

Seismic Dips Help Unlock Reservoirs

By Farrukh Qayyum and Paul de Groot

ENSCHEDÉ, THE NETHERLANDS—Just as unconventional oil and gas resources are becoming ever more prevalent throughout North America and beyond, pressures are increasing on seismic interpretation technologies because of the need to squeeze maximum value out of the 2-D and 3-D data sets generated. This is the case particularly in unconventional reservoirs, with their greater costs required for production, the dramatic variations in reservoir quality and the need to pinpoint high-value sweet spots.

There are a number of specific seismic interpretation challenges as well. Against the background of low permeability that often characterizes such reservoirs, there

is the importance of identifying in ever-greater detail faults that have the potential to divert hydraulic fracturing, as well as the need to understand the role of natural fractures in the fluid flow.

In such circumstances, maximizing the value of seismic data in unconventional reservoirs and accessing geomechanical and petrophysical properties that can help predict the most productive zones rarely has been more important. This is exacerbated by the need to manage costs, particularly with many independent operators having smaller exploration budgets than their larger counterparts.

One seismic attribute—seismic dip—is having an increasing influence on seismic interpretation and on applications for unconventional reservoirs.

Seismic Dip's Importance

Attributes are integral to seismic interpretation, revealing otherwise hidden geological information and allowing relevant information to be extracted for integration purposes. Seismic dip belongs to the category of geometric attributes. These attributes help seismic interpreters improve the visibility of the seismic data, as well as its structural and stratigraphic interpretation.

Seismic dip (and azimuth) are useful attributes, but other geometric attributes—such as similarity, coherency and continuity—generate sharper images of faults, fractures and stratigraphic features. The real importance of seismic dip is that it allows for the analysis and processing of seismic data in the stratigraphic domain. With a process called dip-steering, it is possible to create a virtual horizon along the (paleo-) sedimentation surface from any starting position in a 2-D or 3-D seismic data set. This opens the way to the seismic dip-derived applications of:

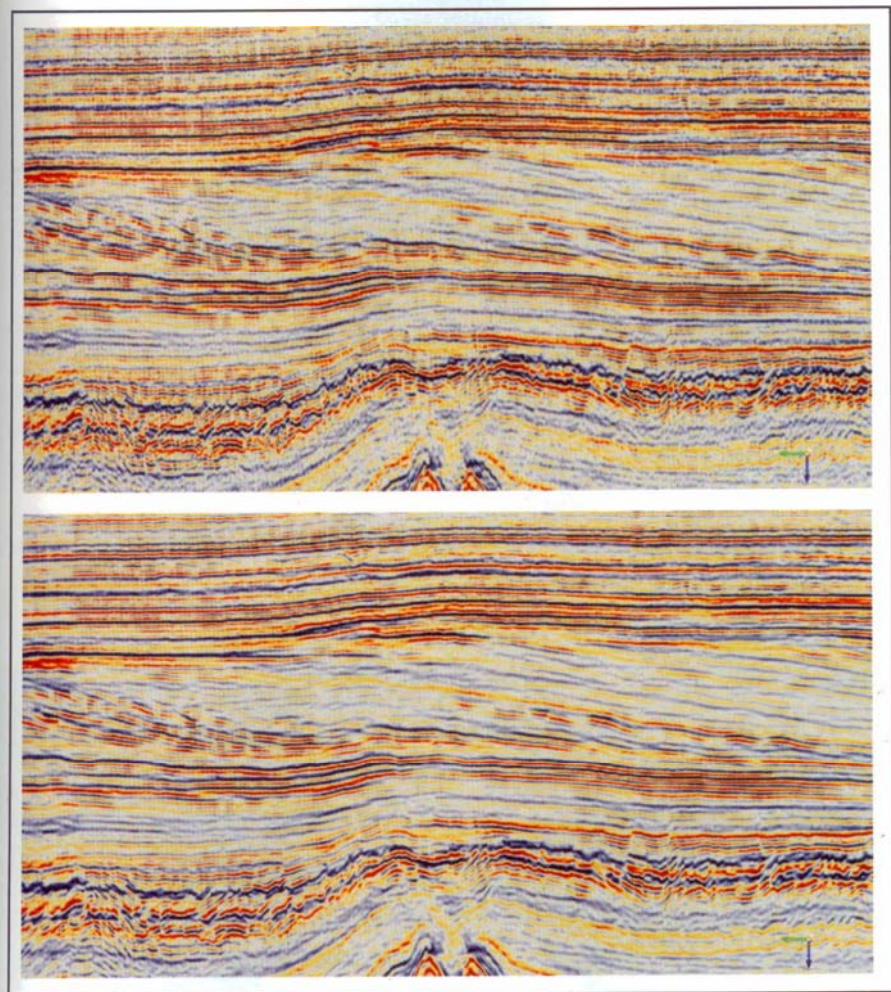
- Dip-steered filtering;
- Dip-steered geometric attributes;
- Volumetric curvature attributes; and
- Applications within a new technology that auto-track a dense set of mapped 3-D stratigraphic surfaces.

