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Directional Grey Level Co-occurrence Matrix-based Attributes for Fracture Detection

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SUMMARY

The grey level co-occurrence matrix (GLCM) is a measure of the texture of an image. It describes how often different combinations of pixel brightness values occur in an image. Based on this, several textural attributes can be calculated. These directional attributes can be used to determine isotropic and anisotropic areas. In anisotropic areas the information of directional GLCM-based attributes can be used for the estimation of fracture intensity, as well as for the determination of strike and dip of fractures.

Introduction

The grey level co-occurrence matrix (GLCM) is a measure of the texture of an image. It describes how often different combinations of pixel brightness values occur in an image. Based on this, several textural attributes can be calculated. These directional attributes can be used to determine isotropic and anisotropic areas. In anisotropic areas the information of directional GLCM-based attributes can be used for the estimation of fracture intensity, as well as for the determination of strike and dip of fractures.

Method

Textural attributes describe the spatial arrangement of constituents, neighbouring amplitudes, rock units, depositional facies and reservoir properties (Gao, 2011). The grey level co-occurrence matrix (GLCM) and its derived attributes are commonly tools for 2D image classification that were initially described by Haralick *et al.* (1973). Principally, the GLCM is a measure of how often different combinations of pixel brightness values occur in an image. In literature several papers on the application of GLCM for seismic attribute calculation are available (e.g. Vinther *et al.*, 1996; Gao, 2003, 2007, 2009, 2011; West *et al.*, 2002; Chopra and Alexeev, 2006; Yenugu *et al.*, 2010; de Matos *et al.*, 2011; Eichkitz *et al.*, 2012, 2013, 2014a, 2014b, 2015).
As the initial workflow for GLCM-based attribute calculation is designed for 2D applications, it was necessary to adapt the given workflow for the 3D seismic case (Eichkitz *et al.*, 2013). In three dimensions any sample point has 27 neighbouring sample points. These neighbouring sample points are aligned in 13 space directions. The GLCM algorithm allows the calculation in single directions or multiple directions can be combined to form an average grey level co-occurrence matrix. These directional dependent GLCM calculations can be used to detect spatial variations in seismic character. In the synthetic image in Figure 1 an approximately northwest-southeast striking feature is modelled. GLCM-based attribute responses show a clear directional dependency. Eichkitz *et al.* (2014a, 2014b, and 2015) used this methodology to detect facies variations within a channel system. In these works only the four horizontal directions were used.
In this work we present a workflow for fracture detection using directional GLCM-based attribute calculations in 13 directions (Figure 2). The principal workflow is similar to the one presented by Eichkitz *et al.* (2015). The first step is the GLCM-based attribute calculation in 13 different space directions. To enhance the output of GLCM-based attribute calculation the structural dip is integrated in the calculation. After that the attribute responses from the 13 different directions are compared to each other. Based on this comparison the maximum and minimum attribute values, as well as the direction in which they occur are determined (step 2). As the minimum and maximum values might be very close to each other, it is possible to overestimate anisotropy in the seismic data. Therefore, we need to condition the data to distinguish between isotropic and anisotropic areas. In step 3 the ratio between maximum and minimum value is calculated and a certain threshold value for isotropic areas is defined. In step 4 we now use the ratio and the threshold value to distinguish between isotropic and anisotropic areas. The calculated ratio between maximum and minimum values can also be used to estimate the intensity of fractures. In the final step of the workflow we now use the direction of maximum and minimum values to determine the strike and dip of fractures for each sample point. The final result of the workflow is a 3D grid of fracture planes that can be used as input for a discrete fracture network.

Application of the workflow

The developed workflow for fracture detection using directional GLCM-based attributes is applied onto different data sets provided by OMV as well as on the Teapot Dome dataset. In all case studies the GLCM-based attributes are calculated using reflector dip information. Then the workflow is applied onto all datasets and fracture networks are generated. For verification of the calculated fracture directions, the results are compared to information from well data and to other seismic attributes.

