Advanced Automatic Seismic Detection of Structural Features in Carbonate Reservoirs: Technology Overview, Validation and Application on a Libyan Offshore Case Study*

Filippo Tosoratti[1], Antonio Corrao[2], Massimo Fervari[2], Corrado Magistroni[2], and Vincenzo Milluzzo[2]

Search and Discovery Article #40825 (2011)
Posted November 7, 2011

*Adapted from extended abstract prepared in conjunction with oral presentation at AAPG International Convention and Exhibition, Milan, Italy, October 23-26, 2011

[1]eni E&P, San Donato Milanese (MI), Italy (filippo.tosoratti@eni.com)
[2]eni E&P, San Donato Milanese (MI), Italy

Abstract

Structurally complex carbonate reservoirs often challenge geophysicists with a difficult interpretation; “standard” approaches usually consist of manual interpretation and picking of faults and discontinuities: even if greatly assisted by advanced seismic attributes (continuity, curvatures, etc.) it can still be very time-consuming and the result can be too subjective (based on the interpreter’s experience). Moreover - and hence the purpose of the proposed workflow - we always fail to effectively capture, represent, and summarize the huge amount of information contained in the seismic data and its derived structural attributes.

This is particularly true for sub-seismic structural features, which might carry a lot of useful information and yet are hard to detect and properly describe. Therefore, they are very susceptible to interpreter’s subjectivity or to the risk of being simply discarded. In this frame, we present the experience built in several case studies from offshore Libya, pertaining to Eocene bioclastic carbonate reservoirs in a structurally complex area.

Although complex and challenging interpretation, the target reservoirs are generally well imaged and seismic data has proven to be reliable in the area. These facts, together with extensive knowledge of the area, represent the premises of the present paper.

A new approach for automatic extraction of structure-related heterogeneities from seismic data has been developed, providing a simple, but robust and effective, volumetric representation of the huge amount of information spread in the standard geometric attributes.

The methodology was tested and benchmarked on a well-known Libyan field, where extensive studies had been carried out in the past using several seismic datasets and approaches to properly describe the structural complexity of the reservoir. In parallel to this, an advanced structural

study, supported by manual interpretation, was carried out as a reference.

Comparison of results from the two approaches validated the robustness of the proposed workflow, which then was deemed ready for application to a new dataset.

A nearby field, with similar characteristics (Eocene bioclastic carbonates) and complexities, was an ideal candidate for application; practical outcomes of the new approach (robust description of sub-seismic heterogeneities) contributed to the seismic reservoir characterization and, ultimately, improved the quantitative description used in the reservoir modeling study.

Introduction

Structurally complex carbonate reservoirs often challenge geophysicists and geologists with a difficult interpretation; “standard” approaches usually consist of manual interpretation and picking of faults and discontinuities: even if greatly assisted by specific seismic attributes (continuity, curvatures, etc.) they can still be very time-consuming and the result can be too subjective or biased by the interpreter’s experience. Moreover – and hence the purpose of the proposed workflow – we always fail to effectively capture, represent, and summarize the huge amount of information contained in the seismic data and its derived structural attributes.

This is particularly true for sub-seismic structural features, which might carry a lot of useful information and yet are hard to detect and properly describe. In the last years we have developed a well tested workflow which, starting from the manual interpretation of the continuity time-slices and analyzing the results with a statistical approach, allows to obtain structural information from the sub-seismic features. Although reliable and extensively tested, this approach is still very susceptible to interpreter’s subjectivity and extremely time consuming.

On these premises, we propose a new automatic approach, built on top of the manual workflow for detection of seismic structural heterogeneities, providing a simple, but robust and effective, volumetric representation of the huge amount of information spread in the standard geometric attributes.

We present a case study from offshore Libya pertaining to Eocene bioclastic carbonate reservoirs in a structurally complex context. Good knowledge of the area, reliable seismic data, and successful application of the manual approach on several fields made offshore Libya area a good candidate for testing the proposed automatic workflow.

