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Seismic Fracture Characterization of Hydrocarbon Reservoirs – a Comprehensive Workflow

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Summary

Presence of fractures in hydrocarbon reservoirs immensely adds to the complexities of such reservoirs. Fractures exist below seismic resolution and hence cannot directly be seen in seismic data. However, different seismic attributes enhance different features of existing fractures and working with the attributes in a stepwise manner can help to understand the fracture network leading to a quantitative interpretation of it. In shallow formations, fractures can cause drilling hazards like mud loss. In the reservoir section, fractures can lead to water encroachment thereby, shortening the life of the well. Again, fractures in reservoirs can enhance hydrocarbon recovery by aiding the peripheral water injectors. However, not all fractures bring in water or pose drilling complexities, but their presence increase the permeability of a reservoir by several orders of magnitude, and hence can be considered as a permeability multiplier in a reservoir. Dual porosity-dual permeability models need a reliable fracture model in the simulation stage for a better history match. Fracture information from well data in the form of image log or dynamic data are sparse. Therefore, any geo-model based on such scanty data introduces many extrapolations which more often than not are untrue and unreliable as fracture models. Seismic data is by far the densest data and a comprehensive fracture characterization based on seismic, when constrained with well and other dynamic data, can lead to a reliable fracture network which can be integrated into the geological model. This paper presents a step-by-step workflow to show how to use fractures from seismic data in reservoir characterization.

Workflow

Fractures are of sub-seismic resolution and hence cannot be detected directly from seismic data. However, the presence of fractures can be inferred from the data when we create different attributes. Fractures often show up as discontinuities in a seismic attribute section or time slice. However, the presence of noise makes this identification extremely challenging. Some of the noises have seismic characteristic similar to fractures and it is forever a problem for the geoscientists to separate noise from signal.

Fracture detection from seismic data is attempted mainly in three different ways, i.e., attribute analysis of post-stack data, offset/walkaround VSP and azimuthal AVA analysis/inversion (Hawas et al., 2018).

In this abstract, we deal with only post-stack seismic data analysis.

We have developed a workflow (Figure 1) that demonstrates how fractures can be successfully extracted from seismic data and ultimately used for modelling fractures in reservoirs The different steps of this workflow are taken up later for detailed discussion.

Results & Discussions

Data Conditioning

Coherent noise is filtered out by using a structure oriented coherent noise filter. A random noise filter is run on the filtered output to further clean the data. A simple algebraical subtraction of the original and filtered data can show the amount of noise present in the data.

