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Texture attributes for detection of salt

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ABSTRACT

Within areas of salt tectonics, seismic imaging requires extensive updating of the velocity model. This includes defining the boundaries of salt structures which are often characterized by changes in texture of the seismic signal rather than reflectivity. The main characteristics of texture inside salt structures are identified. Three groups of texture attributes are studied: gray-level co-occurrence matrix (GLCM) attributes, frequency-based attributes, and dip and similarity attributes. Various combinations of the selected attributes are tested in a supervised Bayesian classification method. Experimental results show that the classification performance improves by combining at least two texture attribute groups. The classifier computes an estimate of the pixelwise probability of salt. It can then be applied to compute the probability of salt on different seismic sections. Classification results were found more robust based on timeslices. The result from classification, the salt probability image, is then input to a segmentation algorithm that produces a smooth border delimiting the extent of the salt. The segmented salt contours corresponded fairly well to the contours provided by an interpreter.

1. Introduction

Within seismic imaging of complex settings such as areas of salt tectonics, prestack depth migration (PSDM) is needed. This method requires an accurate velocity model, which includes defining the boundary of salt structures. Detecting salt contours is a critical issue since possible hydrocarbons can be trapped against the salt flanks as well as below. Salt boundaries can be delimited by strong reflectivity but they are more often characterized by a change of character of the seismic signal also called texture. The aim of this study is thus to describe seismic textures in the context of salt geology, then to identify attributes tailored to detect those textures, and finally to extract the border of the texture associated with salt.

A few approaches have already been proposed in the literature to detect salt structures. Gao (2003) applied attributes derived from the gray-level co-occurrence matrix (GLCM) (see Conners et al., 1984; Haralick et al., 1973) to detect a salt canopy and concluded that using his 'seed-based propagation method may cause "bleeding" across the salt boundary and thus is not effective for automatic salt detection'. Lomask et al. (2007) considered salt structures with boundaries defined by strong reflectivity and used the instantaneous amplitude as an attribute for automatic segmentation. Their approach consisted of building a weight function indicating the possible presence of a boundary between pairs of pixels in the image. In the vicinity of a strong reflector, the weight associated with creating a boundary was low. This algorithm was not able to detect salt without strong reflectors on the boundary. Halpert et al. (2009) extended this approach to combine two attributes: instantaneous amplitude and dip variability. Aqrawi et al. (2011) proposed to use a Sobel filter to detect salt and compared the segmentation results with those obtained using the variance attribute (van Bemmel and Pepper, 2000). This technique can be employed if the salt area has a very small magnitude and variation in amplitude. Berthelot et al. (2011) investigated the feasibility of salt detection in the case where the salt area is characterized by incoherent signals without a strong decrease in amplitude level as compared to the surrounding geology. The approach used was a supervised classification using a small set of seismic attributes.

The originality of the present paper is its focus on texture to characterize the change of seismic character between the salt structure and its surrounding geology and using this knowledge to select different texture approaches. The texture attributes considered belong to three groups: GLCM attributes, frequency-based attributes, and dip and similarity attributes. The periodicity and orientation of the seismic textures are described using frequency-based attributes. Texture changes in terms of the joint gray level distribution of a pair of pixels along a chosen direction and in a local neighborhood are characterized by GLCM attributes. Finally, variations in dip, trace to trace similarity or signal amplitude strength are described by dip and similarity attributes.

In Section 2, we will define seismic texture within the geological context of salt. Potential texture attributes from the literature are then presented (Section 3). A 3D dataset from the North Sea (Section 4) is used to test the selected texture attributes (Section 5).

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Using various subsets of attributes, all pixels of a seismic section are then classified (Section 6) into one of the textures identified. The best performing subset (Section 7) is then used for segmentation of the salt boundary.

2. Seismic texture in the context of salt geology

Many definitions of texture can be found in the image processing literature (Tuceryan and Jain, 1993). Texture is firstly a concept derived from the human vision system. An image can be considered as a patchwork where each patch corresponds to one texture, i.e. an area with properties (like coherency, homogeneity and orientation) that makes it visually separable from neighboring patches for an observer. A texture can correspond to a random or a periodic distribution. Most textures are a mix of both, like the ones present in seismic images.

In order to characterize the texture within the areas of salt tectonics, some basic understanding of the geological processes driving the salt formation is needed. In extensional basins that are accumulating sediments, salt structures are triggered and driven mainly by extension and differential loading but also sedimentation rate (Warren, 2006). Extension allows salt to pierce the overburden in three related ways: reactively, actively and passively. In the reactive stage (Fig. 1a), the salt moves into space created by extension, and fans of normal faults are created. The active stage (Fig. 1b) occurs in the case of a thin overburden. The salt pressure exceeds the brittle strength of the overburden and as a consequence pierces it. In a later stage, once the diapir emerges at the water level, it becomes a passive diapir (Fig. 1c) meaning that its edges spread and collapse under the weight of the extruded salt mass. During this process, no faults are created around the diapir. Shapes of passive diapirs are controlled by the ratio of salt flow rate to sedimentation rate. When the sedimentation rate is relatively slow, the salt leaks out over its surroundings resulting in a diapir with flanges and a more mushroom-like shape.

