Technical Note #13

TEEC

Describing Fracture Patterns by *Fracture Attributes* from Seismic Data

H. Trappe and J. Schubarth-Engelschall

1. Introduction

Many studies have demonstrated the impact of faults, fractures and joints with respect to production performance of hydrocarbon deposits. Cases are reported where the reservoir performance may increase with appearance of fracture permeability or decrease due to diagenetic processes in the vicinity of such fractures. In any case detailed knowledge of the fracture system is desirable (Fig. 1). In the following we prefer to use the term fracture to include both faults and joints.

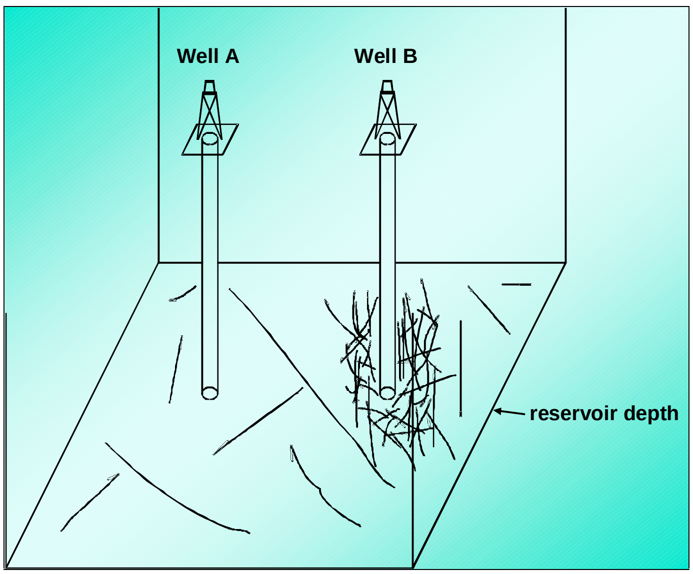


Fig. 1: Production performance in well B is controlled by the fracture system. It is desirable to map the extent of this fracture system by seismic methods.

In this paper an approach is presented allowing the extraction of attributes from seismic data characterising fault systems. Combining these *fracture attributes* with all relevant geological information allows to forecast the production performance for undrilled areas.

Our approach consists of the following four steps:

1. Coherency or volume attribute processing of the seismic data to achieve the best possible resolution of the fracture system at depth of interest
2. Interpretation of visible lineaments
3. Derivation of attributes describing the fracture system (*fracture attributes*)
4. Searching for relationships between derived attributes and production data and forecasting

In the following a workflow is presented for a Rotliegend reservoir in the Northsea at a depth of about 3500 m.

2.1 Coherency Processing

The CohTEEC® technology provides a range of algorithms to carry out coherency calculations on seismic data. This approach ensures a most detailed picture of the fracture system. A typical example of this process is presented in Fig. 2 where a detailed fracture pattern at the depth interval of the reservoir is shown.

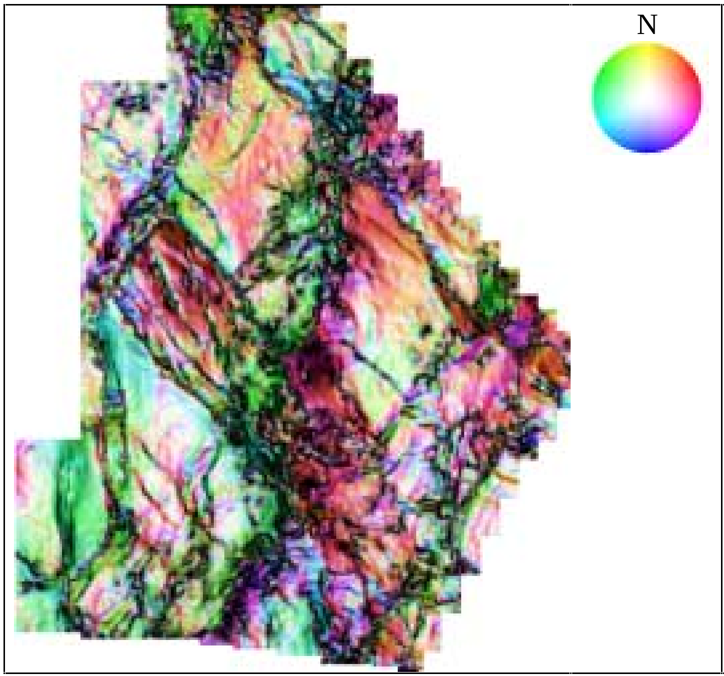


Fig. 2: IHS display shows the fracture pattern at reservoir depth as the result of the coherency processing (10x12 km^2).