Methodology Overview

We propose a seismic characterization workflow (Figure 1) that comprises the following steps:

1. **Structural seismic attribute computation**: to highlight structural features a suitable attribute is computed first. Available choices include coherency-like attributes and most positive or most negative curvature (Al-Dossary et. al., 2006). As far as the methodology is concerned, any attribute which is deemed structurally relevant can be used (Figure 2a).

2. **Volumetric scan and lineaments picking stage**: the attribute volume is scanned and lineaments are detected and collected. Each identified lineament (described by its start/end coordinates and attribute intensity) is stored in a database which serves as input to compute all the following deliverables.

3. **Lineament volume**: the lineaments database is used to 'fill' a 3D volume, the Lineaments volume, with a pictorial representation of all collected lineaments. Such volume can be overlaid with transparency on top of the structural attribute computed in step 1, and sliced (either along Z slices or along interpreted surfaces) to verify the quality of the automatic picking (Figure 2b).

4. **Rosette volume**: the lineaments database is used to compute a statistical analysis of the lineaments (rosette diagrams), which is then graphically rendered as a 3D volume. Such volume can be overlaid with transparency on top of the structural attribute computed in step 1, and sliced (either along Z slices or along interpreted surfaces). Animating a Z axis slice thru the volume will give insights on the tectonic trends present in the area (Figure 2c).

5. **Attributes**: the lineaments database can be used to compute a few attributes, the most prominent being a lineaments density one (expressed as the total length of lineaments falling inside an area within a search radius at analysis location). Figure 4a shows a combined visualization of lineaments density attribute and rosette volume.

It is important to notice that all deliverables at step 3-5 can be computed using either the entire population of collected lineaments or a properly selected subset: for instance an azimuthal range selections can be imposed to retain only lineaments associated with relevant trends; weak (in terms of seismic attribute response) or short lineaments can be included in the analysis or removed, and so on. The methodology supports a "pick lineaments once" (step 2), "analyze many times" (step 3-5) approach.

Western Offshore Libya - Geological Setting

The Western Libyan offshore constitutes a good candidate for validation and testing of the proposed workflow, because of geological characteristics, quality of seismic data and, last but not least, the extensive knowledge built on the fields of the area.

The area of interest lies in the central part of the Gabes-Tripoli-Misurata Basin (GTMB), one of a system of intracratonic pull-apart basins existing on the North African margin, initiated in Middle Jurassic to Lower Cretaceous with the opening of central Atlantic and the eastward movement of Africa relative to Europe. Subsequent changes in direction and rate of relative movement of Africa and Europe have controlled subsidence, fault reactivation and tectonic inversion episodes in the basin. The GTMB has been characterized by strong subsidence phases throughout its history, resulting in the deposition of a thick Mesozoic-Cenozoic sedimentary cover. More in particular, it recorded a minimal clastic input throughout the Cretaceous, resulting in the development of carbonate ramps with local reefs/shoals on structural highs. Paleocene and Late Eocene marked a rapid subsidence related to renewed rifting, interrupted in the Late Paleocene/Early Eocene by an uplift episode, with erosion of intra-basinal highs. Early Eocene records a widespread marine transgression, with deposition the Farwah Group: platform/ramp carbonates and shales in deeper waters. This is the setting of our reservoir rocks: shallow water carbonates, with high energy bioclastic carbonate deposition on the existing structural highs.

After Middle Eocene, the GMTB underwent a more or less continuous subsidence, particularly significant throughout the Neogene and recorded by the deposition of thick siliciclastic sequences, with subordinate carbonates and evaporites, and by the gradual infill of the accommodation space. The basin was affected by the development of the Alpine collision up North, and by the eastward movement of the African plate with respect to the European plate.

Both studied fields consist of Lower Eocene bioclastic (nummulitic) carbonates, deposited in shallow waters on existing structural highs. They record the various rifting, compressional, and wrench tectonics phases succeeded in the area with a complex pattern of structural features; perhaps the most striking are the NNW-NSE lineaments, organized in distinct deformation zones and showing a counter-clockwise rotation of the stresses in the eastward direction.

