PS A New Analytical Method to Evaluate Maximum Flexure for Improved Fracture Characterization from 3-D Seismic Data*

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Abstract

In 3-D seismic interpretation, maximum flexure is one of the most useful attributes for depicting the geometry of seismic reflections and detecting fractures in the subsurface. There are various approaches to evaluating maximum flexure from 3-D seismic data that are different in accuracy and efficiency. This study presents a new analytical solution to maximum flexure from 3-D seismic data. The new approach transforms the original co-ordinate system to a new one so that an analytical equation for maximum flexure can be easily derived in the transformed co-ordinate system. The advantage of the analytical approach is demonstrated through application to a fractured reservoir at Teapot Dome (Wyoming). Our new algorithm is analytically accurate and computationally efficient. In particular, the magnitude of maximum flexure illuminates faults and fractures more clearly than previous algorithms; whereas the associated azimuth makes it possible to automatically plot histograms and/or rose diagrams for defining fracture orientations, which is fundamental in fractured reservoir characterization and prediction.

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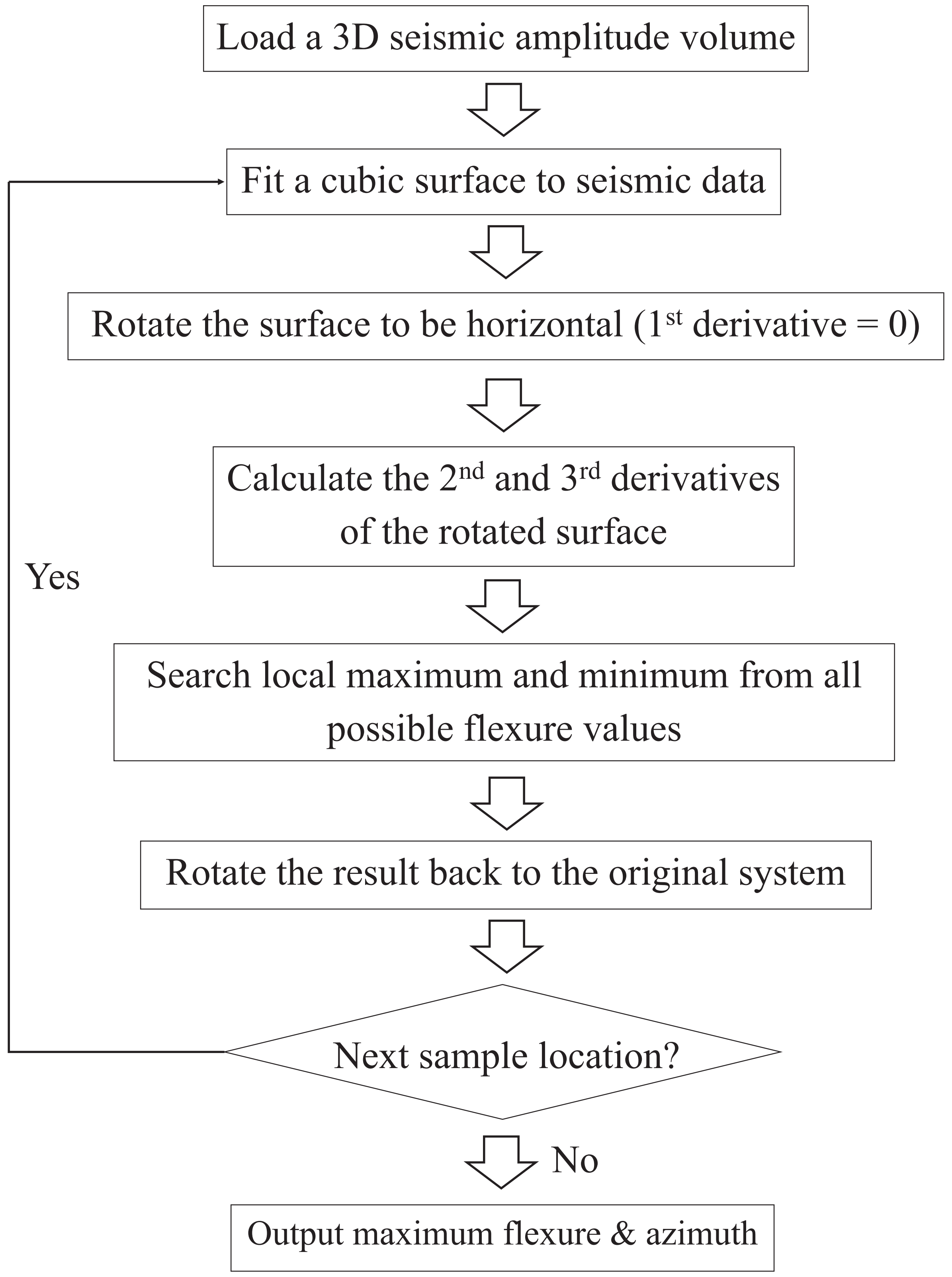
Algorithm



