Method of Transformation between Reflector Dip Angle and Stratigraphic Dip Angle

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ABSTRACT

The calibration of stratigraphic horizon usually depends on outcrop data when interpreting seismic data in frontier area where there is lack of well. The outcrop data is often expressed as the stratigraphic dip angle, how can we directly and easily transform the stratigraphic dip angle from depth domain to time domain. The paper derives a depth-time transformation equation of the stratigraphic dip angle with various scale parameters of seismic section and outcrop data by analytic geometry, which may be suitable for the depth-time transformation under any geological structural feature and other field.

Keywords: Stratigraphic dip angle, Reflector dip angle, Depth-time transformation

INTRODUCTION

Generally, when calibrating the stratigraphic horizon by the well data, we use the equation (1) to transfer the data from depth to time domain, which can be used as a reference during the interpretation of the seismic data.

$$h = \frac{1}{2}vt \qquad \textbf{(1)}$$

But, in the complicated tectonic deformation area, the outcrop data we get is often expressed as the azimuth and the stratigraphic dip angle. Then it's hard to transfer these data in the depth domain to those in the time domain by the equation (1), especially for those seismic sections whose showing parameters or scales are different.

Can we derive an equation like the equation 1 to perform directly the transformation of depth-time in dip angle? We are discussing below.

THEORY

As stated above, when interpreting seismic section, well data and outcrop data are needed to calibrate the stratigraphic horizon. But in frontier area, it is important to use the later. The outcrop data is often a depth profile which measured in afield, and the stratigraphic dip angle is also measured in depth. But the most of seismic section is the time section, not the depth one. Giving a transformation measure, velocity ***v,*** then we can use the equation (1) to get the depth in time domain (e.g., a curve of topographic can be transformed from the depth to the time domain).

We will discuss respectively how about to transfer the stratigraphic dip angle measured in depth to the one in the stacked time section and the migrated time section.

TRANSFORMATION OF THE STRATIGRAPHIC REAL DIP ANGLE TO APPARENT ONE

First, the stratigraphic real dip angle should be converted to apparent to coincident with the direction of seismic line by the equation as below.

$$\sin\varphi = \sin\phi\cos\theta$$

Where φ is the stratigraphic apparent dip angle
ϕ is the stratigraphic real dip angle
θ is the included angle between the stratigraphic trend and the seismic line

THE STRATIGRAPHIC APPARENT DIP ANGLE TRANSFORM FROM DEPTH TO TIME DOMAIN IN MIGRATED TIME SECTION

Figure 1 is a sketch map, in the migrated section, showing a relationship between the stratigraphic apparent dip angle in the depth and that in the time.

Where
k_1 = the vertical scale of seismic section **(cm/s)**
k_2 =the horizontal scale of seismic section**(m/cm)**
v = the velocity of transformation **(m/s)**
l =the horizontal length read from seismic section **(cm)**
h_t =the vertical length read from seismic section **(cm)**
t =two-way time **(s)**

L =the real horizontal length corresponding to l **(m)**
H =the real vertical length corresponding to t **(m)**
φ =the stratigraphic apparent dip angle in the depth
α =the stratigraphic apparent dip angle in the time

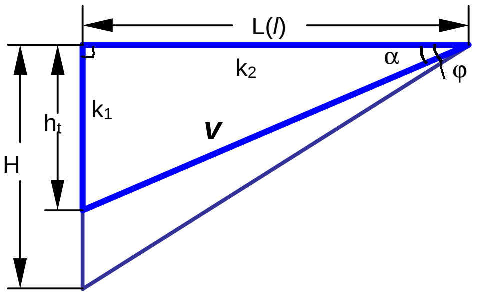


Figure 01 *The relationship between the stratigraphic apparent dip angle in depth and that in time(corresponding to the stacked section)*