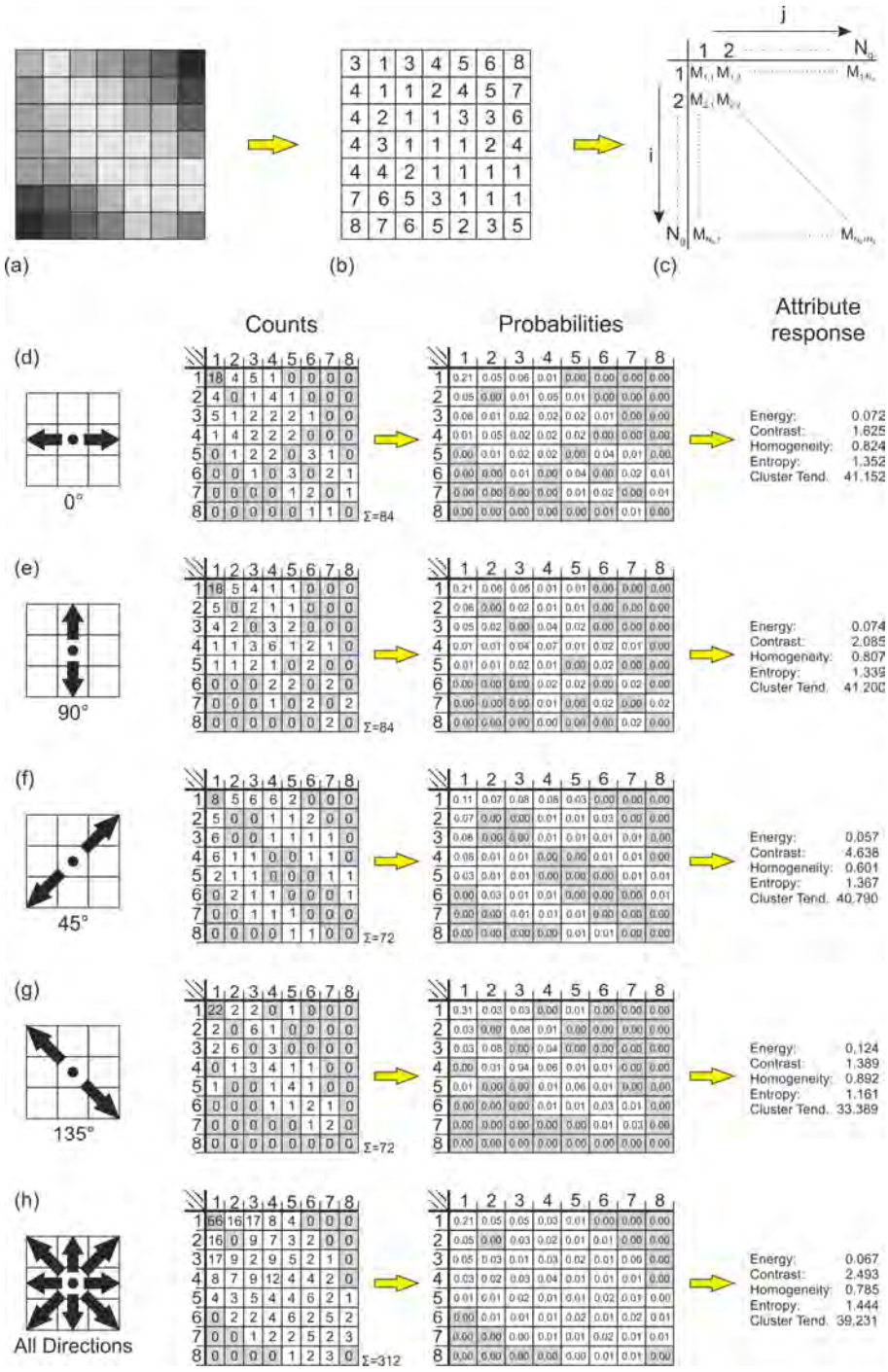

Figure 1 *Example for the calculation of GLCM-based attributes using eight grey levels from a synthetic 2D grey-scale image (a). The grey-scales of the image correspond to discrete values (b). The number of co-occurrences of pixel pairs for a given search window are counted and a GLCM (c) is generated. In this synthetic case, the analysis window is 7 x 7 and attribute response would be assigned to the centre image point. Based on this co-occurrence matrix, several attributes can be calculated. In this example, the grey level co-occurrence matrices are determined for the 0° (d), the 90° (e), the 45° (f), the 135° direction (g), and for all directions at once (h). The first step in calculation is the determination of co-occurrences (figures in the middle). Zero entries are marked in grey and the highest value of each matrix is marked in dark green. It is evident that calculations in single directions lead to sparse matrices. The GLCM is normalized by the sum of the entries to get a kind of probability matrix (figures in the right). Finally, the probabilities are used for the calculation of the GLCM-based attributes. In column "attribute response" the results for entropy, contrast, homogeneity, entropy, and cluster tendency are shown.*