Test Case

The automatic workflow was first tested on an offshore Libya field, where the results of the manual workflow were available for comparison. The lineaments derived from the automatic extraction were checked with the manually interpreted lineaments in terms of strike, distribution (rose diagram), and density (P21 maps). The results are comparable and so we can assess that the automatic workflow works properly (Figure 3).

Workflow Application

A nearby field, with similar characteristics (Eocene bioclastic carbonates) and complexities, was an ideal candidate for application. Parameterization was optimized on this specific area of study.

The main structural lineaments characterizing the field are clearly captured in a curvature volume (Figure 2a) and show a complex pattern of faults trending NNW-SSE in the western part of the field, with a rotation to a NW-SE trend further east. This rotation, combined with a sinistral strike-slip character of the regional structural framework, provides a complex stress pattern which is particularly clearly recorded by the brittle bioclastic carbonates in the top part of the reservoir.

The generated attributes were controlled with results from core fracture analysis from two wells. Although the resolution capability of the two methodologies is not comparable, the results match and are aligned: one well characterized by high core fracture count is located in a particularly "hot" zone (high density of lineaments), whereas the location of the other well (whose cores show much fewer discontinuities) corresponds to a low density area on the attribute volume.

Figure 4b shows on a vertical section the correspondence between high lineament density and structural features.

Although the studied field is not considered a "fractured reservoir" from the engineering point of view (i.e., it does not feature a dual porosity behavior), we believe that it is correct and important to quantitatively include the character, pervasiveness, and distribution of seismic lineaments in the reservoir model, because they must control in some way important reservoir properties as permeability and porosity.

Once assessed that the workflow's output is an effective volumetric representation of the sub-seismic structural lineaments, we suggest using it as a multiplier of reservoir properties. The use of this specific outcome in the reservoir model is currently being evaluated. For sure, it is a very promising technique as it can provide a quantitative use of a seismic attribute directly in the reservoir model, providing a geologically consistent constrain to its static and dynamic behavior description, along with an intuitive and effective volumetric representation of geologic structural features.

References

Al-Dossary S. and K.J. Marfurt, 2006, 3D volumetric multispectral estimates of reflector curvature and rotation: Geophysics, vol. 71, p. 41-51.

Cappanera, F., A. Cappalletti, I. El-Ageli, M. Fervari, C. Magistroni, C. Nonesi, F. Porrera, and C. Rizzetto, 2008, Integrated seismic characterization and reservoir modeling in a structurally complex carbonate field, Libyan offshore: 70th EAGE Conference & Exhibition incorporating SPE Europec, Rome, Italy, June 9-12, 2008, CD-ROM of extended abstracts, Paper 1004, 5 p.