Then $\tan\varphi = \frac{H}{L}$ $\tan\alpha = \frac{h_t}{l}$

Where $L = k_2 l$ $h_t = k_1 t$ $H = \frac{1}{2}vt$

Hence $\tan\alpha = \frac{h_t}{l} = \frac{k_1 t}{l}$

$$\tan\varphi = \frac{H}{L} = \frac{(1/2)vt}{k_2 l}$$

Two equations above are divided each other, thus

$$\alpha = \arctan\left(\frac{2k_1k_2}{v}\tan\varphi\right) \quad \cdots$$

The stratigraphic apparent dip angle transform from depth to time domain in stacked time section

If the seismic section is a stacked one, the reflector apparent dip angle **α** derived from above needed to perform anti-migration conversion, so that we can get a reflector apparent dip angle suitable for the stacked section. Figure 2 shows the relationship between the stratigraphic dip angle of unmigrated and that of migrated, **β** is a stratigrahpic apparent dip angle suitable for unmigrated seismic section, and **α** for migrated one.

h_1 and h_2 are respectively plumb depth unmigrated and normal depth migrated, h_1• h_2.

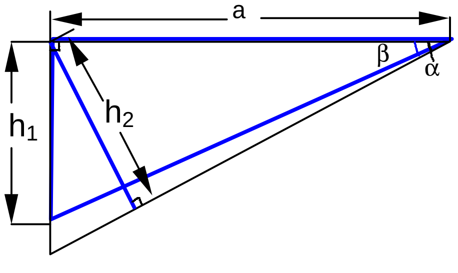


Figure 2 *The relationship between the stratigraphic apparent dip angle in depth and that in time(corresponding to the migrated section)*

$$\tan\beta = \frac{h_1}{a}$$

$$\sin\alpha = \hbar^2 = \hbar^1 = \tan\beta$$

Where $\tan\alpha = \frac{2k_1k_2}{v}\tan\varphi$

Suppose $(\frac{2k_1k_2}{v}\tan\varphi) = M$

Then $\frac{\sin\alpha}{\cos\alpha} = M$

$$\sin^2\alpha = M^2(1-\sin^2\alpha)$$

$$(1+M^2)\sin^2\alpha = M^2$$

$$\sin\alpha = \frac{M}{\sqrt{1+M^2}}$$

Thus $\tan\beta = \sin\alpha = \frac{M}{\sqrt{1+M^2}}$

$$\beta = \arctan\left(\frac{2k_1k_2\tan\varphi}{\sqrt{v^2+4k_1^2k_2^2\tan^2\varphi}}\right) \quad \textbf{(3)}$$

COMPARISON OF GENERAL DEPTH-TIME TRANSFORMATION WITH THAT OF STRATIGRAPHIC

Equation 1 and equation 2 and equation 3 are fixed and listed as below:

$$h = \frac{1}{2}vt$$

$$\tan\varphi = \frac{1}{2}v\frac{\tan\alpha}{k_1k_2}$$

$$\tan\varphi = \frac{1}{2}v\frac{\tan\beta}{k_1k_2}\frac{1}{\sqrt{1-\tan^2\beta}}$$

The k_1 and k_2 are constant quantity, and v can be also regarded as constant quantity, for a certain seismic time section, suppose

$$\gamma = \frac{v}{k_1k_2}$$

Those equations listed above can be further fixed as below:

$$h = \frac{1}{2}vt$$

$$\tan\varphi = \frac{1}{2}\gamma\tan\alpha$$

$$\tan\varphi = \frac{1}{2}\gamma\frac{\tan\beta}{k_1k_2}\frac{1}{\sqrt{1-\tan^2\beta}}$$

As listed above, the form of the general equation of depth-time transformation for stratigraphic horizon and that of for stratigraphic dip angle is similarity and also comparability. It might means that equation 2 and equation 3 is the extrapolation of the equation 1 not only in theory and also in application range.

APPLICATION OF DEPTH-TIME TRANSFORMATION OF STRATIGRAPHIC DIP ANGLE

The effect of the transformation of the stratigraphic dip angle is discussed here.

