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# Statistical Analysis of Well Fracture Data to Distinguish and Extract Fracture Corridors from Diffuse Fractures

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## SUMMARY

Recognizing fracture swarms from diffuse fractures, and interpreting them as being related to corridors, thin rock beds or facies, is a critical and often time-consuming step in naturally fractured reservoir (NFR) characterization. On the one hand, it is necessary to decide whether or not visually aggregated fractures are indeed anomalous and should be considered as belonging to a single fracture corridor. On the other hand, user-friendly tools are needed to differentiate fractures within and outside corridors so as to properly take them into account in NFR models.

An innovative statistical approach, associated with post-processing tools for automatic and assisted recognition of within-corridor fractures, is presented. Based on the SiZer method (SIgnificant ZERo crossings of derivatives), the statistical identification of fracture swarms relies on statistical hypothesis testing to detect significant fracture density trends along wells at different observation scales. Knowing zones of very likely increasing, stationary or decreasing fracture densities, a post-processing algorithm allows to distinguish fractures that are inside and outside of identified corridors, to mark them distinctively and to generate equivalent data that can be used to characterize and model large scale fracture corridors. The paper presents the approach and illustrates its performances on a real case study.

## Introduction

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The paper presents the approach and illustrates its performances on a real case study.

## Methodological aspects

SiZer is an exploratory data analysis technique which is used in conjunction with smoothing methods to identify significant features on smoothed curves. The method was initially designed to test the presence of modes in probability density functions (histograms) calculated from data (Chaudhuri and Marron, 1999). It was later generalized to identify significant changes on curves and surfaces (Chaudhuri and Marron, 2000). The application to fracture density was introduced by Garcia *et al.* (2005) within the framework of fine scale modelling of fracture densities using mixtures of distribution functions related to fractures in swarms together with diffuse fractures.

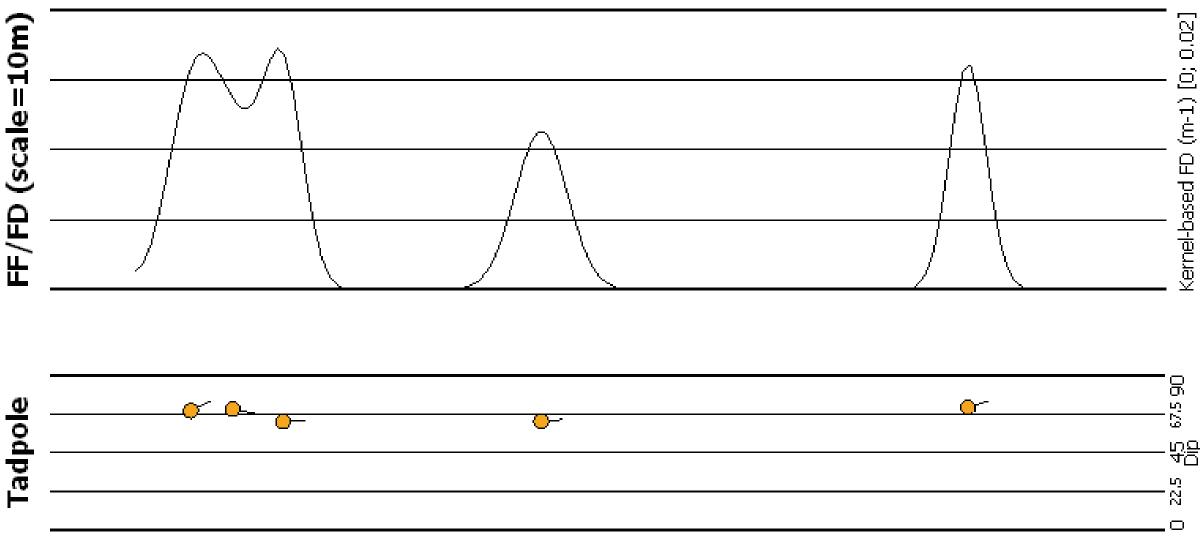


***Figure 1*** *Kernel-based calculation of fracture density logs.*

Applied to fracture densities, the SiZer method consists of statistically identifying significant fracture density trends from fracture density logs smoothed using a kernel-based method. The kernel function is chosen to have good mathematical (smoothing) properties, Gaussian kernel functions being generally preferred. Each fracture being associated with a kernel function centred at the fracture location, the fracture density curve along the well is calculated by summing the kernel functions from all fractures (Fig. 1). A reference kernel size must be selected, which defines the observation scale at which fracture densities are evaluated. Individually, for each fracture, the size of the kernel must be corrected, however, to account for non orthogonality between fracture and well. To be effective, the analysis must apply to a single directional fracture set, different orientation classes requiring to be processed one after the other.