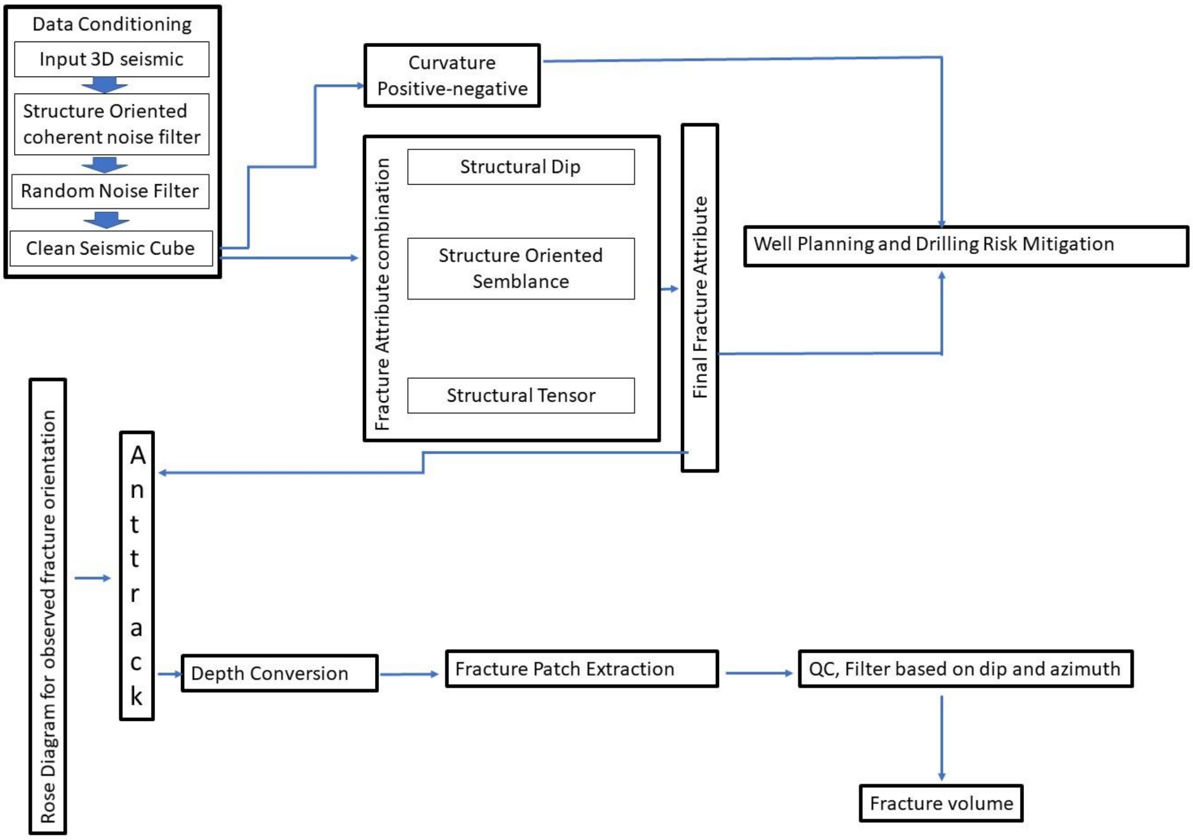

Figure 1. Workflow for seismic fracture characterization

Seismic Interpretation:

Horizons and faults are interpreted on the cleaned data. A velocity model is built using the time horizons and well picks.

Seismic Attributes:

Seismic attributes that reveal the “structural aspect” of a reservoir are considered for seismic fracture studies. Curvature is one of the main attributes in this regard (Chopra et.al,2005). Curvature does not measure the discontinuity in the seismic data, but rather measures how much a surface is curved. If a competent rock is tightly folded, it can be inferred that existence of fracture is most likely at the location of the maximum curvature along the folded strata, most likely the hinge. There are many ways the curvature is calculated but the most relevant are positive and negative curvatures. Curvature attribute has been immensely useful in well planning and drilling risk mitigation.

We can use different edge detection attributes to identify fractures. We consider three such independent attributes i.e., structural dip, structure-oriented semblance and structural tensor. We then calculate them on a cleaned dataset from offshore Australia. While these three independent attributes enhance different features of the structural discontinuity; when combined, it gives the most prominent common features with strong amplitude. The combination is passed through a sharpening filter which gives one-pixel-thick lines of discontinuity which we call the fracture attribute. Figure 2 shows this application on a 3D seismic dataset HCA2000 in the form of a workflow.

Hawas et.al. (2018) applied this workflow to a dataset from the Middle East and overlaid the facture attribute thus derived on the seismic data as seen in Figure 3. The figure shows fracture attribute overlain on a seismic timeslice and a section.

