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Tuning Effect and its Correction for Volumetric Estimation

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ABSTRACT

Amplitude anomalies or bright spots are often linked to hydrocarbon-bearing reservoirs but can also be caused by tuning effect resulting from interference when two reflectors are close together. Tuning effect can be removed from amplitude maps before seismic amplitude and reservoir thickness data are converted into estimates of hydrocarbon accumulations. The most straightforward way of removing tuning effect or 'detuning' is by comparing the reservoir amplitude in seismic data with the response of wedge or thin-bed models and calibrating the reservoir amplitude using the tuning curves from the models. Volumetric estimation for amplitude plays must be based on detuned amplitude maps because hydrocarbon volumes can be significantly overestimated when conventional amplitude maps are used.

Keywords: Tuning Effect, Detuning, Bright Spot, Amplitude Anomaly

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요 약: 진폭이상이나 브라이트 스팟은 종종 탄화수소(가스, 석유)의 집적과 관계 있지만 또한 가까이 있는 두개의 반사면 때문에 생기는 튜닝효과에 의해서도 나타날 수 있다. 탄화수소의 가채매장량을 계산하기 위해서 탄성파 진폭과 저류암의 두께를 계산할 때 탄성파 진폭도로부터 튜닝효과를 제거할 수 있다. 가장 손쉬운 튜닝효과제거(디튜닝) 방법은 탄성파자료의 저류암 진폭을 쐐기모델로부터 얻어진 튜닝반응곡선을 이용하여 보정해 주는 것이다. 진폭이상과 관련된 탄화수소의 집적은 튜닝효과가 제거된 자료를 이용해야 보다 정확하게 예측할 수 있다.

주요어: 튜닝효과, 디튜닝, 브라이트 스팟, 진폭이상

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1. Introduction

Seismic horizon attributes are measures of seismic data that occur along a 3-D surface through the seismic volume. They were first used in the mid-1980s for interpretation of fault traces on reservoirs (Dorn, 1998). Since then, there has been an enormous increase in the number of attributes that can be generated and displayed in 3-D interpretation systems. The meaning and use of some attributes such as reflection amplitude, dip, and azimuth are straightforward compared with those of other attributes (e.g., instantaneous frequency, instantaneous Q factor or attenuation). Reflection amplitude can be related to porosity or net pay, or can provide information about the presence or absence of hydrocarbons in a reservoir interval. Information from the reflection amplitude, however, becomes ambiguous whenever there are two or more closely spaced reflectors because reflections from these reflectors interfere constructively or destructively. The composite wavelet resulting from this interference, called 'tuning' effect, exhibits amplitude and phase effects that depend on the time delays between the successive reflection events and the magnitude and polarity of their associated reflection coefficients (Robertson and Nogami, 1984; Sheriff, 1991). The shape of the embedded wavelet also affects the amplitude and phase of the composite wavelet. Reflection time, measured along the zero crossings or peaks/troughs of a seismic trace, is also obscured when the interference occurs because zero crossings or peaks/troughs no longer coincide with the exact locations of the reflectors. The threshold for the correct measurement of the distance between two closely spaced reflectors is called the tuning thickness.

Hydrocarbon accumulations, especially gas, often appear as amplitude anomalies or bright spots on seismic data but constructive interference due to tuning can also cause amplitude anomalies. Within a hydrocarbon accumulation, for example, the height of the oil/gas column, marked by water-oil/gas contact at the top and oil/gas-water contact at the bottom, commonly decreases toward the periphery of the hydrocarbon accumulation. This leads to convergence of reflections associated with the top and bottom of the oil/gas column. As a result, an exceptionally strong reflection can occur along the periphery of the hydrocarbon accumulation, thereby misleading the seismic interpreter to overestimate the size of the hydrocarbon accumulation.

Tuning effect, therefore, is of considerable importance to the seismic interpreter who relies on bright spot analysis for volumetric estimation. The tuning effect can be removed from horizon amplitude maps – this process is called detuning (Liner, 1999) – before the seismic amplitude and reservoir thickness data are converted into estimates of hydrocarbon accumulations. Detuning can be achieved with sufficient density of well control. If well control is limited, synthetic modeling or statistical methods can be used for approximate detuning (Brown, 1999).

In this paper, I examine the tuning effect on amplitude and bed thickness using synthetic modeling, and discuss how detuning can help better estimate the volumetrics of hydrocarbon accumulations.