Load a 3D seismic amplitude volume

Fit a cubic surface to seismic data

Rotate the surface to be horizontal (1st derivative = 0)

Calculate the 2nd and 3rd derivatives of the rotated surface

Search local maximum and minimum from all possible flexure values

Rotate the result back to the original system

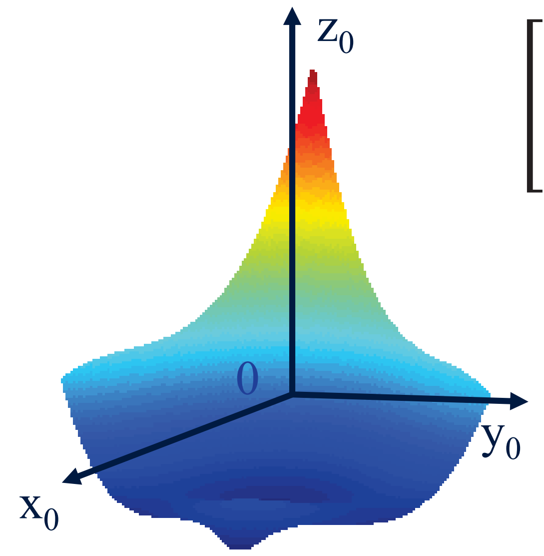
Next sample location?

Yes

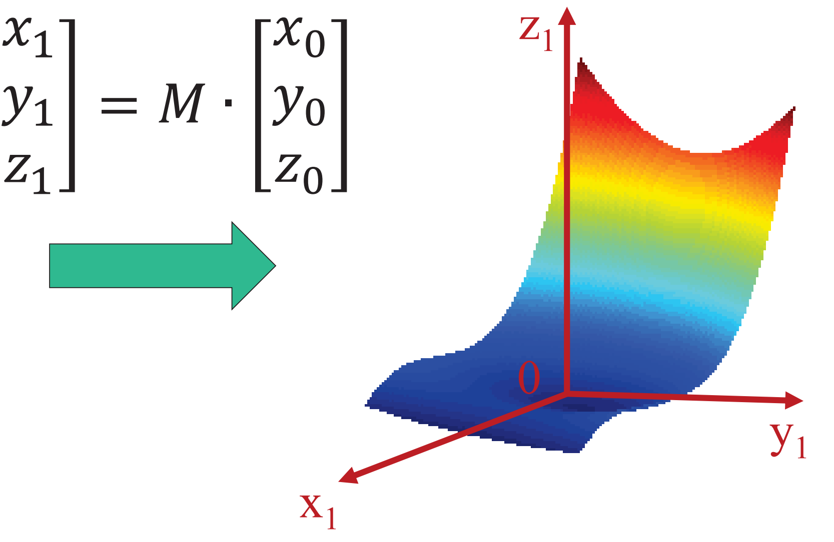
No

Output maximum flexure & azimuth

Surface rotation



$$\begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} = M \cdot \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix}$$