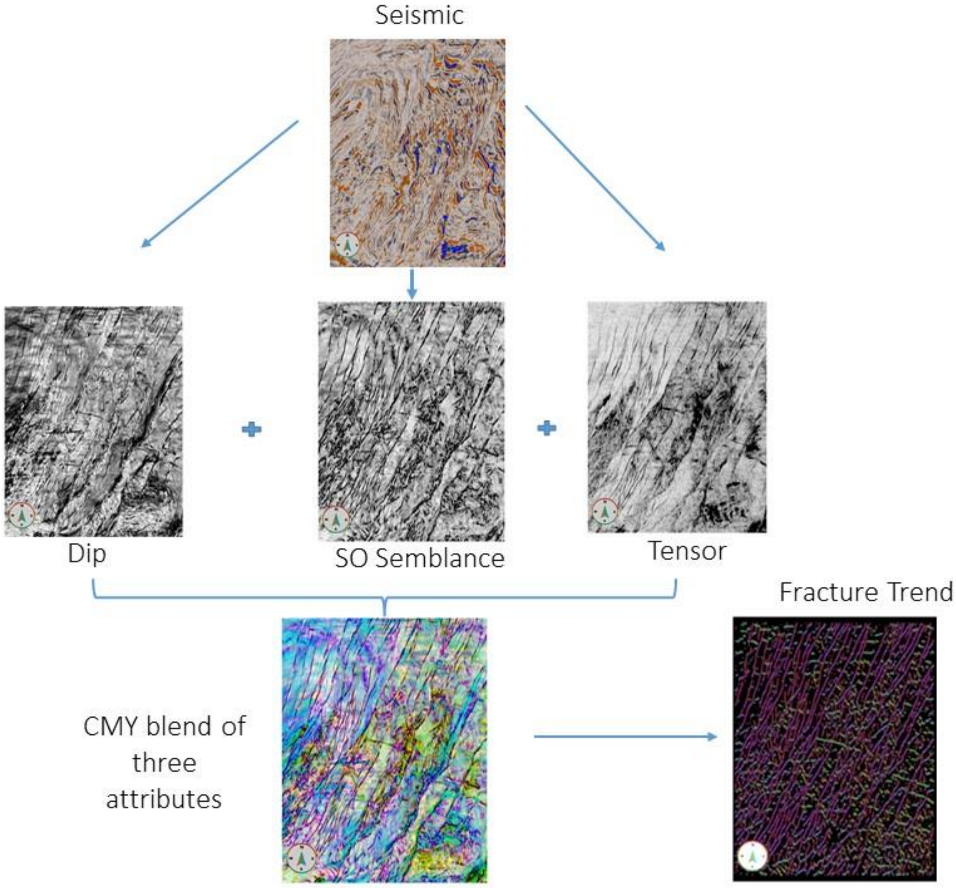

Figure 2. Creation of fracture attribute from three independent attributes: dip, semblance, and tensor.

The attribute cube is then depth-converted using a velocity model and is validated using well and dynamic data. Geobodies with appropriate volume rendering are extracted along well paths which encountered fractures. A well log along proposed well path can be extracted from this fracture cube. With appropriate tweaking of threshold amplitude, this log can show the potential zones where a fracture can be expected.

Incorporation of Seismic Fractures in an Earth Model:

Seismic data is band limited. The vertical extent of the fractures in Figure 3 (bottom panel) shows that the fracture size is too large for modelers to directly incorporate them into a static model. Besides, some of the seismic fractures can be noise. The following sections describe steps in the workflow that may help mitigate these problems.

The azimuths of the main fracture trends interpreted from the FMI and other dynamic data are provided by the geologist in the form of rose diagrams. The fracture attribute is tracked using an ant-tracker (Illidge et.al.,2017) to delineate the seismic fractures along those azimuths. This tracker filters out any trend that is not in sync with the azimuths provided by the geologist. It is beneficial to do a few repetitive runs of the tracker to remove some noise streaks. The output of the tracked volume is fed into a fracture patch extraction algorithm (Du et.al., 2011) to identify the 2D fracture patches.

We filter the data further on the basis of seismic acquisition footprint. Since the seismic data was acquired in a N-S direction, it is likely that the footprint of the acquisition geometry can leave some residual noise which can be misinterpreted as fractures. The filtered patches are displayed on a stereogram and all patches that are within ten degrees of NS and EW orientations are filtered out. Since our interest is in the open fractures enhancing reservoir permeability only, an assumption is made that fractures having less than a dip of 45 degrees are likely to be closed due to the overburden pressure (Hawas et.al,2018). So all such fracture patches that have dip less than 45 degress are filtered out. Finally, we crop the top and bottom of the patch volume to limit it within the reservoir. Figure 4 shows the filtered fracture patches, the dip filter, and final fracture patches truncated to the reservoir limit.

