IDENTIFICATION OF FRACTURE ZONES IN A TIGHT GAS RESERVOIR

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1. Introduction

Intensive research is going on all over the world to gain as thorough a knowledge of different unconventional hydrocarbon reservoirs as possible, and to aid their modeling. One type of unconventional gas reservoirs is the tight gas reservoir. These are characterised by very low permeability related to gas (μ_{grel}< 0.1 mD), therefore the presence of natural fractures and fracture zones, their identification and description of their orientation are essential for the development of an optimal production concept. The subject of my study was a tight gas reservoir located in a Neogene basin of East Hungary.

Fractures and fracture zones of a reservoir can be identified with different methods and in different scales. Just like in the case of other scientific studies, it is the best way to approach the problem with different methods. In my work fracture zones of the reservoir were identified by post stack attribute analysis, examination of drilling cores and well log interpretation.

2. Overview of the applied seismic attributes

When calculating the attributes dealt with in Sections 2.1 and 2.2 I used local seismic dips. With the help of the software OpendTect so-called dip steering cubes can be produced that contain the inline and crossline components of a local seismic dip at a certain point. I acquired a raw dip steering cube directly from the 3D seismic by the application of “BG fast steering” algorithm. This raw cube had to be filtered. I created differently filtered dip steering cubes like background and detailed steering cubes, according to the recommendations of the software’s user guide [1].

2.1. Most positive and most negative curvatures. In the literature a great number of curvature attributes are known [2]. From the aspect of prediction of fracture zones the most positive and the most negative curvatures are of greatest importance [3], but Gaussian curvature may also be useful [4]. If we want to examine the local shape of the surface of investigation or we are looking for flexures along faults, the joint interpretation of most positive and most negative curvatures is essential. In the latter case they appear with a high value, arranged very often in parallel bands along the faults. This is due to the characteristic shape of flexures along the faults. Positive curvature is dominant on one side of the fault (convex part of the flexure), while on the other side (concave part of the flexure) the negative curvature is dominant.

When calculating the most positive and most negative curvatures I defined in every point a geometry of 2-2 (IL-XL) step-out according to the direction of the local dips. On the 25 points marked out by the geometry a quadratic surface was fitted by the method of least squares. From the coefficients of the equation describing this surface

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($g(x,y)=ax^2+by^2+cxy+dx+ey+f$) the most positive and most negative curvatures can be expressed with the help of the following formulas:

$$K_{pos} = (a+b) + [(a-b)^2 + c^2]^{1/2} \quad (1)$$
$$K_{neg} = (a+b) - [(a-b)^2 + c^2]^{1/2} \quad (2)$$

It should be noted that apart from curvature attributes along classical horizons, curvatures were gained here not from the topography of an interpreted horizon but from the 3D dip steering cubes (volumetric curvature). An advantage of this method is that inaccuracies and artificial effects of interpolation appear less frequently on the maps.

2.2. Minimum similarity attribute. For attributes expressing coherence it is generally true that they are suitable for the indication of sudden changes between neighboring channel sections. They are extremely good for the detection of faults, fractured zones or boundaries related to lithological changes. There are several types of coherence attributes. The earliest (1995) and probably the best known one is the so-called coherency cube, while recently developed methods are semblance type procedures, eigen structure or variance based coherence and coherence based on the calculation of least squares [5].

The so-called similarity attribute characteristic for the coherence, used by myself, is a simple one and can be calculated quickly. Its value between two channel sections can be given by [1]:

$$sim(\underline{X},\underline{Y}) = 1 - \frac{\sqrt{\sum_{i=1}^{N}(X_i - Y_i)^2}}{\sqrt{\sum_{i=1}^{N}{X_i}^2} + \sqrt{\sum_{i=1}^{N}{Y_i}^2}} \quad (3)$$

where: sim($\underline{X}$,$\underline{Y}$) is the value of similarity between $\underline{X}$ and $\underline{Y}$ vectors containing N number of data. N can be defined by a time gate. The numerator is the Eucledean distance in the N dimension of vectors $\underline{X}$ and$\underline{Y}$, and the denominator is the sum of the vectors' length.