The complexity of the geological processes that take place within the areas of salt tectonics explains the extreme variety of structural shapes. Despite this extreme variability in shapes, seismic textures inside and surrounding salt structures can be well distinguished (Schlaf et al., 2005). Assume a 3D data cube of processed seismic data. In this paper, we will consider two types of subsets associated with this cube: a vertical section (slice) in the inline direction and a timeslice (horizontal slice). Inside the salt, the texture consists of an incoherent, low amplitude area with small variations in texture for both an inline section and a timeslice. In the surrounding geology, three different textures can be observed: 1) incoherent texture, i.e. disordered arrangement of reflection surfaces in the faulted area around the salt; 2) texture made of thinning reflectors towards the salt or tilted parallel structures around the salt in the case of salt extrusion; 3) texture made of parallel and sub-parallel seismic events: these are typically the reflections further away from the salt boundary.

Seismic reflectors surrounding the salt can be split into two groups: steep-dipping and sub-horizontal reflectors. The visual characteristics of those reflectors can be described for inline sections and timeslices. The steep-dipping reflectors have some common characteristics for both the inline sections and timeslices and appear as a pseudo periodic, high frequency texture. Nevertheless, the actual structures appear different on the inline sections and timeslices. On inline sections, the reflectors can be split into two classes, up- and down-dipping layers. On the timeslices, layers with the same dip (independent of direction) will appear as circle-like curves surrounding the salt as shown on the sketch in Fig. 2a and on the real timeslice data (Fig. 2b). The steepest dips show the highest spatial frequencies, which correspond to the innermost rings in Fig. 2a. The second group of reflectors are sub-horizontal seismic events often seen further away from the salt boundary. On the inline sections they correspond to pseudo periodic, high frequency patterns along a direction normal to the layering but with small dips (Fig. 1). On the timeslices, they are no longer pseudo periodic and cover a wide range of spatial frequencies and orientations (see Fig. 2). Thus, the texture corresponding to sub-horizontal reflectors changes significantly from an inline section to a timeslice. This observation indicates that texture-sensitive attributes have to be adapted for each data type. Potential attributes sensitive to the described textures will be addressed in the next section.

3. Related work on texture attributes

A salt structure can be isolated if its internal characteristics or the characteristics of the seismic textures surrounding it are properly described. Salt can be described as an area of incoherent signal compared to its surroundings. The chaos and trace attributes derived from the covariance matrix (Randen and Sønneland, 2005; Randen et al., 2000) can therefore help to detect salt. The trace attribute measures whether the data considered has a certain consistency in texture or not. Regions where this attribute is relatively low correspond to regions with incoherent signal pattern such as salt. Both the chaos and trace attributes (Randen et al., 2000), have already been applied within salt detection in an earlier study (Berthelot et al., 2011).

Trace to trace similarity is a characteristic of layered structures which can be described using the semblance (Marfurt et al., 1998; Neidell and Taner, 1971) or the coherency computed from the covariance matrix (Gersztenkorn and Marfurt, 1999) which can discriminate between areas with similar dip and areas without coherent dip such as salt. Analyzing the eigen structure of the covariance matrix can also be used to describe the variation of the seismic signal outside the salt area. Berthelot et al. (2011) showed that two coherency-based texture attributes, the cross-correlation and the difference in mean cross-

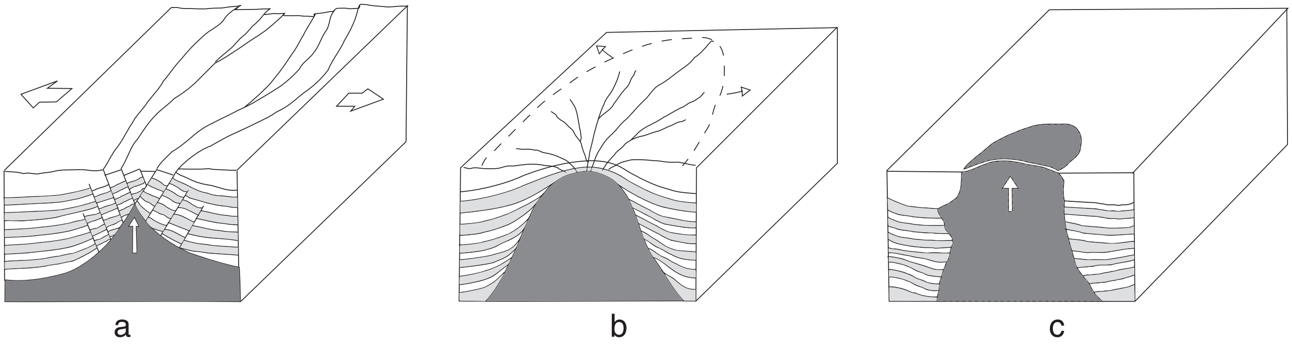

Fig. 1. Three piercement modes for diapirs (salt in dark gray): a) reactive, b) active and c) passive and their characteristic structures.
Adapted from Warren (2006).