interpretation including stratigraphic and structural interpretation was performed based on few seismic attributes. These include True Amplitude, Relative Acoustic Impedance, Coherence-Variance and Curvature attributes. Seismic reflection geometries were also applied during interpretation. Seismic reflection geometries were recognized and interpreted for the purpose of understanding the environment of deposition for each interpreted sequences.

B. Structural/Cross-section Balancing/Restorations

Balancing a section is about putting back the point where deformation initiates to its undeformed state. It is an aid to validate our interpretation, be it seismic interpretation or interpretation based on outcrop by applying certain geometric rules. It involves removing the effects of fault displacements, folding associated with faulting and flexural slip and volume loss generated from compaction and erosion. A balanced cross section does not necessarily provide a correct restoration (Fossen [1]), because there could have been layer thickening involve and also growth of carbonate strata on the layers. In this work, cross-section or structural balancing was performed using MOVE software. MOVE is structural modeling and analysis software, made available by Midland Valley Exploration. Briefly, there are seven computer algorithms used in Kinematic Modeling for balancing a cross-section, depending on the tectonic settings. In the case of extensional tectonic setting in offshore Sarawak, two balancing techniques are applied, Simple Shear and Rigid Block Restorations. Simple Shear and Rigid Block Restorations techniques are most suitable for the purpose of balancing cross-sections in extensional setting as it involves growth listric faults, dominos fault system and non-planar normal fault.

1) Simple Shear

The Simple Shear algorithm models the relationship between fault geometry and hanging wall deformational features. It can be divided into Vertical Simple Shear (VSS) and Oblique Simple Shear (OSS) techniques. Using VSS, the shear plane is assumed to make an angle of 90° to the regional horizontal plane, while OSS on the other hand is simple shear along the horizontal planes at angles other than 90°. Based on the assumptions that the last process of hanging wall collapse, the last fault thought to have developed is restored first (Bland, et al. [2]).

2) Rigid Body Restoration

Apart from simple shear technique, in situation where displacements are too small or involved tilted blocks, rigid- body restoration technique has been adapted to the cross-section restoration.
Rigid-body restoration preserved the original lengths and angles within the blocks of deformed cross-section. This is usually applied to the simplest case of cross-section restoration where fault blocks behave as rigid blocks during deformation, so that rigid rotation and translation are involved in the same restoration step. The domino fault system where both translation (displacement/offset) and rotation (anticlockwise) are involved is the best example for restoration using this method. Each faulted block can be restored either by firstly rotating the block so they become horizontal, before removing the offsets; or secondly by removing the offsets created by the fault, followed by rotation. The exact ways of deformation to take place in the case of rotated fault-blocks were not to worry, as both translation and rotation may actually formed simultaneously (Fossen [1]) in the real process. In rigid body restoration process, if the blocks do not fit together, it is preferable to leave gaps between them, rather than overlapping the blocks (Groshong [3]).

C. Horizon Flattening

One of the available simple and fast techniques to help geologist and geophysicist making decisions during interpretation is horizon flattening. Horizon flattening is the digital version of the interpreter taking a folded paper section and overlaying one part on another to check the character and correlation (Bland, et al. [2]). Horizon flattening technique is available in most geological interpretation software. It provides a good tool to predict the continuity of the stratigraphic and structural elements in the underneath layers.

3.0 Results & Discussions

Twelve horizons, including sea bottom with 5 seismic sequences were interpreted prior to seismic cross-section restoration. The sections were restored in three stages which include Recent (sea bottom) - Early Pliocene sediment removal, Late- Middle Miocene Restoration and Early Miocene/ Late Oligocene Restoration. Each restoration stages include few intermediate restoration phases to compensate small displacements created by small-scale faults within the seismic stratigraphic units. The time interval for the restoration involved is from sea bottom (0 Ma) to Late Oligocene (34 Ma).

Figure 1 below shows the results of seismic interpretation over two Miocene carbonate platform in offshore Sarawak. However, for structural balancing and horizon flattening, Platform EX (Figure 2) was excluded from this technique, due to its' small size of line distribution. Structural balancing and horizon flattening were performed on Platform FY (Figure 1) only. There are three major restoration steps, which include Step 1: Recent- Early Pliocene, Step 2: Late-Middle Miocene and Step 3: Early Miocene to Late Oligocene. Each restorations step involved intermediate balancing to compensate the small scale branching faults within each sequences.