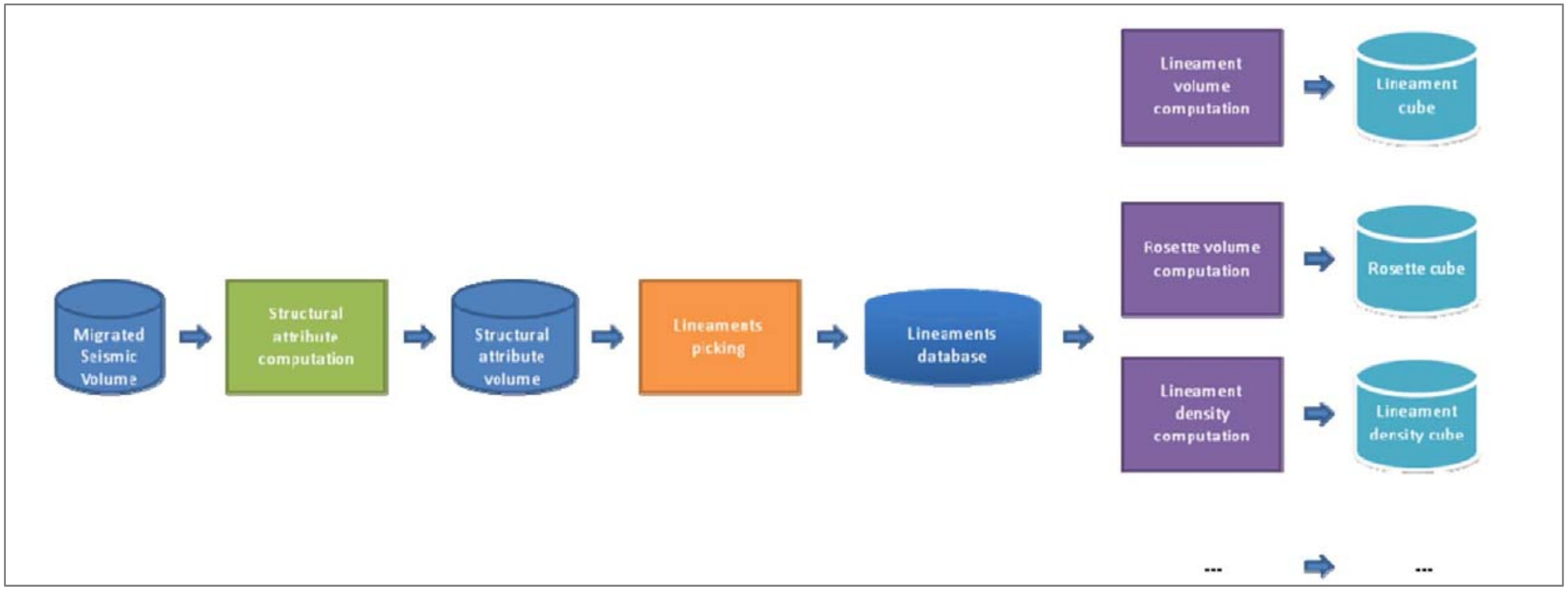

Figure 1. Computation workflow.