Within the SiZer approach, the calculation of the fracture density log is repeated a number of times, for increasing kernel sizes, in order to generate a fracture density map that covers a wide range of observation scales (Fig. 2, middle log). The higher the observation scale, the smoother is the fracture density curve. Based on a probabilistic formalism (see Chaudhuri and Marron, 1999 and 2000), statistical hypothesis testing is then performed on the derivatives of the fracture density curves to find the observation scales at which significant increasing or decreasing fracture density trends are present, given a confidence interval. The classification of fracture densities according to trends is displayed on a map using a colour coding (Fig. 2, top log): blue = no trend, red = increasing. green = decreasing, grey = unknown (not enough surrounding fracture data). In the example of Figure 3, the confidence interval needs to be reduced to 50% to show significant trends, otherwise the high fracture density spots appearing at small scales on the FD map are not sufficiently contrasted to be detected as anomalous compared with surrounding fracture densities.

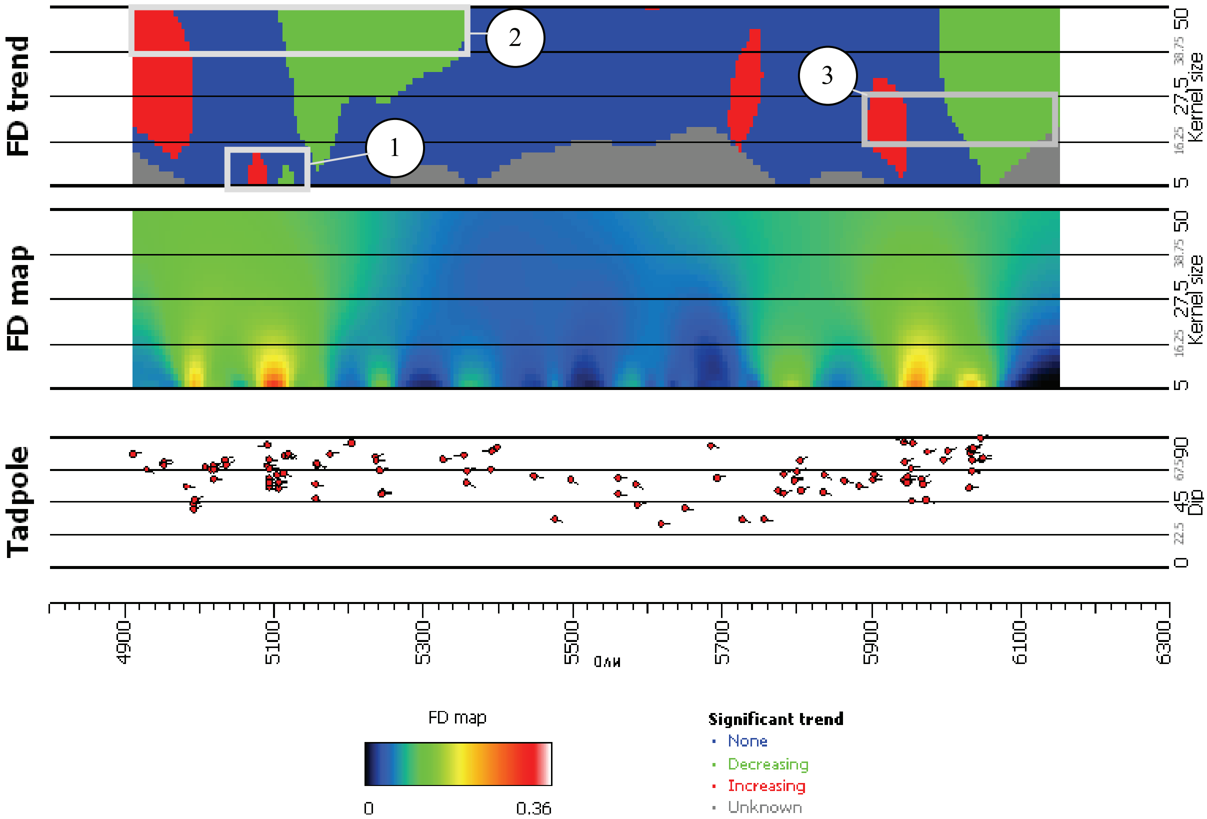


***Figure 2*** *SiZer analysis of fracture density trends. At the bottom, the tadpole log provides depth, orientation and dip information about fractures. In the middle, the fracture density map (FD in m-1) depicts kernel-based fracture densities for increasing kernel sizes (observation scales) from 5 to 50 m. At the top, the statistical classification of fracture densities shows significant trends at different scales for a 50% confidence interval (50% chances or more that the trends are real): 1) small scale trends, 2) large scale trends, 3) intermediate scale trends.*