2. Wedge Model

The response of amplitude to thinning beds and the apparent bed thicknesses resulting from tuning effect are evaluated for minimum-phase and zero-phase Ormsby wavelets (Fig. 1). The Ormsby wavelets are defined by four corner frequencies (4-8-30-40 Hz) and the ramps are formed by the Hanning window in the frequency domain. The wedge model is shown in Fig. 2. Acoustic velocity equals to 2,000 m/s inside the wedge and 2,750 m/s outside the wedge. Thus, reflection coefficients along the top and bottom of the wedge are -0.15 and +0.15, respectively. The wedge is a low-impedance zone, mimicking a gas sand layer embedded in shale. The slope of the bottom of the wedge is 0.1 ms/1 m.

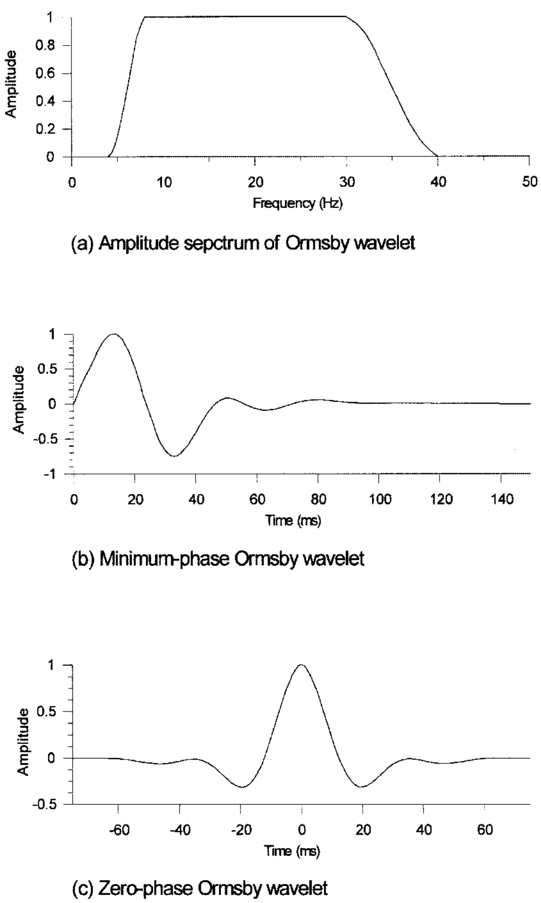

Fig. 1. (a) Amplitude spectrum of the Ormsby wavelet used in the modeling. Four coner frequencies for the Ormsby wavelet are 4, 8, 30, and 40 Hz. The mean frequency is 20.65 Hz. (b) Minimum-phase Ormsby wavelet. (c) Zero-phase Ormsby wavelet.

2.1. Minimum-phase wavelet

Fig. 3 shows the synthetic seismic section for the input of the minimum-phase Ormsby wavelet with the actual geometry of the wedge superimposed. The thickness of the wedge in units of the wavelength (λ = ca. 97 m) estimated from the mean frequency (20.65 Hz) of the Ormsby wavelet is marked along the top of the section. The tuning curves for bed thickness and amplitude are shown in Fig. 4. The vertical lines indicate the thickness of the wedge in units of the wavelength. The top of the wedge, marked by the leading zero amplitude of the trough associated with the top reflection, precisely follows the actual boundary throughout the model (Fig. 3). On the other hand, the interpretation of the bottom depends on horizon-picking algorithms because the leading peak associated with the bottom reflection are not marked by zero amplitude where the bottom and top reflections begin to converge. When 'snap' is used to interpret the bottom, the event from interpretation picks is automatically moved to the nearest zero (or the nearest near zero) that may not be necessarily associated with the leading zero of the bottom reflection. The tuning curve for bed thickness obtained from the snap interpretation is shown by *I* in Fig. 4a; the tuning thickness is about 45 m (< λ/2). The automatic snap is used routinely in horizon picking because the volume of 3D data is usually very large.

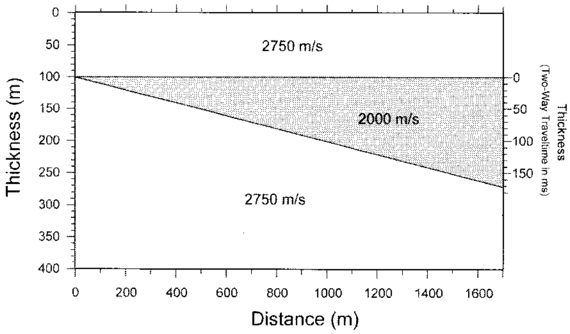

Fig. 2. Geometry of the wedge model in time. The wedge mimics a gas sand layer embedded in shale.