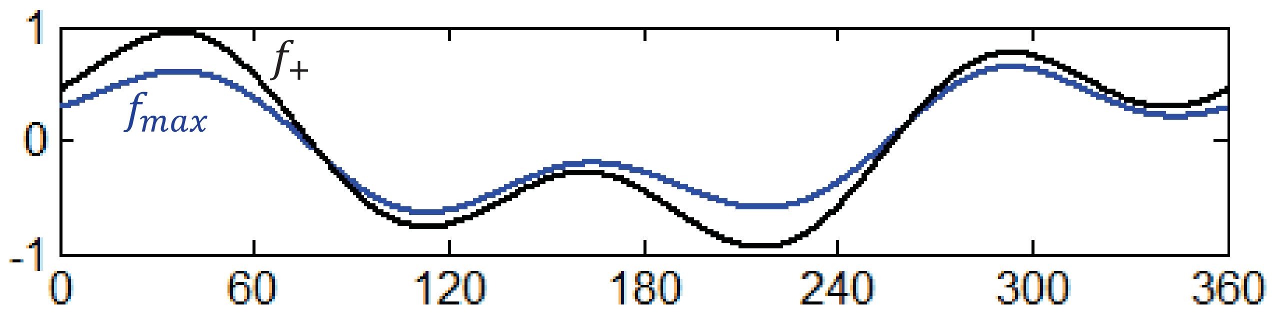
M: Rotation matrix

Abstract

In 3D seismic interpretation, maximum flexure is one of the most useful attributes for depicting the geometry of seismic reflectors and detecting fractures in the subsurface. There are various approaches to evaluating maximum flexure from 3D seismic data that are different in accuracy and efficiency. This study presents a new analytical solution to maximum flexure from 3D seismic data. The new approach transforms the original co-ordinate system to a new one so that an analytical equation for maximum flexure can be easily derived in the transformed co-ordinate system. The advantage of the analytical approach is demonstrated through application to a fractured reservoir at Teapot Dome (Wyoming). Our new algorithm is analytically accurate and computationally efficient. In particular, the magnitude of maximum flexure illuminates faults and fractures more clearly than previous algorithms; whereas the associated azimuth makes it possible to automatically plot histograms and/or rose diagrams for defining fracture orientations, which is fundamental in fractured reservoir characterization and prediction.

Introduction

- ❖Detecting faults and fractures from three-dimensional (3D) seismic is one of the most significant tasks in hydrocarbon exploration & production;
- ❖Physically, fractures are most likely to develop in zones of abnormal strains often associated with maximum flexure;
- ❖ The traditional azimuth-scanning approach is time-consuming;
- ❖An analytical approach has been developed for faster computation of most positive/negative flexures, which run the risk of overestimating the deformation of greatly-dipping formation.



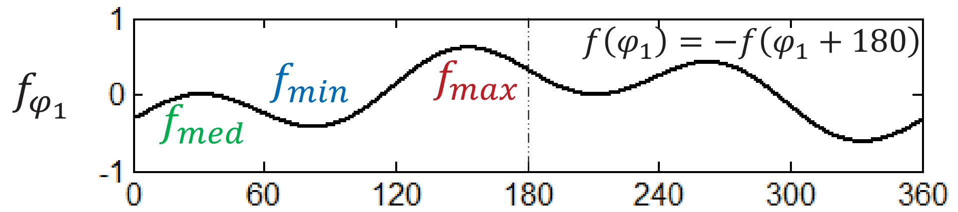
Conclusion

- ❖More accurate and efficient than the traditional scanning process;
- ❖Apply maximum flexure for fracture characterization:
  - Magnitude ------------ intensity
  - Azimuth ------------ orientation
  - Sign ------------ sense of shearing