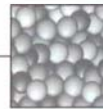
The first three applications track the seismic dip field in a restricted (user-defined) radius from the evaluation point. Typically, a radius of one to four traces in all directions is used, which allows on-the-fly calculations and analyses.

Advanced interpretation technology allows the dip-steering process to be extended over much larger areas. Typically, tracking continues throughout the entire survey area and the process is therefore run in batch mode. The processed result represents a volume that consists of a dense set of correlated 3-D stratigraphic surfaces.

The technology impacts all aspects of seismic interpretation and allows the interpreter to extract more geology from the data. The result can be used for detailed geologic model building, improving seismic inversion, and sequence stratigraphic interpretation and well correlations, and allows visualization and extraction of high-resolution intrareservoir features. It has significant applications for all reservoirs, including unconventional formations.

FIGURE 1
Seismic Data Before (Top) and After (Bottom) Dip-Steered Median Filtering





Dip-Steered Filters

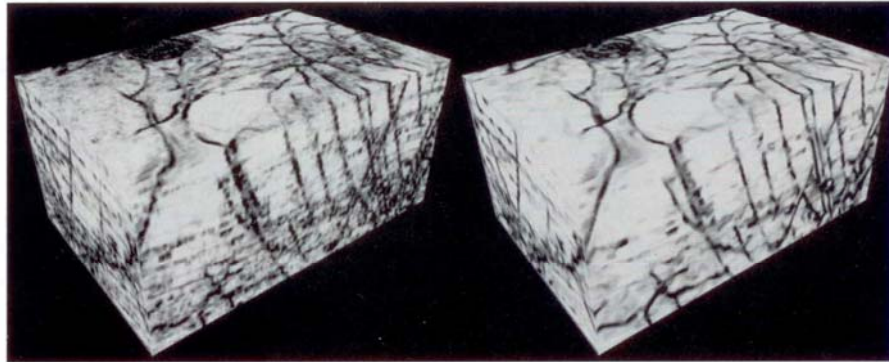
Dip-steered filters, also known as structurally oriented filters, are post-stack filters used to clean seismic data and/or to sharpen edges. Popular dip-steered filters include median, diffusion and fault-enhancement filters. A median filter removes random noise and enhances laterally continuous events. The edge-preserving properties of a median filter ensure that breaks in the data (faults) are not distorted. Figure 1 shows the effect of a median filter.

A diffusion filter evaluates the quality of the seismic data through the similarity attribute. Seismic responses of clean areas (high similarity) are moved along the reflector dip toward areas of low similarity. By this process, the fuzzy zones that often are present at either side of faults are filled by extending the seismic reflectors. Diffusion filters effectively are sharpening faults, but they also tend to distort seismic amplitudes in areas of good seismic quality. This effect is reduced in the fault enhancement filter, which is a logical filter that combines the median filter with the diffusion filter. The median filter is applied in good quality data areas (high similarity), while the dif-

FIGURE 2
Similarity Attribute on a Mapped Horizon Before (Top) And After (Bottom) Fault Enhancement Filtering



FIGURE 3
Enhancing a Fault Volume by Dip-Steered Filtering, With Original Fault Volume (Left) and Dip-Steer Filtered Volume (Right)