Classification maps generated with the SiZer approach provide valuable information about significant fracture density trends. In order to exploit them, a post-processing is needed to reach the following objectives.

- Automatic recognition of fracture corridors (location and extension).
- Validation or modification (resetting, removing, possibly adding) of recognized fracture corridors (e.g. to discard fracture swarms related to highly fractured thin units).

- Type assignment to fractures to distinguish fractures attached to corridors from those outside.
- Generation of fracture corridor data from fractures identified as belonging to corridors: calculation of fracture corridor depths and orientations.

Given a confidence interval and a range of observation scales, the automatic recognition of fracture corridors is obtained by detecting successive increasing (red) and decreasing (green) trend zones around zones of no trend (blue). In Figure 2, one or two corridors can be detected depending on the expected width of fracture corridors (between the small and intermediate scales).

In the next section; the approach is illustrated on a real case study.

**Application to a case study**

The case study is a highly fractured and faulted reservoir in Europe. Fracture data come from interpreted borehole images available in five wells in which a total of more than a thousand fractures have been picked (Fig. 3). From a detailed statistical analysis of the spread of fracture orientations, three joint (mode I) sets, perpendicular to bedding, are interpreted. Within each set, fracture swarms occur, which could be structurally related to fracture corridors if not related to highly fractured thin beds. Defining and extracting these potentially highly permeable and vertically persistent features from the more diffuse background fractures is therefore a key issue for reservoir modelling.

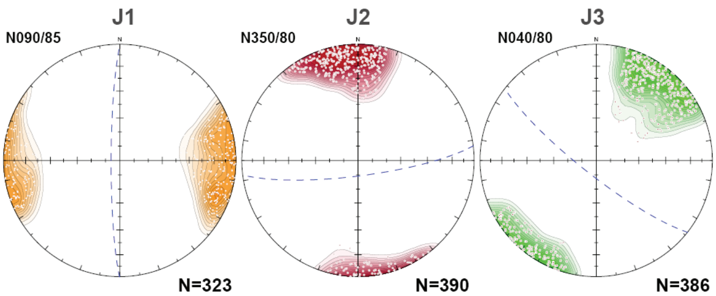


***Figure 3*** *Stereonets of mode I fractures separated into 3 orientation classes. All well data have been grouped after structural dip removal for this orientation analysis.*

Our SiZer and post-processing tools were successfully used to identify fracture swarms corresponding to significant fracture density trends at different observation scales (Fig. 4.a), to recognize fracture corridors at an observation scale between 5 and 10 m (Fig. 4.b), discarding when necessary fracture swarms related to highly fractured thin units, to assign distinctive types to fractures in corridors and to diffuse fractures, and to generate fracture corridor data that were subsequently used to model sets of large scale objects (Fig. 4.c). This analysis was repeated for each well.

**Conclusions**

The SiZer approach applied to fracture densities, together with suitable post-processing algorithms, has proved to be a powerful data analysis and processing tool to assist geologists in identifying fracture corridors and differentiating fractures attached to corridors from diffuse fractures. Using this tool, fracture characterization tasks that were time-consuming and often subjective can now be performed very rapidly and in a consistent way.

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## References


Chaudhuri, P. and Marron, J.S. (1999). SiZer for exploration of structures in curves, *J. Amer. Statist. Assoc.*, Vol. **94**, 807–823.

Chaudhuri, P. and Marron, J.S. (2000). Scale space view of curve estimation, *Ann. Statist.* **28**, 408–428.

Garcia, M., Allard, D., Foulon, D., and Delisle S. (2005). Fine scale rock properties: towards the spatial modeling of regionalized probability distribution functions, in "Geostatistics Banff 2004 – Volume 2", O. Leuangthong and C.V. Deutsch ed., Springer, 579-589.


