Detailed Seismic Mapping and Time-Lapse Analysis of a Fault Network in the Chalk*

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Abstract

Detailed mapping of a fault network from seismic data is critical for reservoir modeling for it either establishes compartmentalization or enables inference of the subseismic fracture network distribution. However, manual picking of fault surfaces is time-consuming and often inaccurate, and capturing the complete set of structural lineaments can be impossible without semi-automated techniques.

The superposition of two or more tectonic events complicates the task. In addition, the seismic data do not give a precise image of the underburden and fluids distort the signal: faults can leak and gas clouds can obscure the image of part or the entire field. Production introduces further complexity. On the other hand, changes observed in time-lapse seismic data often carry useful information on the connectivity of the fracture network.

The case we present is from a chalk reservoir and it contains all these challenges. One example is the coexistence of an initial fault and fracture system assumed to have developed during Late Cretaceous or Early Tertiary, coeval or just after the chalk deposition. It is associated to pulse growth of the structure, which caused slumping and sliding of the semilithified chalk, and to a newer set developed during the Tertiary by inversion tectonic (Evans et al. 1999) that might have partially reactivated the older system. The geologic section of interest is relatively thin on seismic sections and partially obscured by a gas cloud.

The two structural sets can have a dramatically different impact on fluid flow depending on the diagenesis the rock was subjected to from the time of development to the time of the oil charge. Consequently, their responses to stress changes resulting from current production can be dissimilar and possibly reflected on the seismic data. Reactivation cannot be excluded.

Our challenge is to separate seismic faults of different ages and characteristics for later validation by dynamic simulation and geomechanical modeling, which is not a part of this study. To reduce the uncertainties in the prediction of the effective fluid pathways, we integrate published research components and techniques still under development with common tools used by seismic data interpreters.

Fault Detection by Seismic Mapping

The detailed 3D fault mapping is performed by combining attributes that represent different parts of the seismic signal (Aarre and Astratti, 2011): amplitude variations (e.g., variance and coherency); structural information (e.g., volumetric curvature); and structural uncertainty (e.g., chaos).

These attributes are generated using a computational method for the seismic dip field that makes it structurally consistent, thus avoiding conflicting dips commonly resulting from the calculation of the instantaneous dip (Aarre, 2010). In addition to providing the input to variance and 3D curvature, the process also outputs a precise volumetric prediction of structural uncertainty. Discontinuity-enhancing seismic attributes and feature-extraction algorithms are then used to generate a static fault pattern.

We assume a simple model in which the reactivated faults—genetically related to the Tertiary structural inversion—vertically extend into shallower formations, the older set is confined within the chalk section, and the fractures caused by slumping are more disorganized than the ones associated to the more recent set. Azimuthal filters can be applied to separate sets of different orientation, which can then be analyzed in isolation. Similarly, footprints can be removed if they do not align with geologic features.

The network of lineaments detected on seismic data is quite detailed (Figure 1). Well data (i.e., fracture and fault geometry interpreted from borehole image logs, cores, and production information) are then used to support the interpretation and refine the results through multiple iterations.

Time-Lapse Fault Analysis

With access to time-lapse seismic data, the different vintages can be analyzed for evidence of changes in fault transmissibility properties and reactivation caused by production or injection (Borgos et al. 2009). The detailed fault extraction is repeated using the same parameters on each time-lapse section at locations selected based on production history and observed amplitude response.

The fault population is expected to change on the different surveys and the difference can be qualitatively analyzed with reference to the production history using a statistical approach. A requirement for reliable comparison of the results is to have high-quality 4D repeatability. Changes in the seismic response can also be investigated along the major fault surfaces assuming we achieve a precise representation of their geometry.

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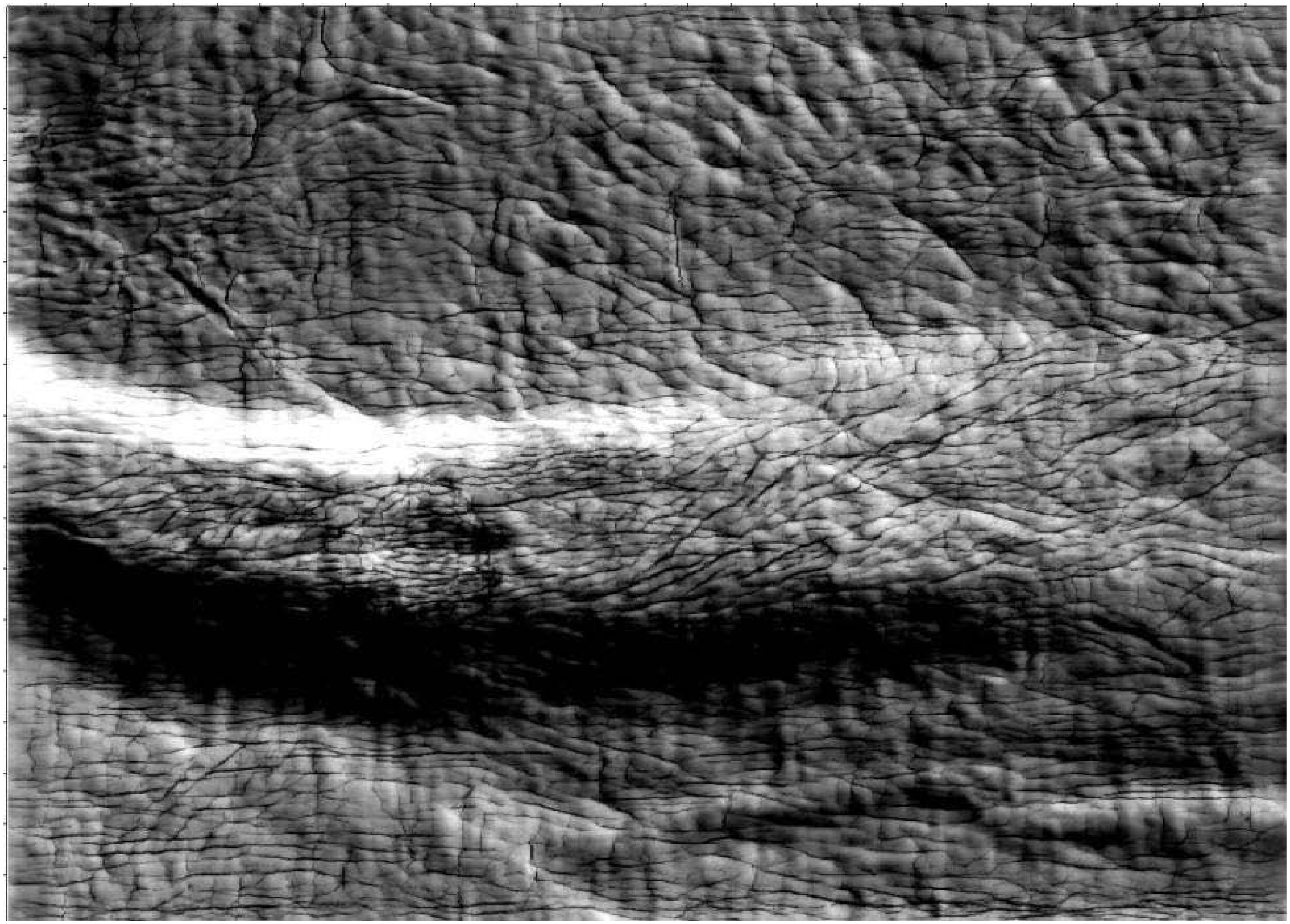

Figure 1. Fault detection along the top chalk: preliminary results.