ANALYSIS OF THE RELATIONSHIP OF EACH DIP ANGLE WITH DIFFERENT SCALE SEISMIC SECTION

We read the parameter from different seismic time section with different displaying parameter, and then we analysis the relationship of the measure of the stratigraphic dip angle measured with different physical measure (depth and time).

Example 1, k_1=6cm/s, k_2=250m/cm(that is 1:2.5 ten thousand, 1CDP=15m), the transformation velocity is v, where v=4000m/s, and the φ is determinate. According to the equation 2 and equation 3 to calculate, the corresponding relationship among φ and α and β is acquired in table 1a and figure 3a.

Example 2, k_1=5cm/s• k_2=500m/cm(that is, 1:5.0 ten thousand, 1CDP=25m), the transformation velocity is v, where v=4000m/s, and the φ is determinate. According to the equation 2 and equation 3 to calculate, the corresponding relationship among φ and α and β is acquired in table 1b and figure 3b.

Table 1a or figure 3a shows α≤φ and β<φ. The greater φ is, the greater the difference between β and φ is. There is a greatest difference between α and φ when both α and φ are 45^0. But α tends to φ when the measure is approaching 0^0 and 90^0.

Table 1b or figure 3b shows α≥φ; when φ is smaller, β>φ. But when φ >31^0, β<φ , and the difference between β and φ is accreting

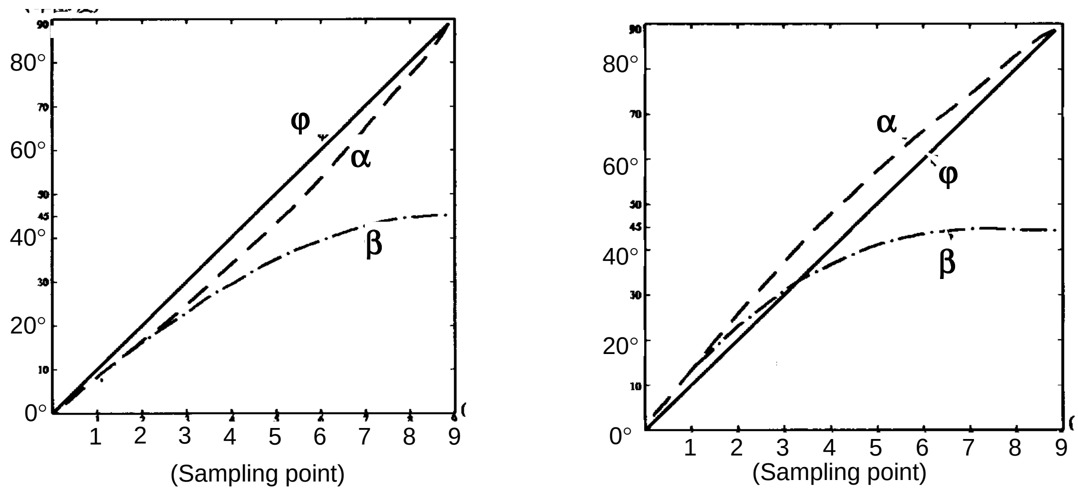
Table 1 *Showing the apparent dip angle before and after transformed*

(a) *k_1=6cm/s, k_2=250m/cm, v=4000m/s*

φ	α	β
0.00	0.00	0.00
10.00	7.58	7.47
30.00	23.41	21.67
45.00	36.87	30.96
60.00	52.41	38.39
80.00	76.77	44.23
89.00	88.66	44.99

(**b)** *k_1=5cm/s, k_2=500m/cm, v=4000m/s*

φ	α	β
0.00	0.00	0.00
10.00	12.43	12.15
30.00	35.82	30.34
45.00	51.34	37.97
60.00	65.21	42.73
80.00	81.97	44.72
89.00	89.20	44.99



(a) *k_1=6cm/s, k_2=250m/cm, v=4000m/s* (**b)** *k_1=5cm/s, k_2=500m/cm, v=4000m/s*

Figure 3 *Showing the apparent dip angle before and after transformed*

Thus, it is not difficult to see that α and β has a relationship of direct ratio with φ, and also with the scale of seismic section and the transformation velocity. If regarding the relationship between the real dip angle and the apparent dip angle of stratigraphic, The corresponding relationship between them will become much more apparent or the difference of dip angle measured with different physical measure (before and after the transformation). Hence, when calibrating the stratigraphic horizon by the outcrop data, the precision of seismic section interpreted will be influenced if the depth-time transformation of stratigraphic dip angle does not regarded.