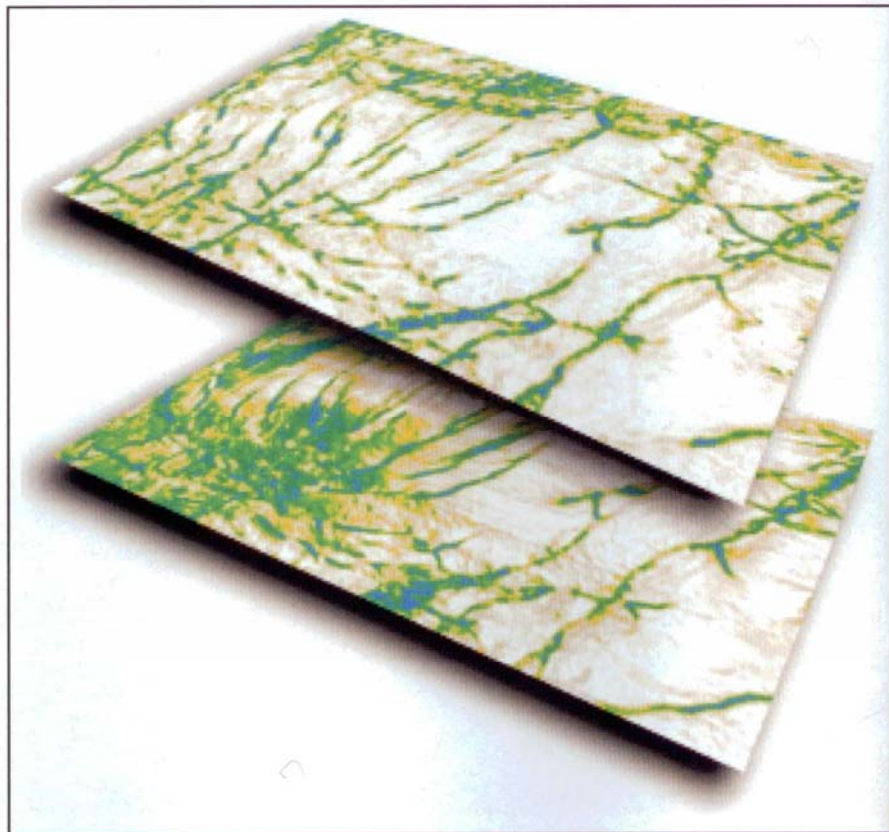
fusion filter is applied in low-quality areas (low similarity). The effect of a fault enhancement filter is shown in Figure 2.

Dip-steered filtering normally is applied only to seismic volumes (Figure 3). Provided the dip of a fault attribute volume (such as similarity) is known, similar filters can be applied to clean fault cubes.

Geometric And Curvature Attributes

Geometric attributes are multitrace attribute computations. Around each evaluation point, a small subvolume of seismic data is extracted to serve as input for the attribute calculation algorithm. The simplest way to extract the subvolume is to use a constant seismic time (depth) gate.

FIGURE 4
Seismic Time Slice Showing a Similarity Attribute, With Upper Image Showing Dip-Steered Similarity and Lower Image Showing Horizontally Extracted Similarity



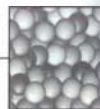


FIGURE 5
Most Positive Curvature Attribute Used to Map
Subseismic Scale Faults and Fractures

