

# Research on the Method of Seismic Record Synthesis Based on Well Deviation and Stratigraphic Dip

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**Abstract.** According to the direction of seismic record synthesis method, currently there are two methods of seismic record synthesis. One is synthetic seismic record production along the well trajectory and the other is along the TVD direction. However, in case of a large stratigraphic dip and well deviation, the synthetic record obtained has poor comparability with seismic profile. In order to solve this problem, the method of seismic record synthesis based on well deviation and stratigraphic dip is proposed, which is the use of simulation well trajectory data computed with the well deviation data and stratigraphic dip data to making the seismic record synthesis. Both forward modeling and practical application show that the wave group relationship obtained with this method has good comparability with seismic profile and this method is better than the other two and has broad prospects of application.

## Introduction

Synthetic seismic record production is an important step of seismic interpretation, a link between good combination of geology and earthquake as well as the basis for fine reservoir description. There have been a lot of research on the improvement of seismic record synthesis [1-7] and the research directions roughly include: (1) improving the quality of log data; (2) improving the accurate estimation of wavelet; (3) improvement of seismic record synthesis method. This Paper mainly studies the seismic record synthesis method. Currently there are two methods of seismic record synthesis. One is synthetic seismic record production along the well trajectory and the other is along the TVD direction. For example, practical application shows that these two methods are not satisfactory in case of a large stratigraphic dip and well deviation, which affects the calibration of seismic horizon. It is found in actual work that the inappropriate calibration of synthetic seismic record will affect the identification of igneous rock, the reflection of sedimentary rules in seismic attribute and the quality of low frequency trend reflected by geologic model in seismic inversion. In-depth research was conducted on the improvement of the quality of synthetic seismic record in view of a large stratigraphic dip and well deviation and the synthetic seismic record production technique based on well deviation and stratigraphic dip is proposed.

## Theory of synthetic seismic record production based on well deviation and stratigraphic dip

Base on the relationship between well deviation trajectory and low-level dip direction, three conditions were studied, including a. the same direction, which means the well deviation trajectory

direction is consistent with the dip direction (Fig. 1a); b. opposite directions, which mean the well deviation trajectory direction is opposite to the dip direction (Fig. 1b); c. mixed directions, a combination of both a and b above (Fig. 1c).

Suppose the log data along the well trajectory is  $\{D_i, AC_i, \rho_i | j=0, 1, 2, \dots, n\}$ , where  $D_i$  denotes depth;  $AC_i$  denotes sound wave;  $\rho_i$  is density. Suppose that well trajectory is divided into  $m$  parts.

Fig. 1a, 1b and 1c in Fig. 1 are respectively the diagrams for the same well deviation trajectory and dip direction, opposite well deviation trajectory and dip direction as well as a combination of the two. In the figures, the well deviation trajectory is composed of a series of line segments  $\{A_j A_{j+1} | j=0, 1, 2, \dots, m-1\}$ ; the corresponding hole deviation angles of the line segments are  $\{\alpha_j | j=0, 1, 2, \dots, n-1\}$ ; the end of well deviation trajectory passes through a series of strata, which can be denoted by  $\{L_j | j=1, 2, \dots, n\}$ ; the stratigraphic dips of the strata are  $\{\beta_j | j=1, 2, \dots, m\}$ . In the figure,  $A_j B_j$  is a line segment perpendicular to the stratum  $L_{j+1}$ . The calculation of synthetic seismic record has five steps:

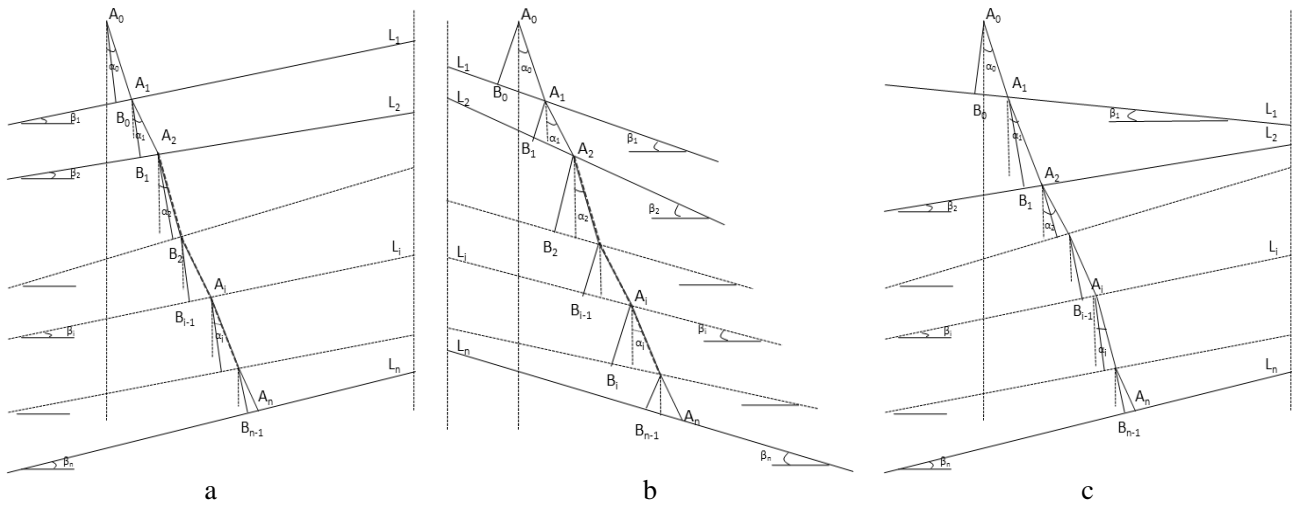


Fig. 1 Relationship between well deviation trajectory direction and dip direction

a. Same direction b. Opposite directions c. Mixed directions

(1) Calculate the length of line segment  $A_j B_j$ ;

As for the same direction:

$$A_j B_j = A_j A_{j+1} \cos(\alpha_j + \beta_{j+1}) \quad (1)$$

As for opposite directions:

$$A_j B_j = A_j A_{j+1} \cos(\alpha_j - \beta_{j+1}) \quad (2)$$

As for mixed directions:

$$A_j B_j = \begin{cases} A_j A_{j+1} \cos(\alpha_j + \beta_{j+1}) & A_{j+1} \text{ and } L_{j+1} \text{ are equidirectional} \\ A_j A_{j+1} \cos(\alpha_j - \beta_{j+1}) & A_{j+1} \text{ and } L_{j+1} \text{ are opposite directional} \end{cases} \quad (3)$$

(2) Calculate the sum of each line segment  $A_j B_j$  and let the sum of line segments  $A_j B_j$  be  $L$ ;

$$L = \sum_{i=0}^{n-1} A_i B_i \quad (4)$$

- (3) Convert the log data along  $A_j A_{j+1}$  to log data along  $A_j B_j$ , and use  $\{D_i r, A C_i, p_i | j=0, 1, 2, \dots, n\}$  to denote it;
- (4) Calculate the reflection coefficient with the converted log data;
- (5) Perform convolution with the known wavelet and reflection coefficient.

## Forward modeling

Fig. 2 is a geologic model of a well trajectory with different dip directions. The well trajectory is in red and divided into four segments  $A_0 A_1$ ,  $A_1 A_2$ ,  $A_2 A_3$  and  $A_3 A_4$ . The hole deviation angles of the line segments are shown in Table 1. The mid-upper part of Fig. 2a and 2b are horizontal strata and the lower part are strata with the same dip direction and different stratigraphic dips. Fig. 2a is a typical equidirectional geologic model; Fig. 2b is a typical opposite-directional geologic model; Fig. 2c is a typical mixed geologic model, with rightward-dip strata in the upper part and leftward dip strata in the lower part. The values of the lower strata stratigraphic dip  $\beta$  in Fig. 2a and 2b and strata  $\beta_1$  and  $\beta_2$  in Fig. 2c are shown in Table 2. Suppose the gray parts in Fig. 2 is mudstone formations and white parts are sandstone formations. Let the mudstone velocity be 3000m/s and sandstone velocity be 3500m/s. The density is calculated with the classic Gardner equation. Table 3 shows the coordinates of points  $A_0$ ,  $A_1$ ,  $A_2$ ,  $A_3$  and  $A_4$  in the model.

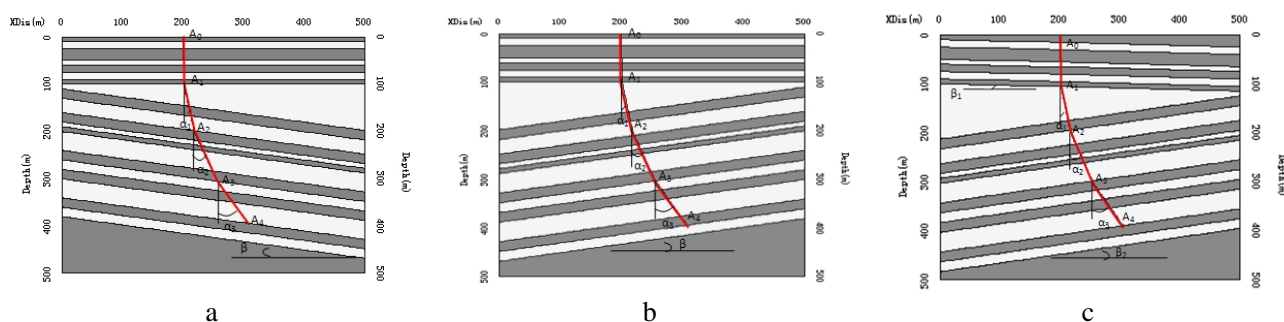


Fig. 2 Geologic model

a. Same direction mode    b Opposite directions mode    c. Mixed directions mode

Table 1 Line segment well deviation angle

Line segment	Angle expression meets	Angle value
$A_0 A_1$	$\alpha_0$	$0^0$
$A_1 A_2$	$\alpha_1$	$10^0$
$A_2 A_3$	$\alpha_2$	$20^0$
$A_3 A_4$	$\alpha_3$	$30^0$