Analytical solution

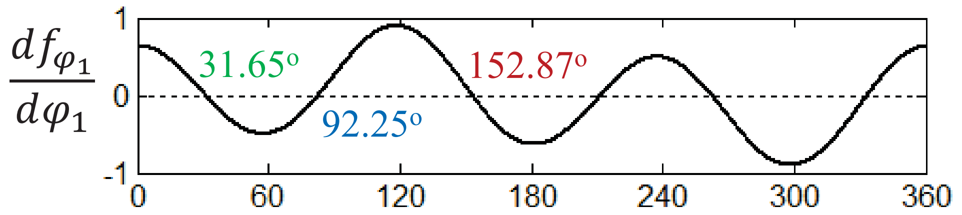
Start from the equation for computing azimuthal flexure:

$$f_{\varphi_1} = \frac{\partial^3 z_1}{\partial {x_1}^3} cos^3\varphi_1 + 3\frac{\partial^3 z_1}{\partial {x_1}^2 \partial y_1} cos^2\varphi_1 sin\varphi_1 + 3\frac{\partial^3 z_1}{\partial x_1 \partial {y_1}^2} cos\varphi_1 sin^2\varphi_1 + \frac{\partial^3 z_1}{\partial {y_1}^3} sin^3\varphi_1$$



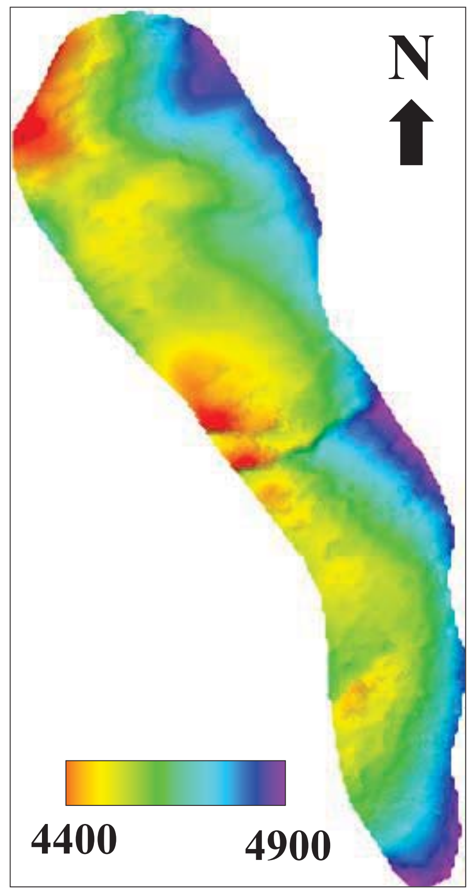
Step 1: Take a derivative with respect to azimuth and obtain $\frac{df_{\varphi_1}}{d\varphi_1}$

Step 2: Solve equation $\frac{df_{\varphi_1}}{d\varphi_1} = 0$ for three roots



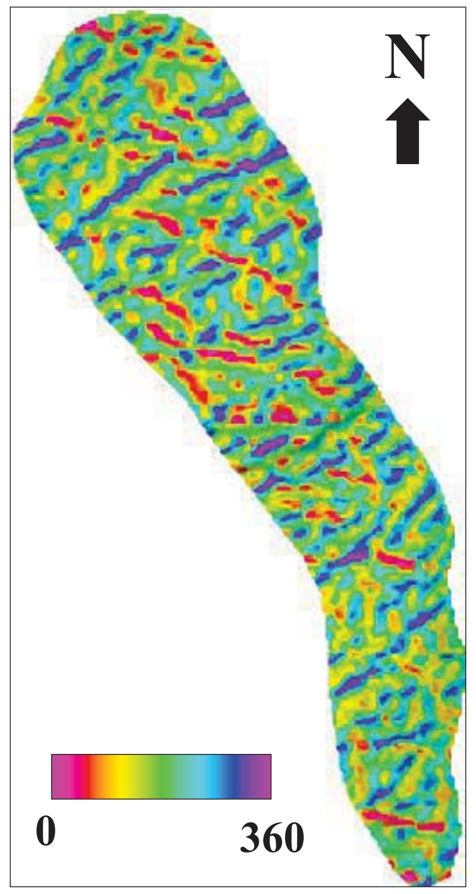
Step 3: Compare and find the maximum from three roots

Results (Teapot Dome)



Horizon structure

Flexure



Flexure azimuth

- ❖ Tight-sand fractured reservoir;
- ❖ Northwest-trending regional thrusting & folding;
- ❖ Northeast-trending cross-regional fractures.