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Interpretation of Seismic data for thrust/fault identification using variance and inverse of variance attribute analysis

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ABSTRACT
Seismic attribute is classically defined as a component extracted from seismic data that can be analyzed in order to enhance the hidden information used to identify a better geological or geophysical prospect in certain depositional environment. Seismic attributes are the components of the seismic data which are obtained by measurement, computation, and by logical or experience based reasoning. It is well established by seismic experts that seismic attributes help visual enhancement or quality of the features of interpretation interest. They became a valid analytical tool for lithology prediction and reservoir characterization. A good seismic attribute is either directly sensitive to the desired geological features or reservoir properties of interest. In this study, variance and inverse of variance attribute analysis has been carried out first for the synthetic data and thereafter applied to the real field seismic data for automatic fault /thrust identification. Synthetic seismic traces are generalized and data has been digitized to calculate the variance on the said seismogram. With the help of MS excel sheet, theoretical formulation has been carried out to study, variance and inverse of variance of different traces using three point window in the excel sheet. After studying the variance and inverse of variance attribute, it is noted that these attributes can provide better identification for fault/ thrust and edge detection. The variance and inverse of variance attribute analysis applied to the real field seismic data for automatic interpretation for thrust/fault identification, has helped in clearly distinguishing the fault locations.

Key words: Seismic data, attribute analysis, three point window, variance and inverse of variance, attribute analysis.

INTRODUCTION

The interactive interpretation of seismic data and attribute analysis can help evaluation of fault pattern and fault location along with the continuity and discontinuity of the traces in seismic sections. In order to bring out meaningful subsurface images the seismic attribute analysis (Chopra and Marfurt, 2007; 2009) with integrated approach of geo-scientific data can play an important role for understanding the subsurface features.

In this study, attribute analysis has been carried out in the Dibrugarh area falling in the Assam-Arakan basin of north-eastern part of India (Samik, 2003). Various attribute studies have been carried out such as- dip deviation, sweetness, local structural dip, local structural azimuth, variance and inverse of variance to study the images and proper structural lineaments of the subsurface. From this analysis it is suggested that the variance and inverse of variance attribute jointly can give the proper picture of the fault and structural edge location.

A theoretical study has been carried out using variance attribute analysis applicable to the synthetic data set. Further, this approach has been applied to the real field seismic data for automatic fault identification. With the help of MS excel sheet, theoretical formulation has been carried out to study mean, variance and inverse of variance for each sample data using a windows shift of 3 data point.

This attribute analysis can be applicable for automatic thrust/fault identification. It has been observed that the fault locations are clearly distinguished through variance and inverse of variance analysis.

METHODOLOGY AND THEORY

The role of variance and inverse of variance play an important role for mapping the thrust and fault identification. As variance is the opposite of coherency it can be calculated through trace to trace variability in a certain sample interval using seismic traces. This produces an interpretable lateral changes in acoustic impedance and leads to low variance coefficients. While in the other case, higher variance coefficients signify higher discontinuities in the case of inverse variance. Thus by studying low variance coefficients and high variance coefficients in seismic signature, one can identify/detect the thrust and fault location.

Initially, we have selected a synthetic seismic dataset having thrust and fault demarcation. This data containing all relevant information has been digitized. In this study, we have selected 10 seismic traces of 500 ms length (2800ms

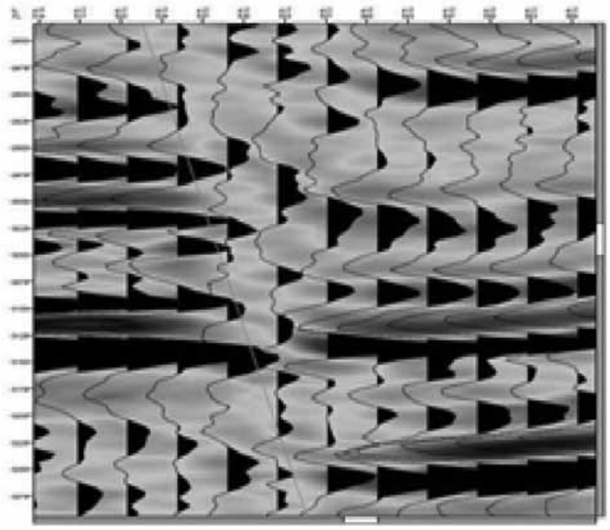

Figure 1. The window of a seismic section of the fault zone from where the data of the traces are taken for various attribute calculations.

to 3300 ms). The data has been digitized for all the seismic traces for the calculation of variance and inverse of variance attribute analysis. Using MS excel sheet, we have calculated the mean and standard deviation. This has been followed by calculation of variance and inverse of variance for each trace. The output has been plotted in the MS excel sheet.