Table 2 Stratigraphic dip

Angle	Angle value
$\beta$	$10^0$
$\beta_1$	$1.72^0$
$\beta_2$	$10^0$

Table 3 Positions of the points in the model

Coordinates	X	Y
A0	200	0
A1	200	100
A2	217	198
A3	256	305
A4	308	394

Fig. 3 shows the corresponding seismic profiles of different models in Fig. 2 and the seismic profiles show the comparison between the three synthetic seismic records and seismic profiles. MD, TVD and VF respectively denote the seismic records made along measured depth, true vertical depth and the depth vertical to formation. It can be seen that VF has good consistency with seismic profile, while MD and TVD have greatly different wave group relationships with seismic profile. In the place with strong seismic profile, the measured depth position shows weak information (Fig. 3a); the actual profile is wave trough, but the synthetic record obtained based on vertical depth shows wave peak (Fig. 3b and 3c). Obviously, the synthetic seismic record obtained with comprehensive well deviation and stratigraphic dip is more helpful to the solution of geological problems.

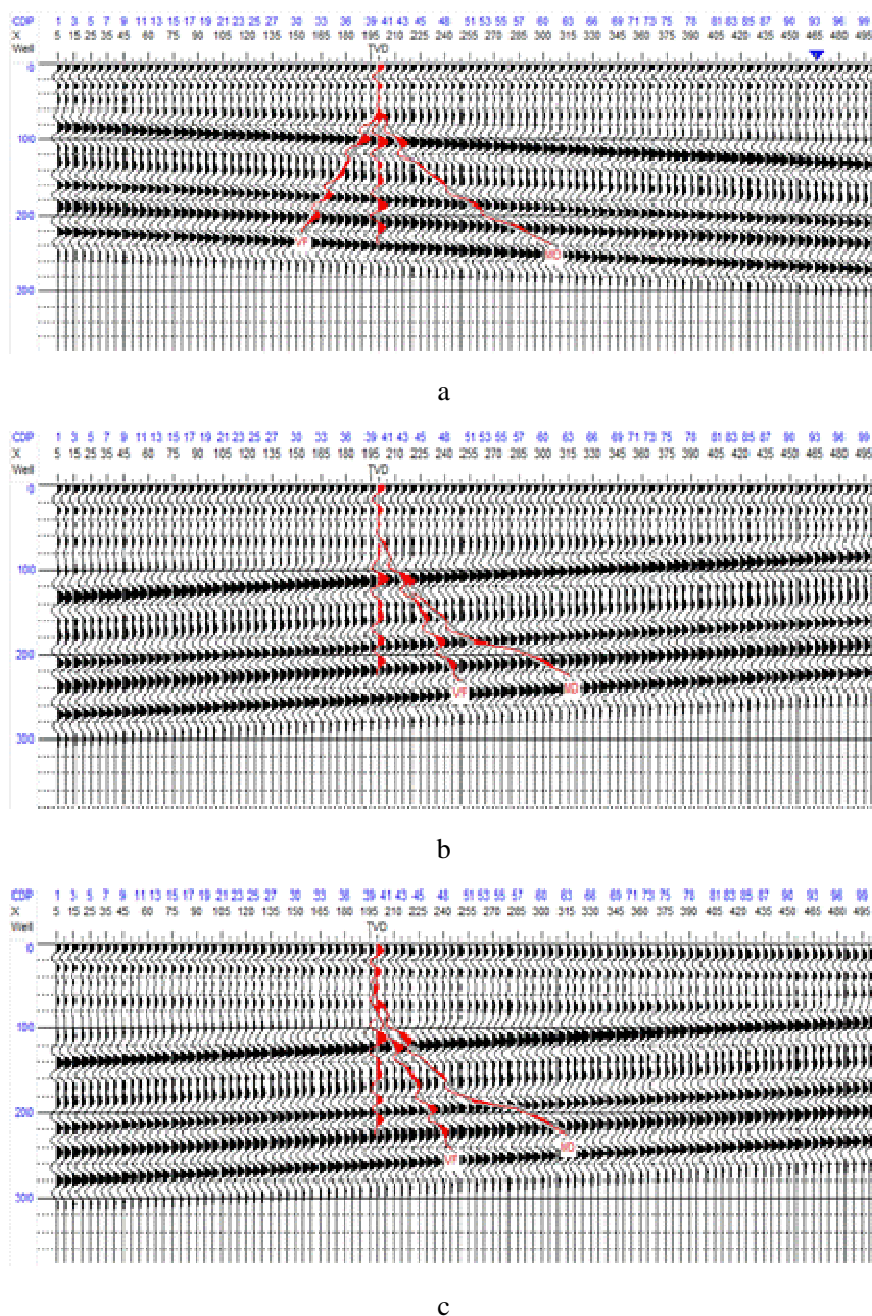


Fig. 3 Comparison between three seismic record synthesis methods and profile of the synthetic records  
a. Same direction mode; b. Opposite directions mode; c. Mixed directions mode

### Practical application

Fig. 4 shows the comparison between the synthetic seismic record obtained based on measured depth