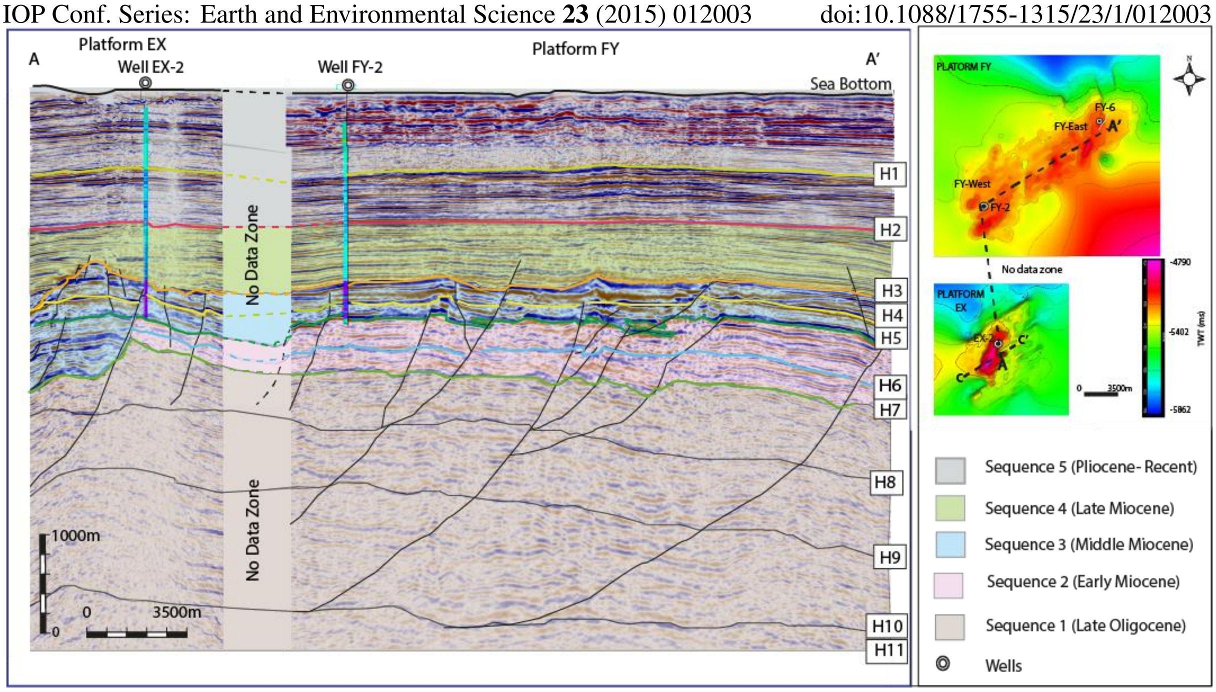
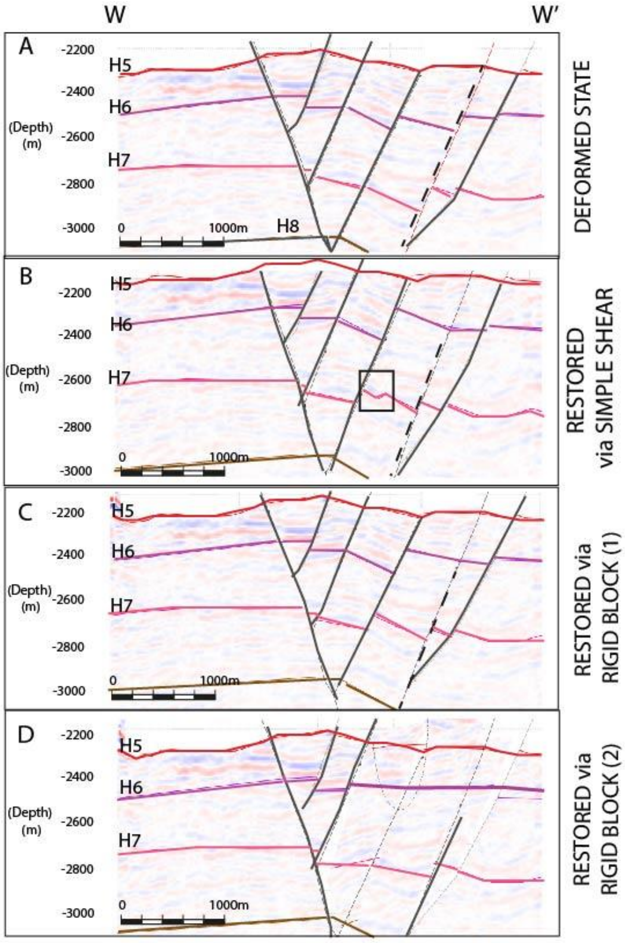


Figure 1: Seismic interpretation based on structural and stratigraphy characteristics from Line A-A' crossing Platform FY and EX. Interpreted horizons are marked as H1 to H11. Map is showing the location of the line.