I calculated similarity values in the direction of the local dips of previously counted background steering cube. By the calculation in the dip direction, sensibility of the attribute to horizontal discontinuities can be ensured. Use of a background steering cube was expedient so that the attribute should not be sensible to frequent reflection bends along faults. In order to enhance strong discontinuities I chose the minimum of the similarity values calculated between a certain point and its 9 adjacent points in the dip direction.

2.3. Spectral decomposition. Spectral decomposition of seismic channels for attribute analysis belongs to the innovations of the last decade. It is applied usually for estimation of bed thickness or stratigraphic units but it can also be suitable for identification of faults [6].

Prediction of fractures and faults by this method is based on the consideration that a seismic wave is reflected in a different way in a fractured zone: some of its components can be partially absorbed, which causes a characteristic trace in the reflected wave. Therefore it is expedient to examine and observe the spatial distribution of characteristic absorptions.

For the creation of a frequency spectrum of a seismic channel different DFT transforms (FFT, SWDFT) and also continuous wavelet transform (CWT) can be applied. I used the latter one in my work. Its basic principle is similar to different Fourier transforms, because the function to be transformed is correlated with base functions, and so we gain the component in the direction of the base function. The formula defining the transformation is the following:

$$CWT(a,\tau) = \frac{1}{\sqrt{a}} \int f(t) \Psi^* \left(\frac{t-\tau}{a}\right) dt \quad (4)$$

where: $CWT(a,\tau)$ is the continuous wavelet transformed function of *f(t)*. $\Psi(t)$is the mother wavelet, which should be localized, and $\int_{-\infty}^{\infty} \Psi(t)dt = 0$ should be true. Here, the chosen mother wavelet was the Morlet wavelet, which is a harmonic wave windowed by a Gaussian function. $1/\sqrt{a} \cdot \Psi((t-\tau)/a)$ are the base functions of the transformation, which are the compressed and shifted variants of the mother wavelet parameterized with a positive integer of τ time-shift and a real of a scale factor. The sign * represents the operation of complex conjugate.

I carried out the wavelet transform of the 3D seismic. Out of the gained discrete frequency components (10 Hz, 20 Hz, 30 Hz, 40 Hz, 50 Hz, 60 Hz) I found the strongest absorption lineations at 20 Hz frequency, so I chose this component for the attribute analysis.

2. Methodology and results of attribute analysis within the reservoir

Mapping of the fracture zones in the reservoir was carried out by the integrated attribute analysis of curvatures, similarity and spectral decomposition described previously. These attributes were calculated and imaged along four interpreted horizons of the reservoir. In the gained images lineations indicating fracture were marked with polylines. In my method only those lines were acceptable which were indicated by at least two of the three attributes.

In Figure 1 it is visible that the distribution of lines' directions are not randomized but arranged according to definite directions. In order to characterize orientation I calculated the azimuth values of the sections defined by the end points and nodes of the polylines, disregarding the Z coordinates.

By weighing with their own lengths I displayed the azimuth distribution of the interpreted lines in a rose diagram shown in Figure 2. Consideration of the length of sections is important because the frequency of picking nodes during the attribute analysis is a rather subjective matter. I found it expedient to develop a program in order to create an azimuth data set to be displayed in the rose diagram. This program made multiplied copies of the azimuths in a quantity proportional to their own lengths.

From the rose diagram it is obvious that the azimuth of the most characteristic strike direction is approximately 105 degrees, while that of the second one is 85 degrees. A group of lines with an azimuth of approximately 20 degrees is strongly separated from them, they are approximately perpendicular. Consequently, it can be stated that the fractures had developed because of tectonic effects.