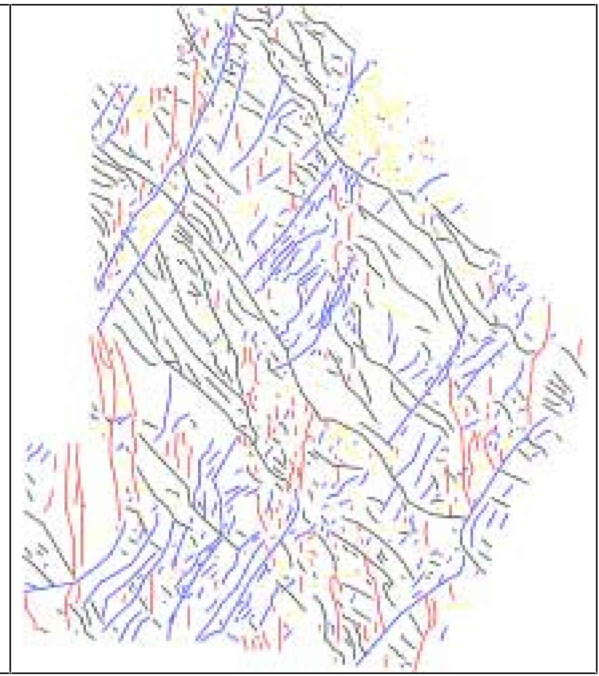


Fig. 3: Interpreted lineaments.

2.2 Interpretation of Visible Lineaments

Within the CohTEEC®technology an interpretation system is implemented by now. In the following step it is used to interpret lineaments on both maps and sections while at the same time the geological reliability of all features has to be verified. This includes the identification of artefacts resulting from processing, poor signal/noise ratio etc. This part of the study requires experience of the user concerning the interpretation work with coherency data. The interpretation benefits from the fact that the interpreter has the choice to view different aspects of the fracture pattern by loading out different seismic volumes representing the coherency, dip and azimuth volume. A combination of these three volumes can be realised by generating IHS (Intensity, Hue, Saturation) displays as shown in Fig. 2.

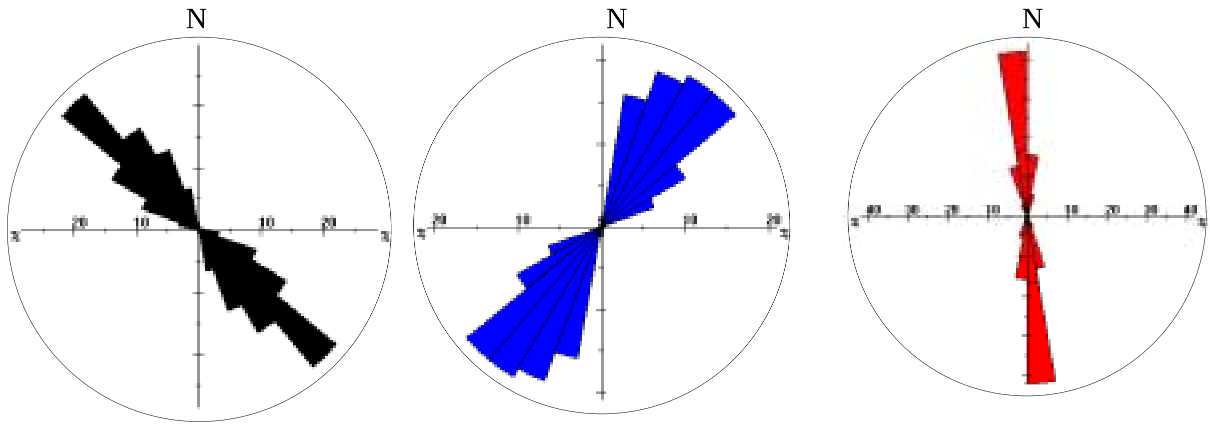
2.3 Derivation of Attributes Describing the Fracture System

In this part of the paper *fracture attributes* are derived which are able to characterise the observed fracture system. Table 1 lists a number of possible *fracture attributes*.