Variance Attribute

Variance is statistically defined as the square of the standard deviation (Fisher, 1918 and Fisher (1925). Mathematically, standard deviation (SD=σ) can be expressed as mentioned in equation (1)

$$\text{Thus SD} = \sigma = \sqrt{\text{Variance}} \quad \text{or} \quad \text{Variance} = \text{SD}^2. \qquad (1)$$

The Arithmetic Mean (AM) of a series is obtained by adding the values of the series and dividing the number of items.

If x_1, x_2, x_3, ………… x_n, are the values of the variable x. AM denoted by x is given by equation (2),

$$x_m = \frac{x_1 + x_2 + \cdots \ldots \ldots . + x_n}{n} = \frac{\sum_{i=1}^{n} x_i}{n} = \frac{\sum x}{n} \qquad (2)$$

In the case of grouped data, let x_1, x_2, x_3, ………… x_n, are the values of the variable x with frequency f_1, f_2……… f_n then, AM denoted by x and f as given in equation (3).

$$x_m = \frac{x_1 f_1 + x_2 f_2 + \cdots \ldots \ldots . + x_n f_n}{f_1 + f_2 + \ldots \ldots \ldots . + f_n}$$

$$x_m = \frac{x_1 + x_2 + \cdots \ldots \ldots . + x_n}{n} = \frac{\sum_{i=1}^{n} x_i}{n} = \frac{\sum x}{n} \qquad (3)$$

Where N = Σf = Total frequency.

In case of continuous frequency distribution x is taken as midpoint of class interval. Variance is the average of the squared differences from the mean as given in equation (4).

$$\text{Variance} = \sigma^2 = \frac{1}{n} \sum_{f_1=1}^{n} (x_i + x_m)^2 \qquad (4)$$

Where: n= no. of observations

f_i= frequency

x_i= variable

x_m= mean of xi (average)

Inverse of Variance Attribute

Inverse of variance attribute analysis is the reciprocal of variance attribute and mathematically can be expressed as in equation (5) (Sa´nchez-Meca and Marı´n-Martı´nez, 1998).

Inverse of variance attribute = $(1/\sigma^2)$ (5)

Substituting the value of variance (from equation 4) in equation (5), this can be simplified as shown equation (6)

$$(\sigma^2)^{-1} = \left\{\frac{1}{n} \sum_{f_1=1}^{n} (x_i + x_m)^2\right\}^{-1} \qquad (6)$$

Calculation of the detailed mathematical derivations for the variance and inverse of variance, for the theoretical data, has been explained by Gogoi and Ghosh (2015).

CASE STUDY – FOR SYNTHETIC DATA

A particular window of a seismic section is considered where a faulted zone is focused. With the help of Microsoft Excel, each trace of that window, Mean, Variance and Inverse of Variance are calculated. The curves are plotted simultaneously in the graph and interpreted. A theoretical calculation for a sample dataset (Figure 1) is used with

Table 1. Seismic dataset has been used after 3 data point window for calculating variance and inverse of variance.

Sample data	3 point window								Mean
3	3								
4	4	4						(3+4+3)/3	3.33
3	3	3	3					(4+3+2)/3	3.0
2		2	2	2				(3+2+4)/3	3.0
4			4	4	4			(2+4+5)/3	3.66
5				5	5	5		(4+5+1)/3	3.0
1					1	1	1	(5+1+4)/3	3.33
4						4	4	(1+4+4)/3	3.0
4							4		

Table 2. Some examples of the synthetic dataset for calculation of variance and inverse of variance.

1	Data	Mean	Variance	1/Variance
2	0.2	0.13333	0.01333	8.10811
3	0	0	0.04	15.7895
4	0.2	-0.16667	0.12333	75
5	-0.2	-0.46667	0.06333	15.7895
6	-0.5	-0.56667	0.01333	8.10811
7	-0.7	-0.46667	0.06333	8.10811
8	-0.5	-0.16667	0.12333	15.7895
9	-0.2	0.16667	0.12333	15.7895

averaging 3 point dataset for calculating the mean, which is explained in Table 1. The same procedure is applied for calculating the other formulation for variance and for the inverse of variance analysis simultaneously (Table 2).