Although horizon picking without snap is extremely time-consuming because horizon picks must be made on every trace, it can be used selectively to interpret where the inference obscures the data. In the current example, the bottom was also picked manually trace by trace along the minimum between the trailing peak of the top reflection and the leading peak of the bottom reflection where top and bottom reflections begin to converge. The tuning curve (*II* in Fig. 4a) for bed thickness from the manual horizon picking gives the threshold for the correct measurement of the bed thickness of about 3 λ/8

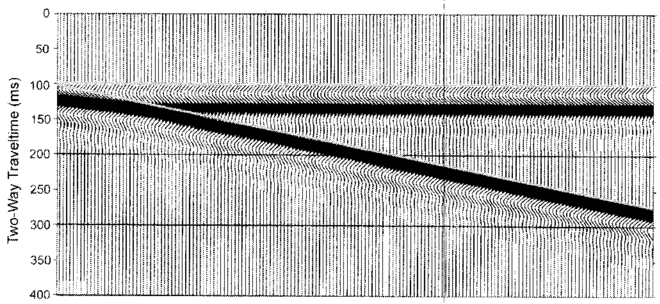

Fig. 3. Synthetic seismic section of the wedge model for the input of the minimum-phase Ormsby wavelet. Grey lines indicate the actual geometry of the wedge. The thickness of the wedge in units of the wavelength (λ = ca. 97 m) estimated from the mean frequency (20.65 Hz) of the Ormsby wavelet are marked along the top of the section.

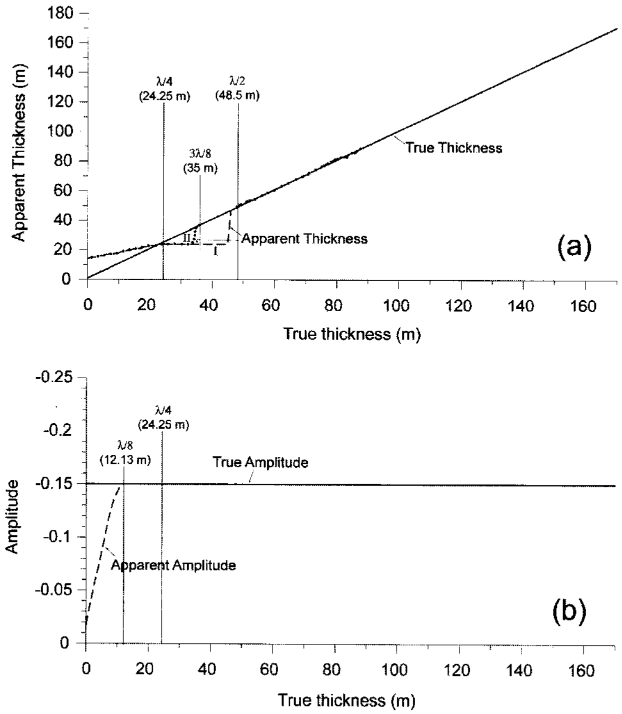

Fig. 4. Tuning curves for bed thickness (a) and amplitude (b) for the wedge model for the input of the minimum-phase Ormsby wavelet. The dashed (I) and dotted lines (II) in (a) are tuning curves from snap horizon picking and manual horizon picking, respectively. Vertical lines indicate the thickness of the wedge in units of the wavelength.

(ca. 35 m). This is greater than the Rayleigh resolution limit (λ/4) (Sheriff, 1991), which is generally accepted as the threshold for vertical resolution (Yilmaz, 1987).

For thicknesses greater than about λ/8 (ca. 12 m), the measured amplitude gives the correct reflectivity of the top boundary. As the wedge thins (< λ/8), the amplitude decreases rapidly, reaching approximately -0.017 that is slightly greater than 10% of the correct reflectivity.