1. orientation
2. length
3. density
4. connectivity
5. spatial distribution
6. fractal dimension
   - of fault length
   - of fault throw

Table 1: *Fracture attributes* for the characterisation of fracture systems.

As an example Fig. 4 presents the major directions of the fractures of the interpreted lineaments (Fig. 3) which are divided into classes by orientation.



100%= 326 (number) 100%= 269 (number) 100%= 194 (number)

Fig. 4: The orientation ranges for each class.

Another attribute of interest is the fault density. Fig. 5 presents a fracture density map derived from the interpreted fractures.

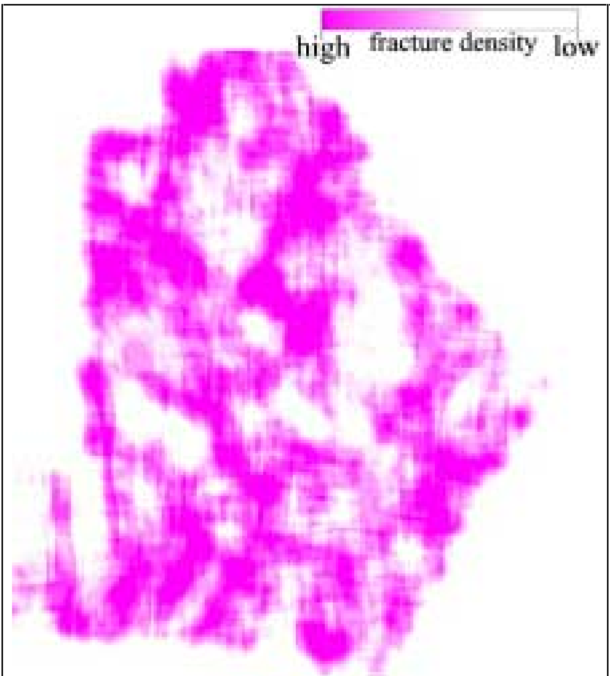


Fig. 5: Fracture density map of Fig. 3.

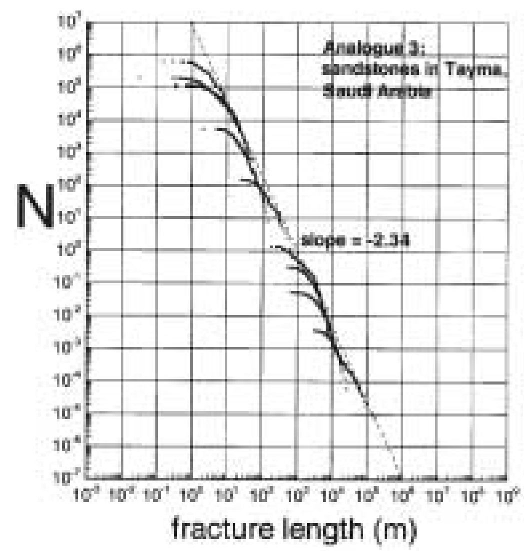


Fig. 6: Power law distribution of fracture length over a large range from outcrop to satellite images([1]).

An other *fracture attributes* is the connectivity, which is derived with the help of the percolation theory. The connectivity depends on the orientation and size of lineaments as well as the spatial distribution and density. If the number of faults or fractures increases clusters of connected lineaments are formed. With increasing numbers of lineaments the clusters grow and finally a percolation threshold is reached where the cluster spans the area ([1]). When considering an impermeable rock matrix the flow of hydrocarbons is strongly controlled by the fracture system, no flow is expected below the percolation threshold.

The attribute describing the spatial distribution could be defined by the coefficient of variation C_v ([2]):

C_v = standard of deviation / mean spacing.