Horizon flattening was performed only on Horizon 2 to Horizon 6. The deeper horizons (H7-H11) do not serve a significant seismic resolution to allow horizon flattening. During Step 3 restoration, all three balancing techniques (VSS, OSS and Rigid Body) for extensional setting have been applied. Step 3 restorations involved balancing few sets of antithetic faults within domino fault systems. Balancing an antithetic fault pose a special dilemma (Rowan and Kligfield [4]), because it terminates at another fault without offsetting it, and displacement along it will therefore decrease to zero, thus none of the standard restoration techniques would resolved this.

Figure 2 shows a small portion of antithetic fault in Inline WW' in depth section. The displacements of these antithetic faults were removed using rigid block restoration and vertical simple shear techniques. Both restoration techniques produce different results. With vertical simple shear, artificial bending occurs above the fault termination. The most likely explanation for this situation is that complex deformation in hanging walls of the antithetic

Figure 2: Small portion of Inline WW', showing antithetic branching faults within Horizon 5-7. Two restorations techniques were tested. The restored fault is corresponding to the dash line. Restoration via simple shear produced an artificial bending (in square) at H7 while restoration via Rigid-Body technique matches H6 in the hanging wall and foot wall. Continuation of restoring in D using Rigid-Body technique had fixed the offsets and flattens H6 and H7.

faults is inadequately modelled by the standard restoration algorithms, therefore, must be carried out with more general area-conservation methods. To simply restore the antithetic faults, rigid block restoration method is more appropriate in this case.

Horizon flattening had revealed significant features present at a particular time. However, this process has a number of drawbacks that always lead to overlooking in the particulars such as distortions in the image and artefacts of the flattening process (Bland, et al. [2]). Artefacts and distortions from flattening processes can significantly mislead interpreter if not recognized. Structural balancing technique on the contrary provides a validation in the interpretation applied to particular cross-sections. Variables techniques through structural restoration such as sediments removal via decompaction technique and isostatic adjustment on the faulting via move-on-fault technique have a geologically valid way of looking on the geological history, with reference to present day acquired seismic image.