(in red), synthetic seismic record obtained based on depth vertical to formation (in black) and seismic profile of S area. In the objective formation (within the blue frame), the synthetic record based on measured depth has a great difference with seismic profile wave group, especially the bottom y-axis (the end of synthetic record indicates the igneous rock development) corresponding to the z-axis of seismic profile. Thus it is believed that igneous rock cannot be well identified based on seismic profile. By considering the well deviation data (Table 4) of the objective formation and stratigraphic dip of approximately  $23^\circ$ , the synthetic seismic record of the objective formation is obtained using the proposed method. It can be seen that there is a good consistency between the synthetic record and the wave group relative relations on the actual profile. The comparison using this method shows that igneous rock should correspond to y-axis, thus laying a solid foundation for understanding igneous rock from the seismic profile.

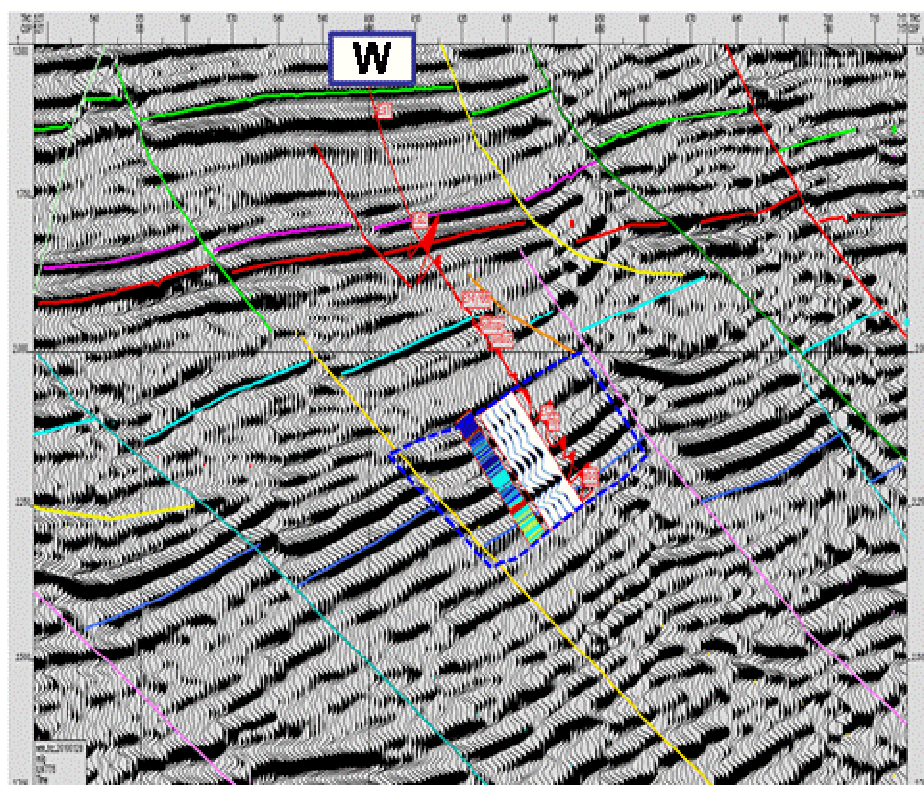


Fig. 4

Table 4 Well deviation in the objective formation

Measured depth	Well deviation
3025	54.52
3050	53.53
3075	52.76
3100	52
3125	50.45
3150	48.94
3175	47.08
3200	45.39
3225	44.22
3250	43.31
3275	43.06
3300	42.23
3325	41.38

## Conclusion

The synthetic seismic record production method based on well deviation and stratigraphic dip proposed through the forward modeling and practical application is superior to the current methods based on measured depth and vertical depth. It has overcome the poor comparability of the two methods with seismic profile and improved the understanding of geological problems, which better helps reservoir prediction.

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