This should be analysed for each orientation class by line samples perpendicular to the average trend of these class ([2]). A random distribution provides C_v values of about 1. For C_v <1 the faults are regularly (parallel) spaced. For C_v>1 a clustered distribution is found.

The theory of fractals provides additional *fracture attributes* useful for describing fracture patterns. The main impact of the theory is that there is a power law expected to be valid between lineaments of small and large scales (self similarity). Results are typically plotted in a log-log diagram. In Fig. 6 length populations are plotted as cumulative frequency distribution. The straight line indicates that the length distribution follows a power law with an exponent -a ([1]).

The exponent (-a) is the fractal dimension which describes the slope of the graph: $\mathbf{N(l)\alpha l^{-a}}$.

For a slope of -2.0 a strict self similarity with respect of the fault length is provided. For values > -2 (e. g. -1.0) a lack of short lineaments is indicated, values <2 indicate a lack of long lineaments.

2.4 Searching for Relationships between Derived Attributes and Production Data and Forecasting

The above defined slope gives one attribute to distinguish between areas of intensive fracturing and those which show regularly fault distributions. Relationships have to be found between production data and all defined *fracture attributes* described above. Under favourable conditions a relationship between *fracture attributes* and production performance can be established. Production performance might be expressed e. g. by flowrates, permeability, drainage area etc. The example given in Fig. 7 shows the result of the interpretation carried out in Fig. 3. The cumulative frequency distribution of fracture length is displayed in a log-log diagram. The result is a slope of -0.96. This slope is related to a common fracture pattern for this stratigraphic unit. A similar approach has been applied for a second survey. It shows a relatively large number of smaller fractures resulting in a steeper slope (-1.41) representing an extreme case. In a further step for each of the two examples a comparison with production data can be performed. This calibration may change from field to field. A considerable increase has been reported for some gas fields showing strong fracturing. In other areas it is known that strong fracturing served as pathways for acid waters ascending from subjacent Carboniferous beds which might cause diagenetic effects and therefore reduce the permeability (see Technical Note No. 10).

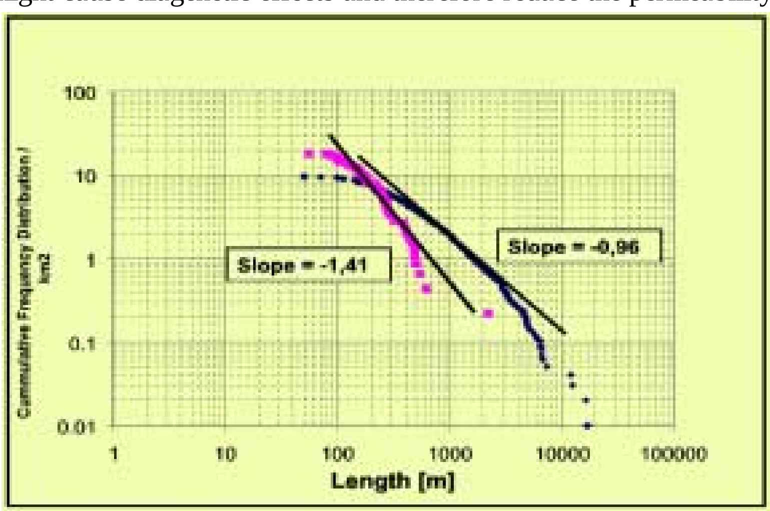


Fig. 7: Cumulative frequency length distribution within the Rotliegend.

Once a relationship between *fracture attributes* and reservoir performance has been established this knowledge is used for an areal mapping of the expected performance. The areal distribution might be used for planning new well locations, side tracks and horizontal well paths. However, please note that this approach provides only one aspect in the estimation of the reservoir behaviour. To come to final conclusions all relevant information such as lithological and petrophysical information has to be considered.

References

[1] Odling, N. E. et al, *Petroleum Geoscience*, Vol. **5**, pp 373-384, 1999.

[2] Cox, D. R. et al, The Statistical analysis of series of events. Methuen, London, 1966.

[3] Yielding, G. et al, *First Break*, Vol. **10**, No. **12**, pp 449-460, 1992.

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