It is significantly observed that the variance and inverse of variance are well correlated for delineating the thrust/fault location in the test data set. The amplitudes for the variance and inverse of variance are opposite in nature. Here, we have attempted to plot the test data for three different interpretations. Figure 2 shows the trace calculations for the cross line. Figure 3 shows the test section of the seismic data of a fault section. Figure 4 shows the variance of the seismic data and Figure 5 shows the inverse of the variance of the seismic data simultaneously.

CASE STUDY- REAL FIELD DATA

We have selected the field data, which is located in Dibrugarh area, a part of Assam-Arakan basin in the northeastern India. Few in-lines and cross-lines sections of this 3D volume are selected for attribute analysis. We have also carried out attribute analysis for Structural dip, Local structural azimuth, Structural Smoothing, Sweetness, Instantaneous Phase, Dip Deviation, Variance etc. The various attributes are shown in Figure 6 (a to h)

We have noticed that in a trace of inverse of variance the low amplitude and in variance the high amplitude indicate presence of the fault. Finally the outcome of the attribute in time slice of basal section gives proper picture of the fault as shown in Figure 7.

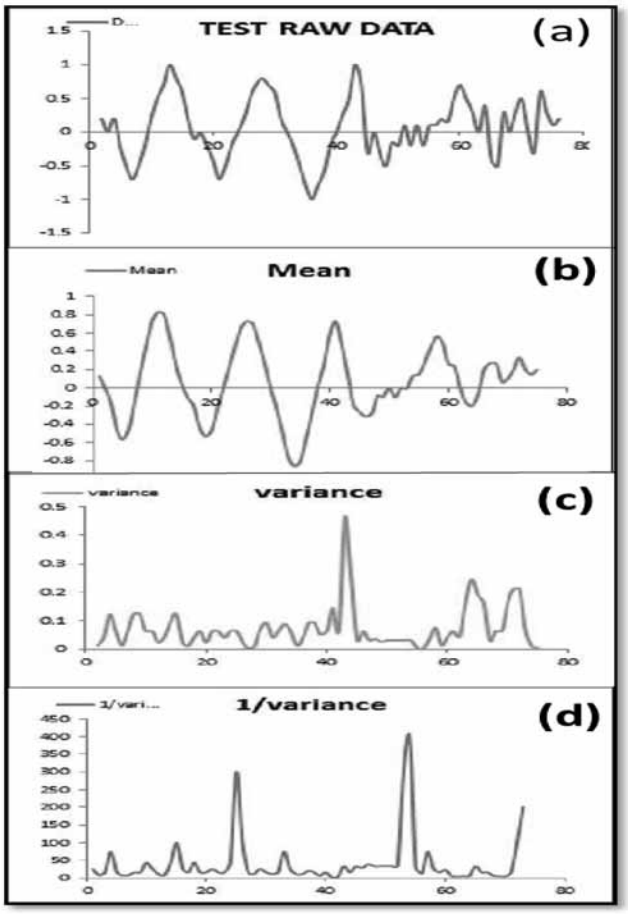

Figure 2. Traces calculation for the Cross line-520 and the corresponding plots of (a)test raw data, (b)Mean data, (c)Variance, and (d)Inverse of Variance are shown.

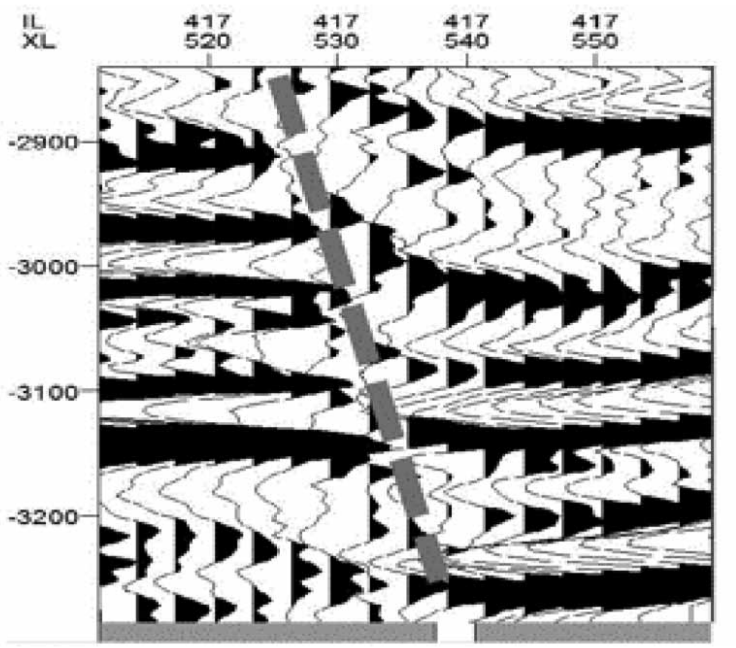

Figure 3. Test seismic data for the calculation of variance and inverse of variance indicated a fault section.