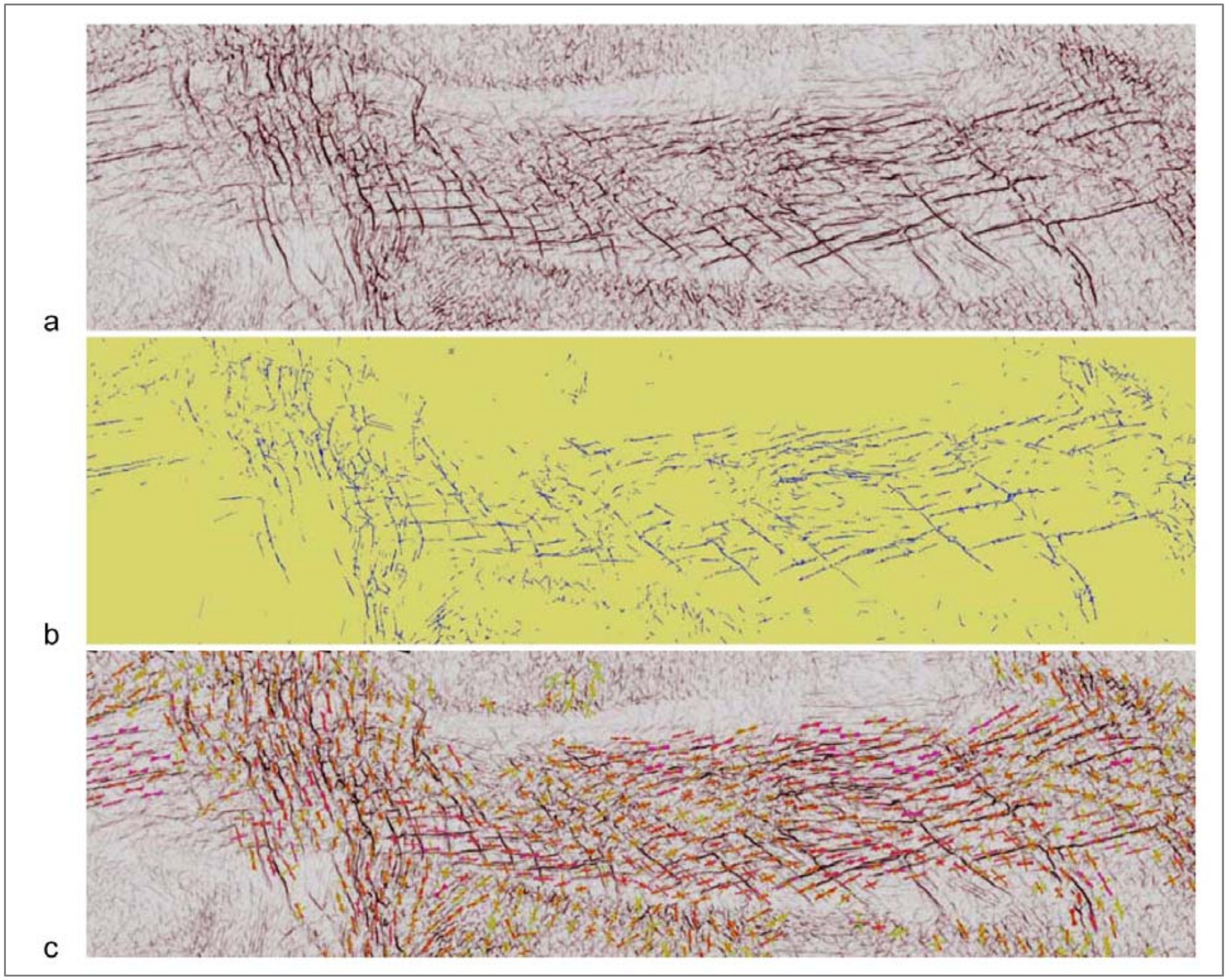

Figure 2. From top to bottom: a) curvature attribute time slice, b) automatically extracted lineaments (lineaments cube), c) rosette cube.

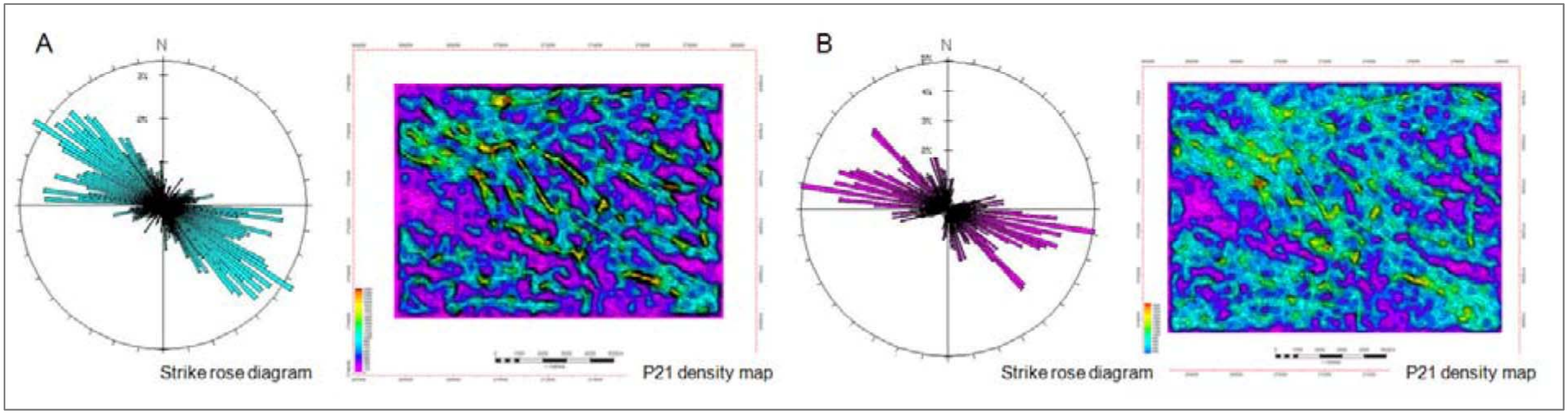

Figure 3. a) Manual workflow lineaments analysis, b) Automatic workflow lineaments analysis.