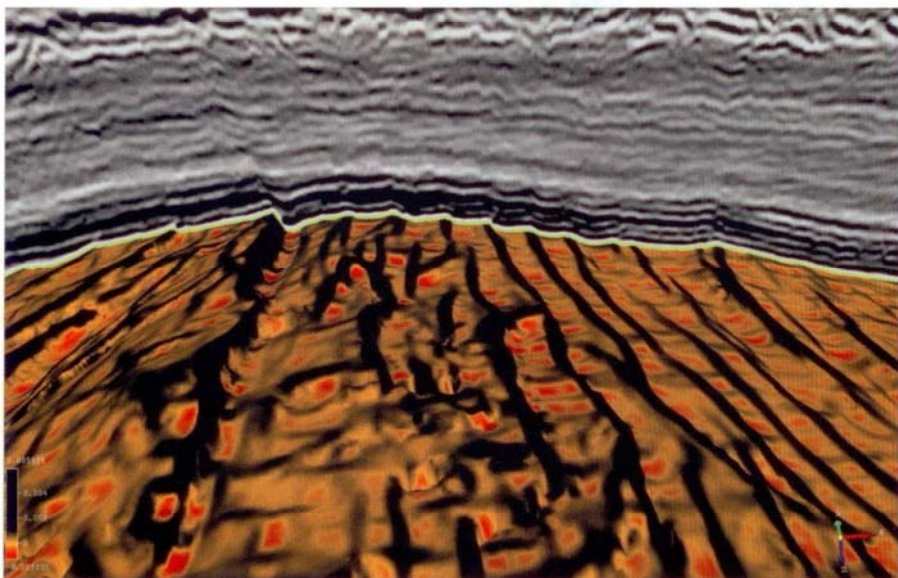
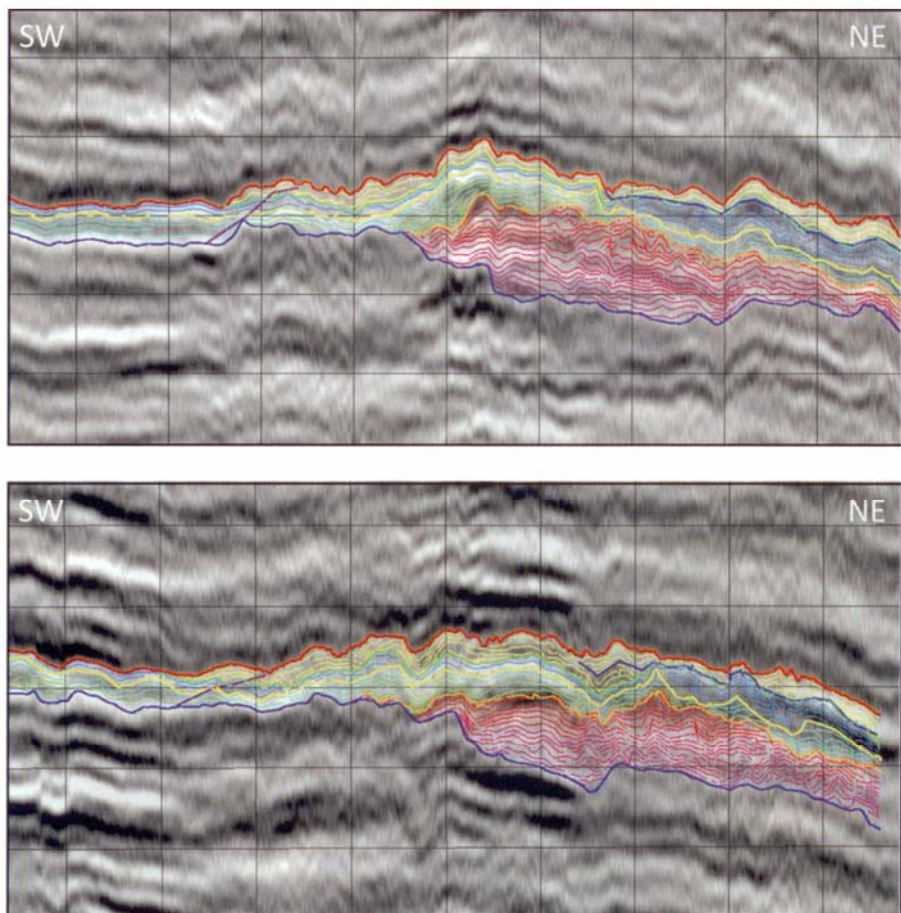


FIGURE 6
Seismic Sections Through a Reef Complex With Auto-Tracked Horizons



In the case of dipping strata, this means that seismic time gates pertaining to parts of the geologic sequence are combined. The resulting attribute response becomes more difficult to interpret. Figure 4 shows the effect of using dip-steering on a similarity attribute. In areas of steeply dipping strata, the horizontally extracted similarity breaks down while the dip-steered similarity shows much sharper fault images.

Curvature attributes measure the amount of bending in a two-dimensional surface. There are a wide variety of derived curvature attributes—from the maximum curvature that defines the largest absolute curvature, to the minimum curvature that defines the smallest absolute curvature through to the shape index, which is a combination of maximum and minimum curvature and describes the local morphology of the surface, independent of scale.

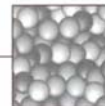
Historically, curvature attributes were restricted to mapped horizons, but through seismic dip and the process of dip-steering, curvature attributes now are routinely computed directly from the seismic data without the need for mapped horizons. Curvature attributes are able to provide important seismic information to the interpreter, measuring the degree of surface curvature and/or volume, and through this, mapping subtle faults and fractures below the resolution of seismic data.

What is particularly applicable to unconventional reservoirs is the fact that curvature tends to correlate with increased fracture density, which often can lead to increased fracture-related permeability. High curvature also can have negative influences on reservoirs, such as the continuous curvature of fractures, for example, leading to heightened top-seal risk and broad curvature near faults leading to fault-seal risk. This is information interpreters need to know when exploring unconventional reservoirs.

Furthermore, with many unconventional reservoirs generating large seismic data sheets, curvature attributes can help identify and map specific structures and determine the size, geometry and degree of reservoir compartmentalization to better identify sweet spots. Figure 5 shows that subtle faults with little or no fault-throw are detected clearly by the most positive curvature attribute.