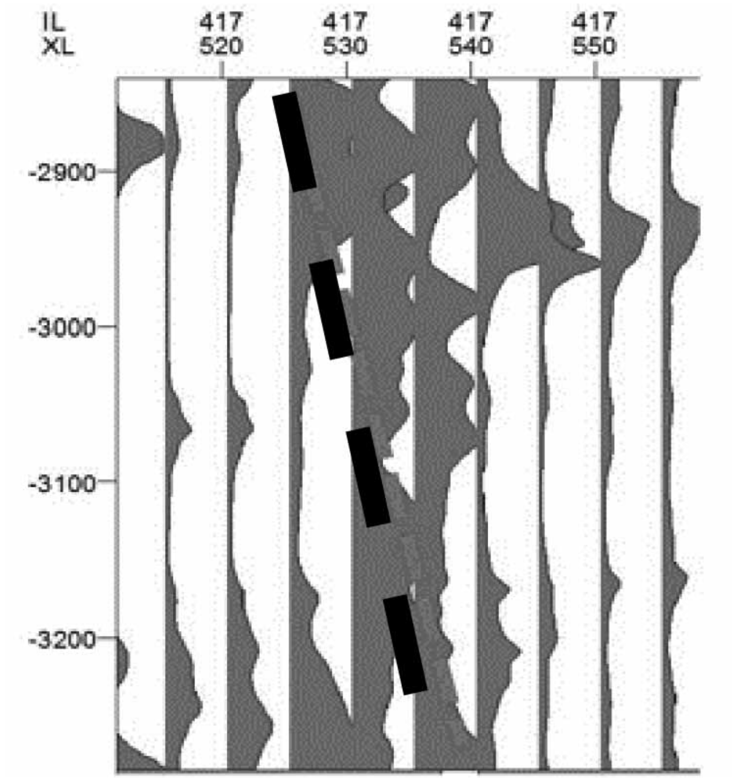

Figure 4. Map shows the variance of the seismic data with Positive filled.

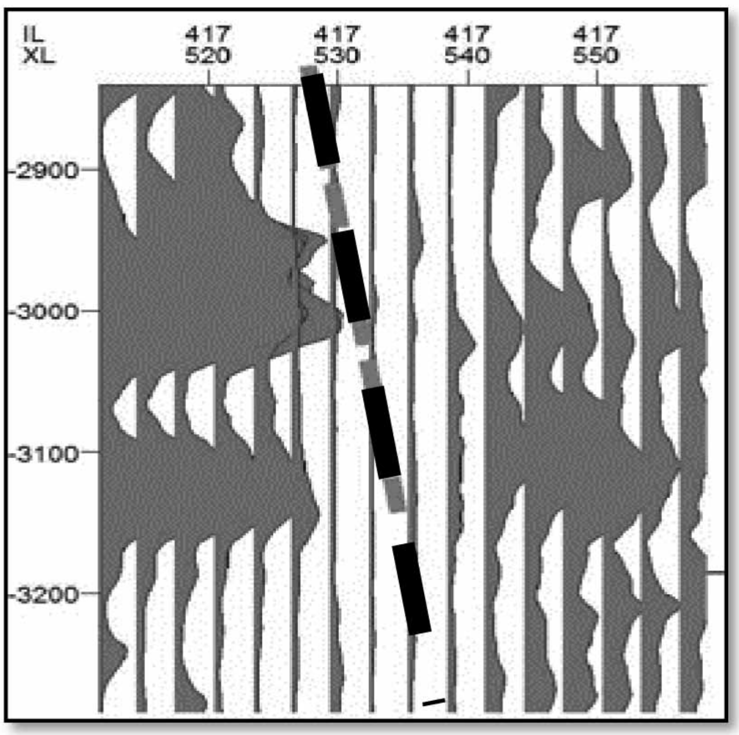

Figure 5. Map shows the inverse of variance of the seismic data with Positive filled.