2.2. Zero-phase wavelet

Fig. 5 shows the synthetic seismic section for the input of the zero-phase Ormsby wavelet with the actual geometry of the wedge superimposed. The thickness of the wedge in units of the wavelength (λ = ca. 97 m) is marked along the top of the section. The tuning curves for the bed thickness and amplitude are shown in Fig. 6. The vertical lines indicate the thickness of the wedge in units of the wavelength. Trough-to-peak time measurements generally give the correct thicknesses for thicknesses greater than about λ/5 (ca. 20 m) although side lobes produce minor errors. Below this tuning thickness, the observed trough and peak that correspond to the top and bottom of the wedge, respectively, are pushed apart, giving arrival times too early for the top and slightly too late for the bottom. Measured thicknesses below the tuning thickness, therefore, are greater than the true thicknesses, similar to the case of the minimum-phase wavelet.

The threshold thickness (5 λ/8, ca. 60 m) above which the measured amplitude gives the correct

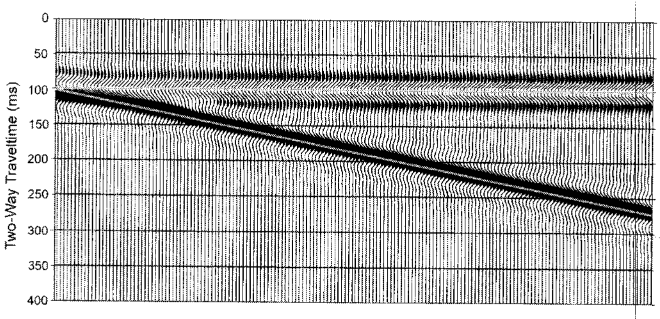

Fig. 5. Synthetic seismic section of the wedge model for the input of the zero-phase Ormsby wavelet. Grey lines indicate the actual geometry of the wedge. The thickness of the wedge in units of the wavelength (λ = ca. 97 m) estimated from the mean frequency (20.65 Hz) of the Ormsby wavelet are marked along the top of the section.

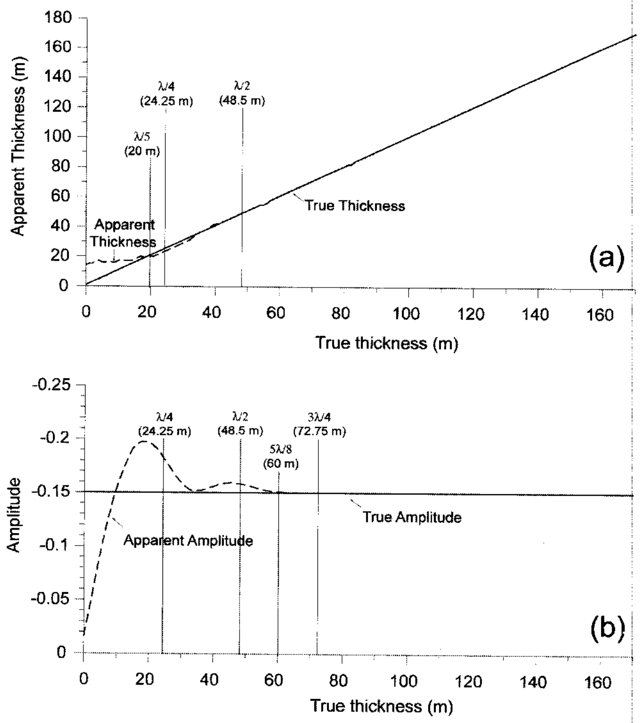

Fig. 6. Tuning curves for bed thickness (a) and amplitude (b) for the wedge model for the input of the zero-phase Ormsby wavelet. Vertical lines indicate the thickness of the wedge in units of the wavelength.

reflectivity of the top boundary is about five times that ($\lambda/8$, ca. 12 m) of the minimum-phase wavelet. Below 5 $\lambda/8$, the tuning curve is characterized by two maxima occurring at about $\lambda/5$ (ca. 20 m) and 2 $\lambda/5$ (ca. 40 m), respectively. This is because the central trough at the top is aligned first with the leading negative side lobe of the wavelet from the bottom and then with the trailing negative side lobe of the same wavelet. As the wedge thins (< $\lambda/5$), the amplitude decreases rapidly, reaching approximately -0.016 that is slightly greater than 10% of the correct reflectivity.