Identifying Sweet Spots

New technologies impact all levels of seismic interpretation. These interpretations are used for:



- Detailed geologic model building;
- Low-frequency model building for seismic inversions;
- Well correlations; and
- Wheeler transformations (flattening) and sequence stratigraphic interpretation.

Identifying sweet spots is crucial to success in unconventional plays. In many cases, conventional seismic trackers cannot be used to identify and map intrareservoir features of interest. In situations where seismic amplitudes vary laterally, conventional amplitude and similarity trackers break down. Seismic dip does not suffer from these limitations. A dip field is a continuous field that can be smoothed by filtering and tracked to extract information at an unprecedented scale.

Figure 6 shows an example case study over a field offshore Abu Dhabi that is producing from a complex reefal and shoal limestone buildup. High production rates are tied to discrete zones. Conventional auto-trackers could not be used to map intrareservoir details. The results obtained from a study utilizing the new interpretation technology provided a clear image of reservoir geometries and facies distribution within the reef core body. The study had a significant impact on the accuracy of the field's geologic model, on which basis economic field development decisions are made.

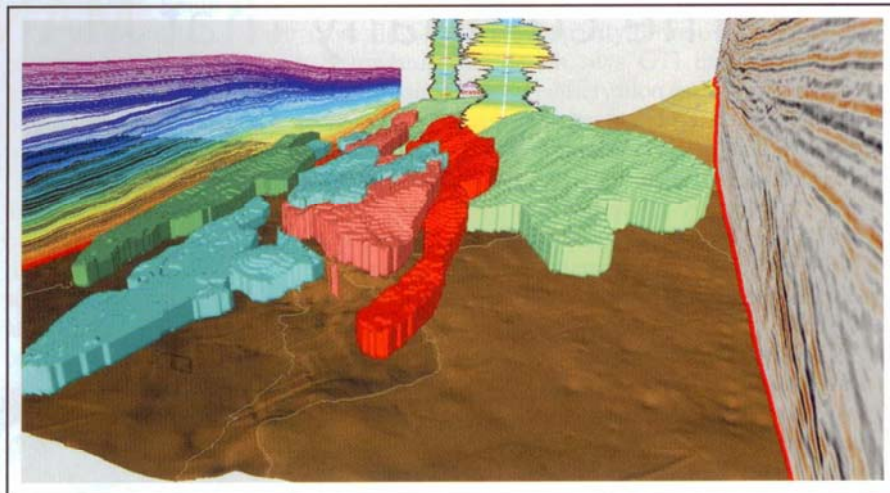
Another example of mapping geologic features at the intrareservoir scale level is presented in Figure 7. In this example from the Dutch offshore, the seismic interpretation technology covers a sequence comprising deposits of a fluviodeltaic system that drained large parts of the Baltic Sea region. The deltaic package consists of sand and shale, with an overall high porosity (20-33 percent). Some carbonate-cemented streaks are present.

With the help of the new interpretation technology, a sequence stratigraphic analysis was performed. Slumped deposits belonging to a falling stage systems tract were identified as potential reservoir bodies. Mapping these 3-D bodies was done with a novel tool that supported interactive analysis of isopach variations between pairs of horizons.

Computing Seismic Dip

Having seen the importance of seismic dip, it also is important for those values to be computed accurately. There are many ways to compute seismic dip. With the seismic interpretation software used to generate the examples in this article,

FIGURE 7
Slumped Bodies Extracted From Seismic Interpretation Technology In the Baltic Sea Off The Netherlands



three main algorithms are supported:

- The complex trace analysis method using the Fast Fourier Transform algorithm;
- The event-steering algorithm, a discrete scan method; and
- The fast steering gradient structure tensor-based method that is named BG Fast algorithm after BG Group, which invented this method.

As independents look to squeeze the maximum amount from their unconventional reservoir seismic data, seismic dips

are playing a key role. Using seismic dip, it is possible to obtain better quality seismic data and geometric attributes, and to use the family of curvature attributes without needing mapped horizons.

The latest application of seismic dip and the one with potentially the largest impact on the amount of geologic information that can be extracted from seismic data is in its use of auto-tracking hundreds of horizons. The result will be a greater insight into the subsurface and improved exploration returns. □



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Paul de Groot is co-founder of dGB Earth Sciences. He worked for 10 years with Shell, where he served in technical and management positions prior to working at the TNO Institute of Applied Geosciences. He co-founded dGB in 1995. De Groot has authored many papers covering a wide range of geophysical topics, and holds a master's and doctorate degrees in geophysics from Delft University of Technology.