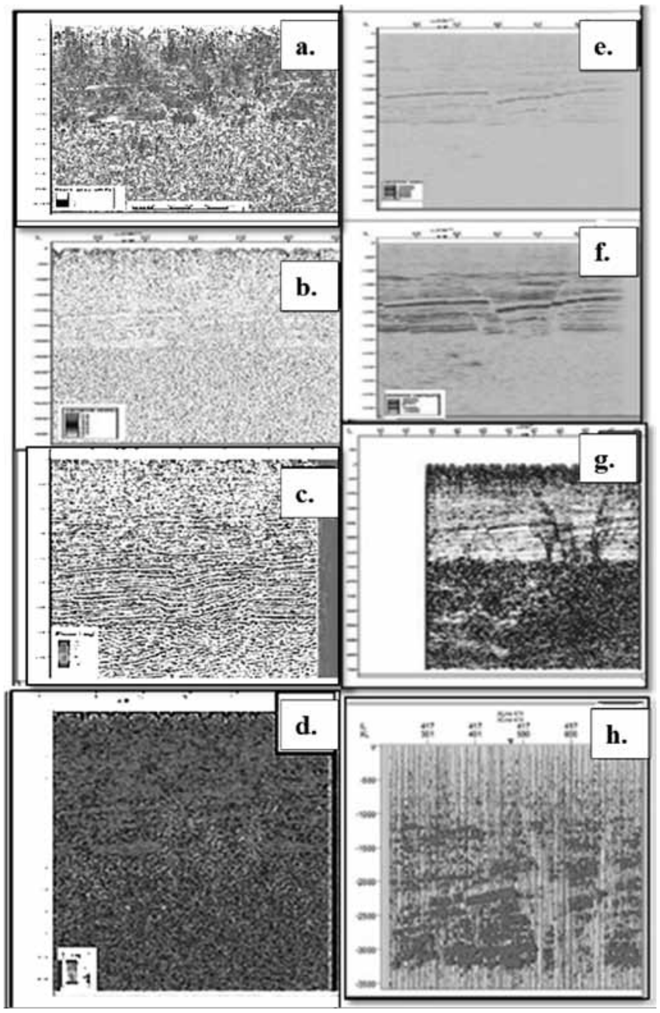

Figure 6. Types of Attributes namely (a) Curvature, (b) Dip Deviation, (c) Instantaneous Phase, (d) Local Structural Dip, (e) Sweetness, (f) Structural Smoothing, (g) Variance, and (h) Inverse of Variance respectively.

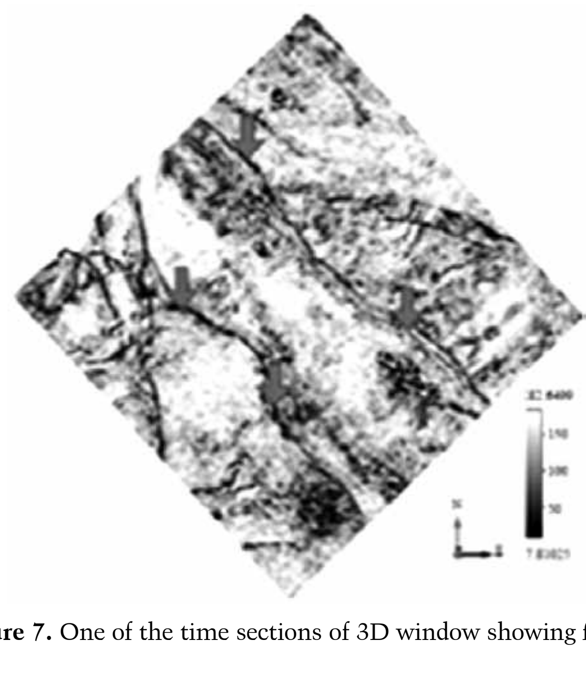

Figure 7. One of the time sections of 3D window showing fault.

CONCLUSIONS

It has been found that the variance and inverse of variance attribute analysis has significantly helped the fault identification in comparison to other attributes.

It is noted that in variance attribute, significant high amplitudes are observed. However, in the case of inverse of variance attribute, the low amplitudes are indicated. By joint inspection with the help of variance and inverse of variance attribute, it is possible to mark and identify the thrust/fault locations reasonably good, and are not visible from the raw seismic section.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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"Try to forget what objects you have before you - a tree, a house, a field, or whatever. Merely think, 'Here is a little square of blue, here an oblong of pink, here a streak of yellow,' and paint it just as it looks to you, the exact color and shape, until it gives you your own impression of the scene before you".

- Claude Monet (1840 –1926) was a founder of French Impressionist painting

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"Geometric shapes hold an energy pattern, and scientists did some experiments which say certain geometric shapes can affect matter around them. It's simply because when a human looks at a shape, they instantly receive energy from their brain".

- Tom DeLonge (1975--) is an American musician and film producer.