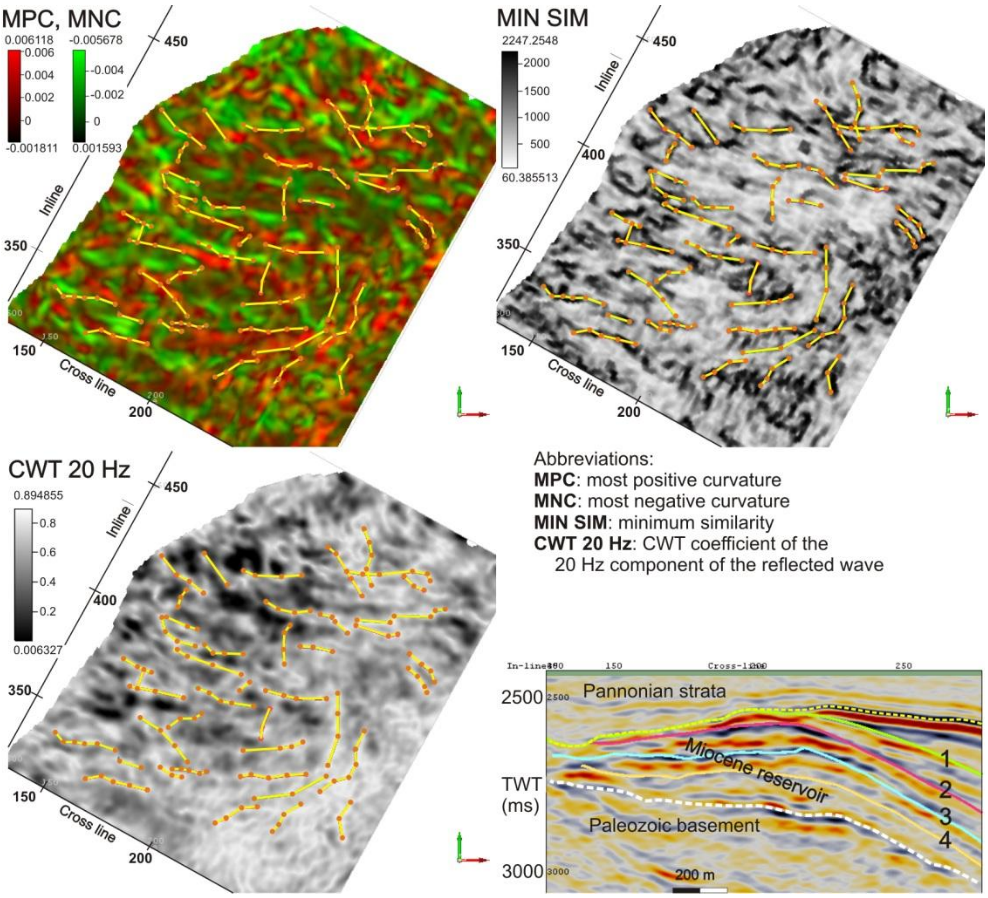

Figure 1. Seismic attribute analysis along horizon Nr. 4, within the reservoir

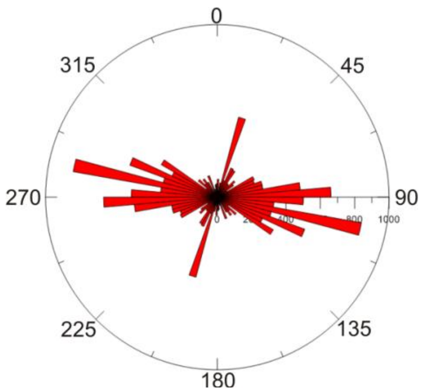

Figure 2. Rose diagram of weighed strike azimuths of the interpreted lines along horizons Nr.1, Nr.2, Nr.3 and Nr.4.

3. Comparison of attribute analysis with the well logs and core data

In the second part of my study I identified fracture intervals along boreholes. I examined macroscopically the cores of the compact, low porosity sandstone–argillite succession. Fractures often appeared more frequently in certain sections; steeply dipping bright sliding surfaces as well as bad core recovery rates or cores broken into small pieces referred to a fracture zone. Sometimes even fault-striae could be observed on the planes of the sliding surfaces.

