Dip interpolation for improved multi-trace seismic attribute analysis

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Summary

The dip steering has been routinely implemented into the multi-trace seismic data retrieval as well as the associated attribute analysis to avoid interpretational artificial leakages for dipping formations. However, in practice, a seismic section/volume consists of discrete samples, and a dipping horizon does not always be exactly on the defined samples; instead, part of it may fall within two neighboring samples. Traditionally, such misfit is addressed by simply approximating the horizon location to its nearest sample, which is not geologically reliable and runs the risk of decreasing the attribute resolution, especially when the seismic reflection significantly changes from sample to sample in the time/depth dimension. This study implements the interpolation for accurately retrieving the seismic signals along reflector geometry to resolve the low resolution due to simple approximation. Applications to the F3 seismic dataset over the Netherlands North Sea demonstrate the associated improvements in the multi-trace seismic attribute analysis, including the discontinuity and curvature attributes for fault interpretation in the subsurface.

Introduction

Reflector dip has been commonly taken into account for multi-trace seismic attribute analysis of a dipping formation to avoid artificial structural leakages (Marfurt et al., 1998; Marfurt and Alves, 2015), such as discontinuity, GLCM texture, and geometric curvature and flexure attributes. In general, at every sample in a seismic section/volume, the dip-steered multi-trace attribute analysis consist of two steps: first, the dip magnitude serves as the vertical shift for retrieving the seismic signals over the adjacent traces within a defined lateral window; second, the seismic attribute is calculated from the retrieved data segments. Therefore, the dip steering ensures the geological consistence of the retrieved seismic signals along a dipping horizon, and the attribute resolution is greatly dependent on the accuracy of the dip-steered data retrieval.

In practice, seismic sections/volumes contain discrete samples, and correspondingly, it is observed that a dipping horizon does not always lie on the defined samples; instead, part of it may be within two neighbouring samples. In such case, there is no seismic signal available on the desired reflector locations, and the traditional solution is to simply approximate them to the nearest sample. However, such approximation deviates from the actual horizon locations and thereby runs the risk of inaccurate multi-trace data retrieval as well as the associated seismic attribute analysis. Figure 1 illustrates such limitation.

For resolving such limitation, this study proposes implementing the interpolation into the multi-trace seismic attribute analysis, which avoids the inaccurate data retrieval along dipping horizons and thereby enhances the resolution of the attribute images. Such improvement is verified through applications to a subset of the F3 seismic dataset over the Netherlands North Sea, which is featured with multiple salt domes as well as the associated faults and fractures in the subsurface.

Methodology

In a seismic volume, for a given horizon, let function \( z=[i, j] \) represents the location of the horizon at the \( i^{th} \) inline and \( j^{th} \) crossline, and vector \( v=[v_i, v_j] \) represents the measured dip along inline and crossline directions, then the desired horizon locations at the adjacent traces are evaluated as,

\[
\begin{align*}
    z(i \pm 1, j) &= z(i, j) + v_i \cdot d_x \\
    z(i, j \pm 1) &= z(i, j) + v_j \cdot d_y
\end{align*}
\]  

(1a)  
(1b)

in which \( d_x \) and \( d_y \) denote the spacing interval along inline and crossline directions, respectively. Correspondingly, the four locations are on the same horizon, and retrieving the seismic data at these locations...
Dip interpolation for improved multi-trace seismic attribute analysis helps best preserving the seismic reflection along the target horizon, without interferences from the upper/lower geologic formations.

However, for discrete seismic data, it is possible that \( z(i \pm 1, j) \) and/or \( z(i, j \pm 1) \) may not be exactly on the defined seismic samples. Take the \( z = z(i+1, j) \) for example, and assume the seismic amplitude \( d \) is the signal for retrieval. Let \( z^- \) and \( z^+ \) represent the samples above and below the estimated location, respectively; similarly, the corresponding amplitude is denoted as \( \hat{d} = d(i+1, j, z^-) \) and \( \ddot{d} = d(i+1, j, z^+) \), respectively. Then the seismic amplitude at the estimated location \( d(i+1, j, z) \) is calculated by interpolating the amplitude between \( \hat{d} \) and \( \ddot{d} \). Among various interpolation algorithms, this study implements the simplest linear interpolation, which calculated \( d(i+1, j, z) \) as

\[
d(i+1, j, z) = \hat{d} + (z^- - z) \frac{\ddot{d} - \hat{d}}{z^+ - z}
\]

To be clear, there exist a suite of methods for dip estimation from 3D seismic data (e.g., Barnes, 1996; Hoecker and Fehmers, 2002; Marfurt et al., 1998; Marfurt, 2006), and the phase dip algorithm is implemented in this study for providing the vector dip used in this study.

**Examples**

We use a subset of the F3 seismic dataset over the Netherlands North Sea to demonstrate the effect of interpolation on dip-steered multi-trace seismic attribute analysis, Figure 2 displays the amplitude in the vertical section of inline 320 and the time slice at 1660 ms, from which numbers of faults can be identified. First, we perform the Canny edge detection (Di and Gao, 2014) to the dataset and Figure 3 displays the corresponding discontinuity maps, in which (a) and (b) are the images without interpolation, but simply approximating to the nearest samples, whereas (c) and (d) are the images with interpolation. It is clear that dip interpolation helps improve the quality of the attribute maps (denoted by circles), where the artificial lineaments due to inaccurate amplitude/waveform retrieval from dipping beddings are eliminated and the faults are highlighted more clearly.

![Figure 2: Vertical section of inline 300 (a) and time slice at 1660 ms (b). The seismic amplitude of the F3 seismic dataset over the North Sea used for demonstrating the effect of dip interpolation on multi-trace seismic attribute analysis.](image-url)
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Besides the discontinuity attribute, the proposed dip interpolation is also applicable to the high-order geometric attribute analysis, such as the curvature and flexure. The major difference lies on the target seismic information for retrieval. In particular, the former retrieves the seismic amplitude and/or waveform, whereas the latter retrieves the reflector geometry. Figure 4 displays the signed maximum curvature maps (Di and Gao, 2016). Compared to the Canny detection (Figure 3), the improvements for the curvature maps are relatively subtle. Such difference may result from the higher sensitivity of waveform/amplitude on retrieval location than reflector geometry, especially in the F3 dataset where the neighbouring reflectors are parallel or subparallel with similar geometry. The effect of interpolation on seismic geometric attribute analysis is expected more apparent in areas with structural complexities, where reflector geometry significantly varies from one location to its neighbours.

Conclusions

The dip steering has been routinely implemented into the multi-trace seismic attribute analysis to help avoid inaccurate data retrieval and artificial structural leakages for dipping formations. Considering the possible misfit between the desired retrieval locations and the nearest seismic samples, the data interpolation not only ensures the consistence of the retrieved seismic signals in geology, but also further improves the accuracy and resolution of the generated attribute images.

Acknowledgements

Data from the North Sea was downloaded from the OpendTect Open Seismic Repository (opendtect.org/osr), where it is available under a creative commons BY-SA 3.0 license.
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Figure 4: Sections of the signed maximum curvature, vertical section of inline 300 (a, c) and time slice at 1660 ms (b, d). Comparison of the dip-steered signed maximum curvature analysis without (top) and with (bottom) interpolation of reflector geometry. Note the enhanced delineation of faults (denoted by circles).
REFERENCES