CASE STUDY

Figure 4 shows an example of the depth-time transformation in the stacked seismic section gathered from certain basin in China.

Before the depth-time transformation of stratigraphic dip angle, the real stratigraphic dip angle should be converted to apparent one. Then the depth-time transformation of outcrop (topography heave) is performed by the equation 1. In figure 5, the dashed lines(powder) show the stratigraphic apparent dip angle and the relative position of outcrop before the transformation; the dot-and-dashed lines(brown) show the stratigraphic apparent dip angle transformed corresponding to migrated section, and the solid lines(blue) show the stratigraphic apparent dip angle transformed corresponding to unmigrated section. It is obvious that only the solid one is much more similar to the attitude of the reflector group in seismic section.

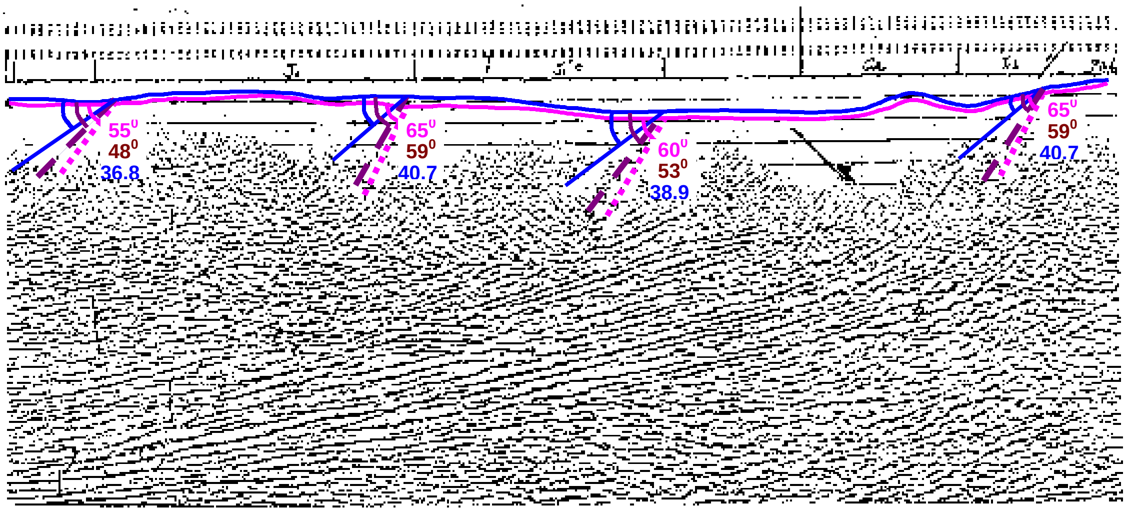


Figure 4 Application of t*he depth-time transformation in a basin in China*

CONCLUSION

The general equation of depth-time transformation for stratigraphic horizon and that of for stratigraphic dip angle is similar and also comparable in the form and also in range applied, and that equation 2 and equation 3 is the extrapolation of the equation 1.

It is not rigorous very much that the stratigraphic dip angle of outcrop measured in depth domain is directly applied to calibrate the stratigraphic horizon when interpreting seismic section. There exits a difference between the stratigraphic dip angle measured in depth domain and the time. Also, there is a great difference between the stratigraphic dip angle transformed from different type of seismic section, stacked and migrated.

The paper derives a depth-time transformation of the stratigraphic dip angle, which may be suitable for the depth-time transformation under any geological structural feature. It has high practical merit for interpreting the seismic data gathered from frontier area, and it is also much significant to improve the precision of interpretation of seismic data.