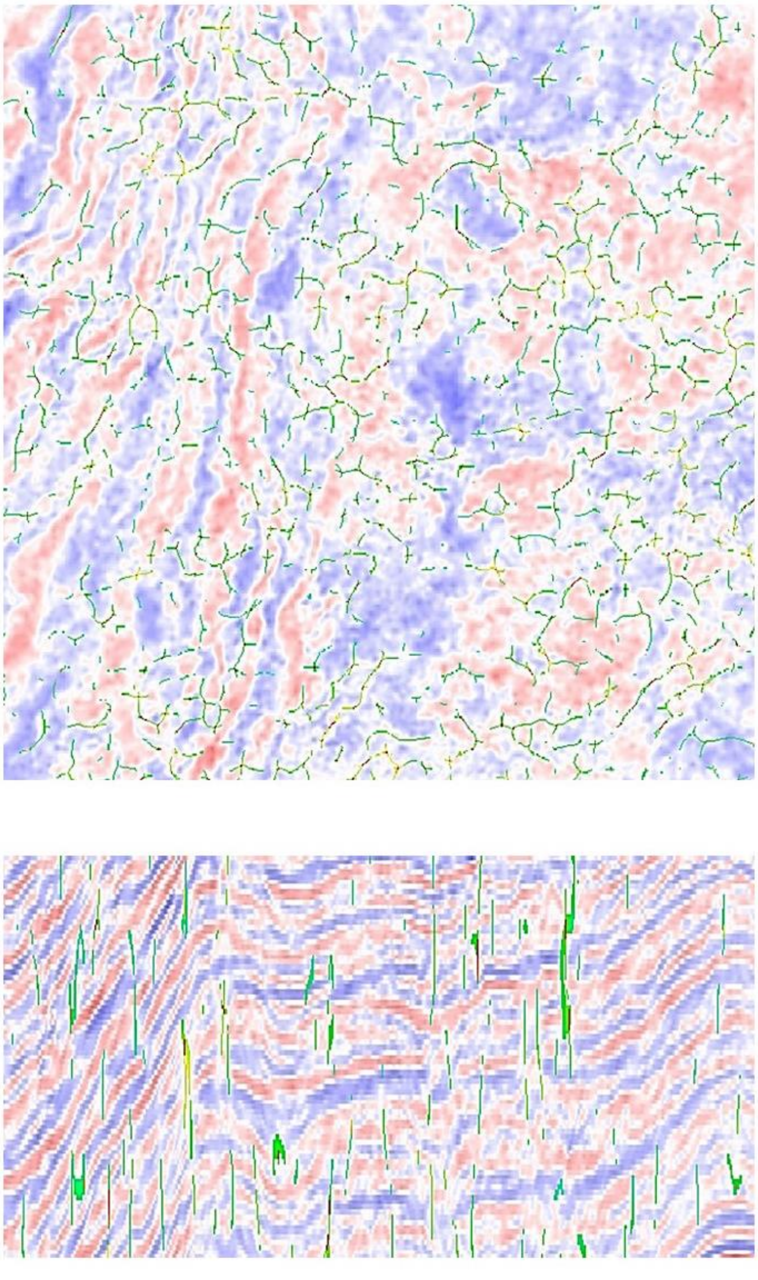

Figure 3. Seismic timeslice with embedded fracture attribute (top) and seismic section with embedded fracture attribute (bottom) [modified from Hawas et.al., 2018]

The fracture patches have distinct dips, azimuths and sizes which can be tabulated on a sheet. Based on these parameters, horizontal permeabilities (Kx,Ky) and vertical permeability (Ky) can be assigned to the model cells depending on how the patches are intersecting the cells.The fracture permeability thus determined from the seismic fractures along with other constraintscan be used as a permeability model.

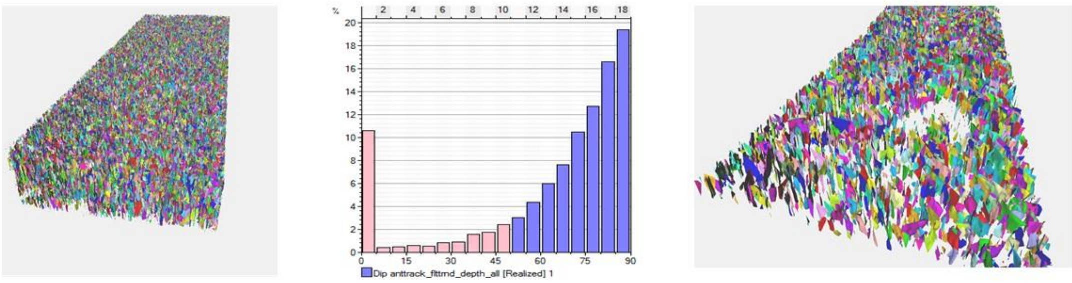

Figure 4. Extracted fracture patches (left); dip filtering of patches (middle); fracture patches truncated to reservoir limit (right). Modified from Hawas et.al, 2018.

Application & Future Avenues

Fractures in the subsurface manifest themselves as discontinuities in the seismic data. Due to the presence of seismic noise, it is not always easy to designate them as fractures. Rigorous ground truthing in the form of validation of the discontinuities is necessary before such discontinuities may be identified as fractures. This paper presents a comprehensive workflow for identifying fractures from seismic data which can help produce a seismic fracture volume to be incorporated in a dual porosity – dual permeability model. In future, we plan to investigate whether the workflow described in this research can be successfully tested with a benchmark dataset with a known subsurface like the one described in Roy et al. (2014, 2015). This study has the potential to grow into an algorithm that allows direct integration of fracture attributes from seismic data into Discrete Fracture Network (DFN) models, an area which remains unexplored till date.

Reference

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