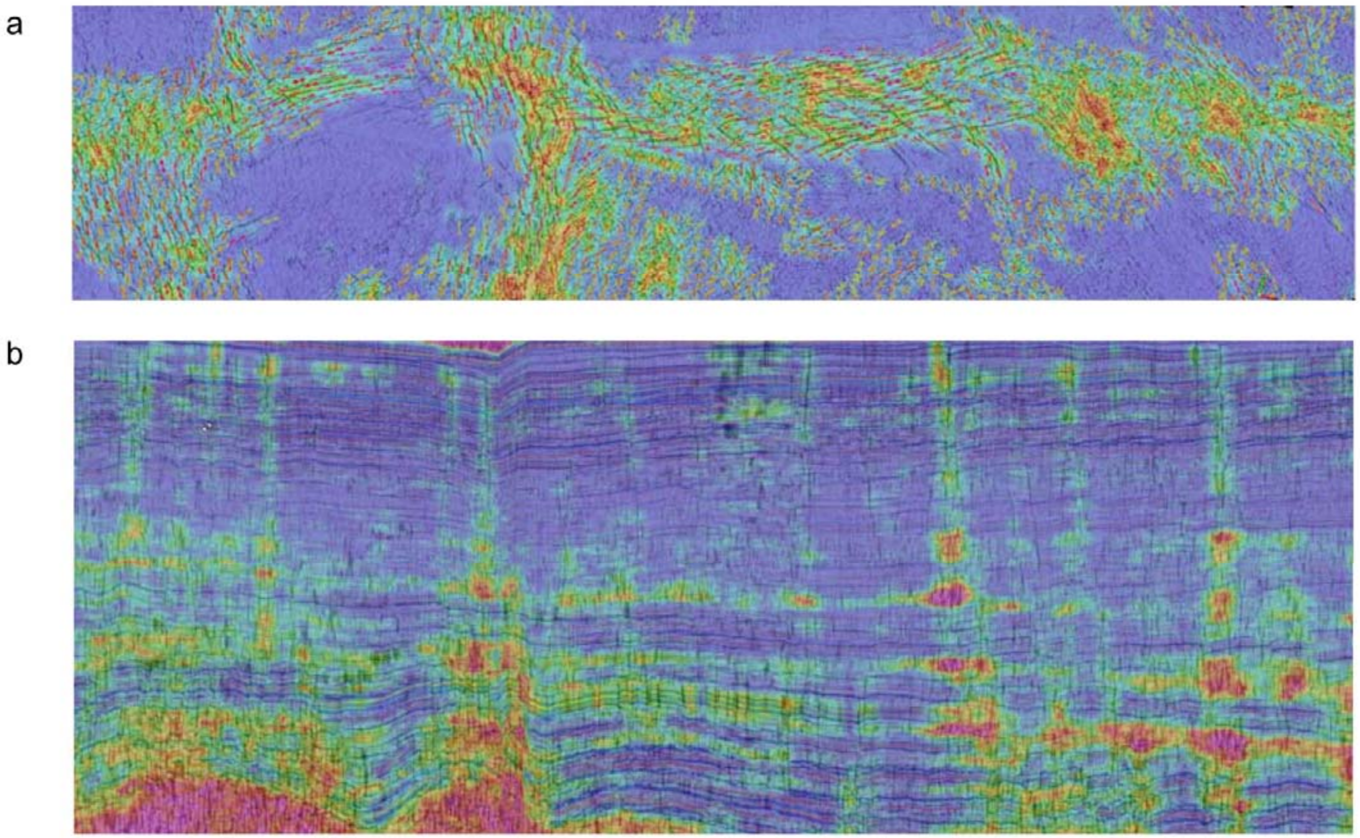

Figure 4. a) curvature attribute time slice with lineament density and rosette cube overlaid on, b) line with migrated seismic data, lineament density and most negative curvature overlay.