For my work the following conventional well logs were available: CAL, SP, GR, RX0, Rs, Rd, CN, DEN, DTC, DTS, K, Th, and U. Although none of them had been developed for fracture detection, the presence of fractures might affect the logs. The theoretical background and describing the interpretation of the logs would be far beyond the scope of this paper, but in the literature a great number of books and articles are available on this topic, e.g., [7]. "B4" zone of "B" drilling can be seen in Figure 3. It was practical to insert the photos of the core boxes according to their measured depth next to the well logs, and in this way an integrated interpretation could be performed. Altogether 17 fracture intervals could be determined in the three boreholes of the reservoir.

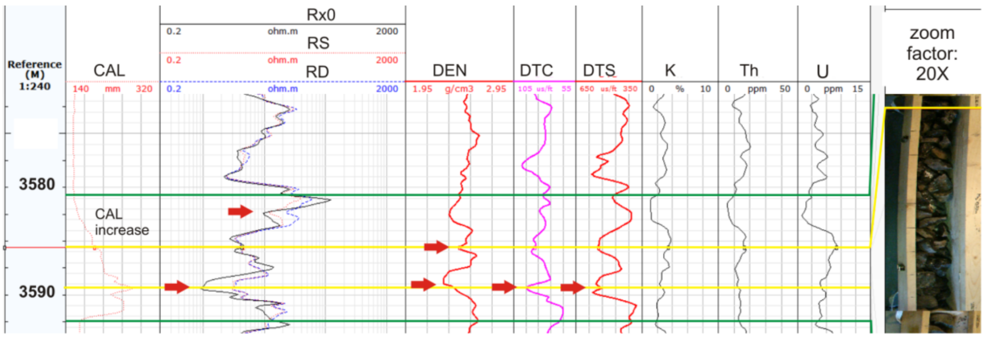

Figure 3. Determining "B4" fracture zone by well logs and drilling cores

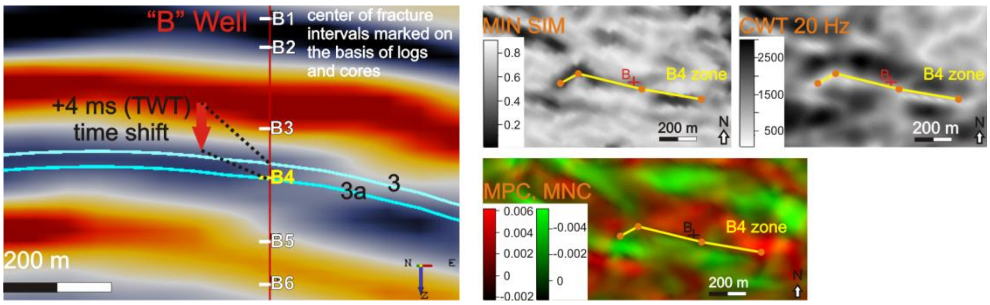

Figure 4. Confirming "B4" fracture zone by seismic attribute analysis along horizon Nr.3a

For the joint interpretation of the wells and the seismic attributes it was necessary to tie wells to seismic with the help of a synthetic seismogram derived from acoustic and density logs. I shifted the nearest interpreted horizons to the adjacent fracture zones. Then I calculated the attributes described above. Out of the 17 fracture zones 13 could be confirmed by at least two attributes. Only in case of two zones did I find no relation with the attributes. Confirmation of the B4 zone is shown in Figure 4. For more detailed information on the study and its results, see [8].

4. Conclusions

Results show that curvature, similarity and spectral decomposition attributes were suitable for the identification of fracture zones. These attributes exploit the possibilities of 3D seismic. A great advantage of them is that they can be easily calculated. They made it possible to determine structural directions, which can be used in further tectonic interpretations. Although the resolution of the methods differs, they were suitable to confirm fractured depth intervals determined on the basis of logs and core examinations.

Beside the methods applied here, there are other useful ways worth trying. Image logs (FMI, BHTV) or oriented core sampling are of great help in case of interpretation along wells. Considering 3D seismic AVAZ or VVAZ analysis of pre-stack data can be a powerful tool for fracture identification. In case of post-stack analysis another possibility is to improve resolution with the help of acoustic logs, which may make even subtle faults and fracture zones visible (seismic spectral blueing).

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