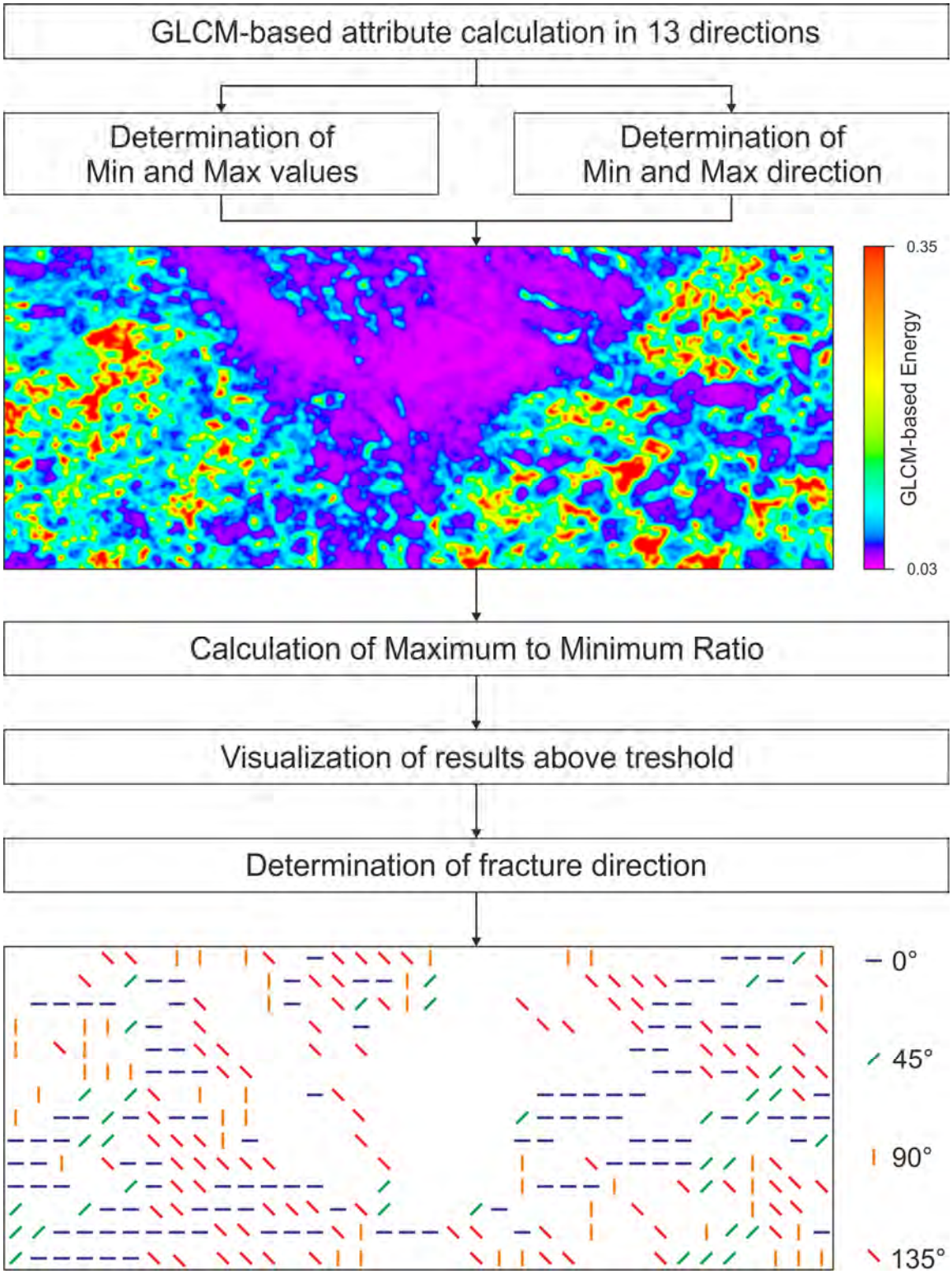

Figure 2 *The workflow for seismic fracture detection by using GLCM-based attributes is divided into five steps. The first step is the calculation of each GLCM-based attribute in 13 space directions. The second step is the determination of minimum and maximum values and their direction for each GLCM-based attribute. In step three the ratio between maximum and minimum is calculated. The ratio is used to determine a threshold value. The threshold value is applied in step 4 to identify areas with higher directional variability and to visualize only these directions of minima and maxima. Finally, in step 5 the minima and maxima values are used to determine the dip and azimuth of fractures.*

Conclusion

In three dimensions the calculation of GLCM-based attributes can be done in 13 principal space directions. These different attribute responses can be used to separate isotropic from anisotropic areas. In anisotropic areas the developed workflow allows the estimation of fracture intensities and the determination of fracture planes for each sample point. First test of this new workflow showed reliable results in comparison to fracture estimations using other seismic attributes and in comparison to available well data.

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