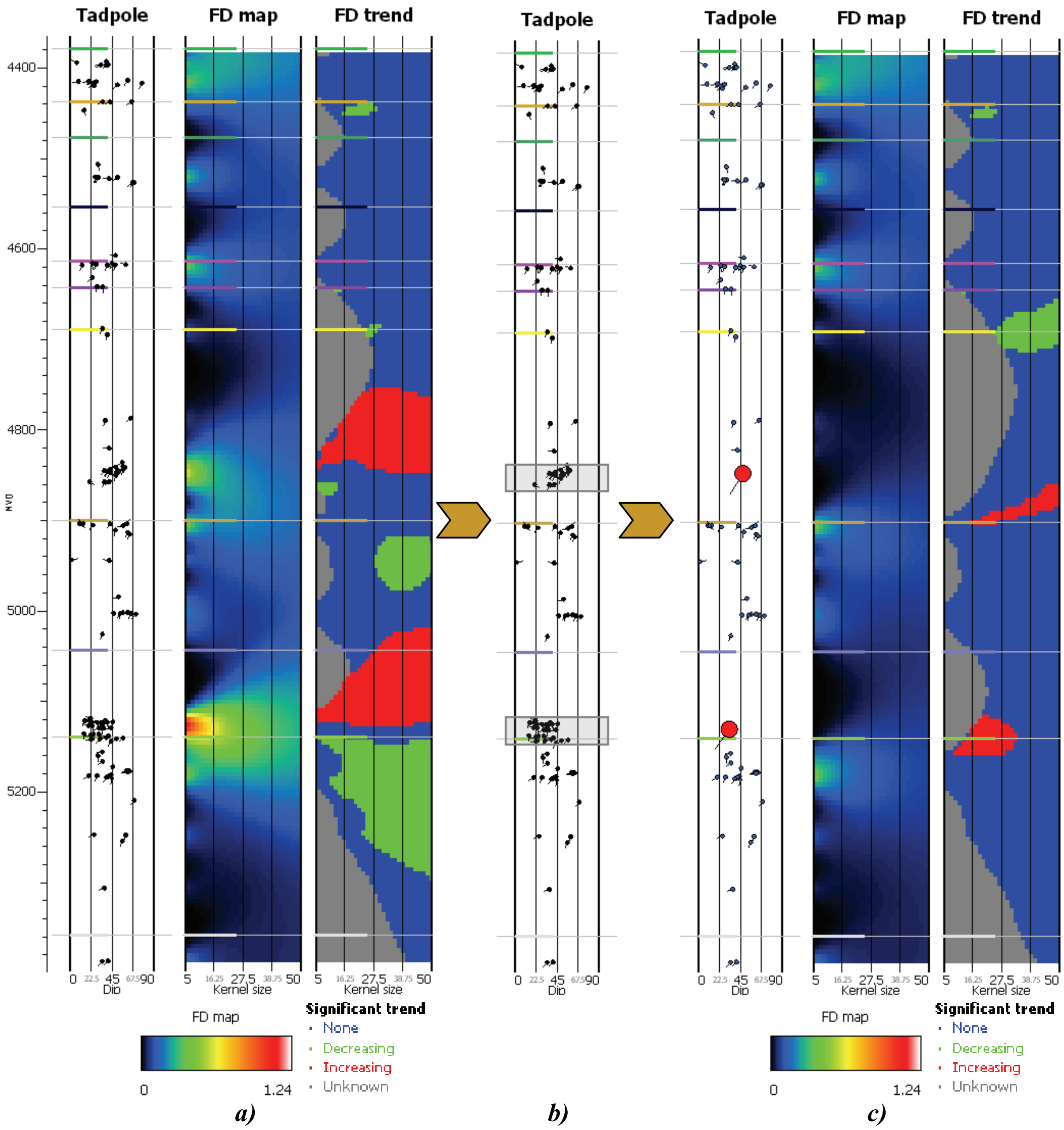


***Figure 4*** *Application of the three-step approach, based on SiZer and post-processing tools, to fracture data from orientation class J3: a) SiZer classification revealing significant fracture density trends with a 95% confidence interval, b) automatic and assisted recognition of fracture corridors for an observation scale between 5 and 10 m (grey boxes), c) automatic differentiation of fractures attached to corridors from diffuse fractures (blue tadpoles), and automatic creation of fracture corridor data (red tadpoles), thus leading to recalculated fracture density and classification maps.*