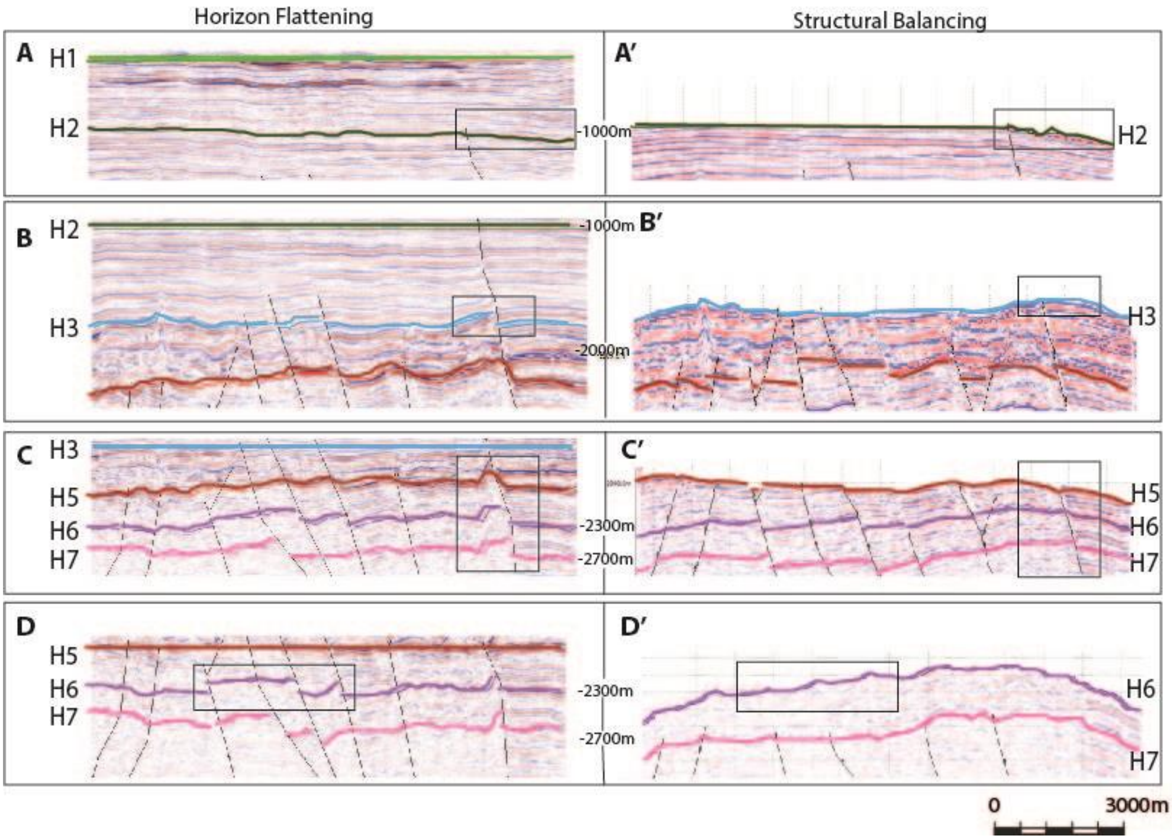


Figure 3: A: Flatten Horizon 1 (H1) to see the morphology of underneath Shale Layer bounded by Horizon 2. A’: Exposed morphology of Shale Layer in Horizon 2 (H2) with undulating effects on the hanging wall (small box). B: Flatten Horizon 2 (H2) exposed the morphology of Horizon 3 (H3) with still obvious displacement on the foot wall and hanging wall. B': Restored Horizon 3 (H3) exposed hump-back features (in small box) which are not seen on Horizon 3 in Figure 3B. C: Flatten Horizon 3 (H3) to see the morphology of deeper horizons. Artefacts (in small box) developed on the foot wall of Horizon 5-7 resulted from flatten Horizon 3. C': A balanced section of Horizon 5 (H5) shows no paleo-topography on the foot wall as per seen in the flattening horizon in Figure 3C. D: Flatten Horizon 5 (H5) give a dragging effects on Horizon 6 (H6) (in small box) and create larger displacement. However, this is not seen in the balanced section of Horizon 6 (H6) in Figure 3D'.

In order for us to see the features present at a particular time, the top (younger) horizon will be flatten. Horizon 1 (H1) has been flatten to reveal the situation during deposition of older layers in Horizon 2 (H2). Meanwhile, structural balancing involved decompaction and sediment removal from sea bottom to Horizon 1 (H1), followed by restoration of foot wall block in Horizon 2 (H2) had brought us back to the time when Horizon 2 (H2) deposited. Referring to Figure 3A and 3A', features in the small rectangular has highlighted that result from structural balancing had formed an undulating effects on Horizon 2, which might be an artefact. In this case, horizon flattening brings out a more logical result compared to structural balancing technique.

Flattened Horizon 2 in Figure 3B has exposed depositional features during deposition of Horizon 3. Displacements on the foot wall and hanging wall are seen during deposition of Horizon 3. However, through structural balancing technique, offsets seen on Horizon 3 have been fixed thus revealing a hump-back structure as highlighted in the rectangular. Structural restoration on Horizon 2 produced a more valid and geologically accepted result compared to horizon flattening technique.

Comparison of these two techniques on Horizon 5, 6 and 7 is shown on Figure 3C and 3C'. Flattening of Horizon 3 had created mounded features on the foot wall of these horizons. Initially, we thought it is stack of reefal group growth. To validate our interpretation, we applied structural balancing for the same horizons. Structural balancing on these horizons however had reveal another view showing that these mounded features were actually not vertically stacked as what we observed from horizon flattening technique. The mounded features turn out to be like a draping gentle fold, explaining that fault was synchronizing to displace these horizons during the time of deposition, suggesting a syn-depositional faulting. Flattened Horizon 5 give a dragging effect on Horizon 6 as highlighted in the rectangular of Figure 3D. However, this is not seen on the balanced section of Horizon 6 (Figure 3D').

4.0 Conclusion

It is good to practice either horizon flattening or structural balancing when performing seismic interpretation on a cross-section, because both techniques provide a mean to reveal the unseen features in the seismic data at the particular time of deposition. Horizon flattening is a simple, easy, user friendly and fast technique to help the interpreters predict what the situation during the time of deposition was. It can be very useful especially for a project that requires a quick-look interpretation result. Structural balancing or cross-section balancing/restoration, on the other hand, is more difficult and requires other information such as the rocks' densities, Poisson's Ratio and porosity values to get to a correct balancing result. However, with the availability of computer software such as MOVE software, these values are made available for testing purposes, and are good enough for work that involve less than 15km length of cross-section, like in our case. Instead of its difficulty compared to horizon flattening technique, structural balancing provide a better correct view for interpreting the environment of deposition and to understand what had happened to the sedimentation and faulting during the time of deposition. Despite all, both horizon flattening and structural balancing techniques are used throughout this work as procedures to enhance and validate our seismic interpretation. Generally, both techniques have their own benefits and drawbacks and what's important is, their geologically logic explanations.

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