3. Detuning and Volumetric Estimation

In areas of sparse well control, the most straightforward way of detuning is by comparing the reservoir amplitude in seismic data with the response of wedge models and calibrating the reservoir amplitude using the tuning curves from the models. Fig. 7 is a seismic section traversing a salt-window basin in the northern Gulf of Mexico

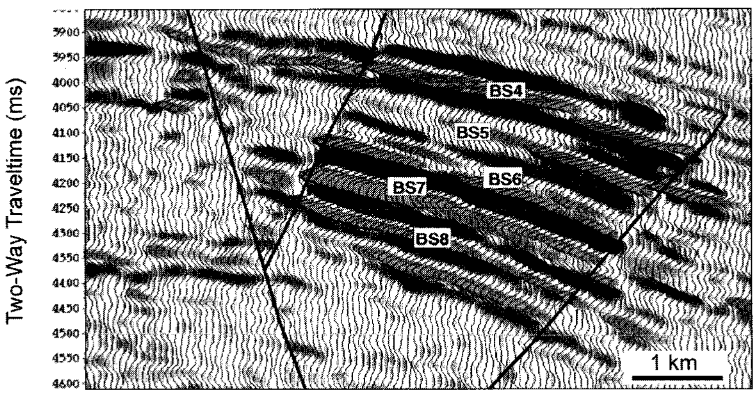

Fig. 7. A seismic section traversing productive Pliocene turbidite sands (BS4-BS8) in an intraslope basin in the northern Gulf of Mexico (location not shown).

slope (location not shown). BS4-BS8 are Pliocene turbidite sands consisting of fan lobes (or sheets) and/or amalgamated channel deposits (Lee *et al.*, 1996). Plio-Pleistocene sands in the intraslope basins in the northern Gulf of Mexico have a lower impedance than the encasing medium and are usually undercompacted and unconsolidated (Rutherford and Williams, 1989). When these sands contain even a small amount of gas (ca. 5%), they appear as bright spots on stacked seismic data because gas-filled porosity has a marked effect on velocity and density of the reservoir (Ostrander, 1984).

Many amplitude anomalies in the northern Gulf of Mexico slope are also associated with oil accumulations as revealed by drilling (Lee, 1993) although the acoustic impedance contrast at the oil-water contact is very small and thus there is theoretically little detectable difference between the oil sand and the water-saturated encasing medium. It appears that diagenesis of reservoir rocks caused by hydrocarbons in pore space lowers the P-wave velocity of the reservoir rocks, increasing the acoustic impedance contrast at the oil-water contact (Jenyon and Fitch, 1985; Brown *et al.*, 1989). The amplitude anomalies associated with BS4-BS8 are considered as being related to oil deposits (Lee, 1993). Parts of these amplitude anomalies, however, may be due to tuning effect especially where the reservoir beds become close to or thinner than the tuning thickness.

Fig. 8 shows the tuning curves for the thickness

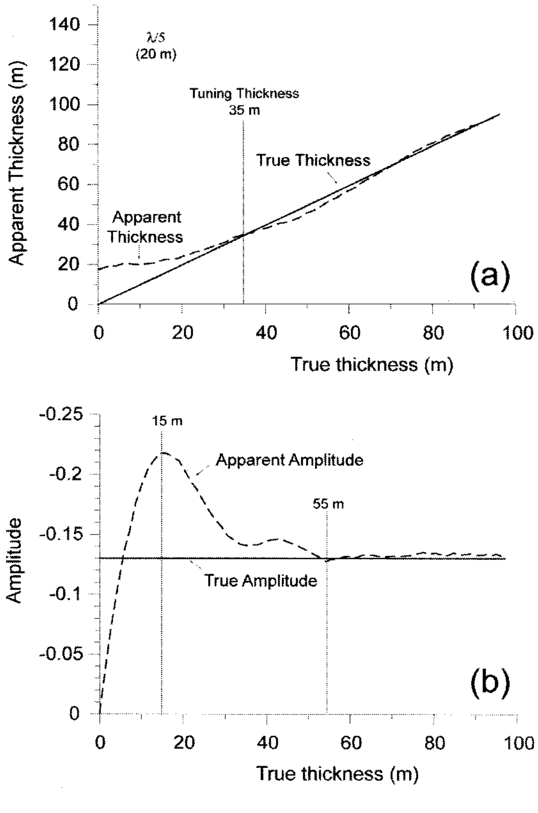

Fig. 8. Tuning curves for the bed thickness (a) and amplitude (b) of BS4.

(a) and amplitude (b) for BS4. The tuning cuves are very similar to those of the zero-phase Ormsby wavelet (Fig. 5) although the thickness (ca. 15 m) where the maximum amplitude occurs does not coincide with the tuning thickness (ca. 35 m). The measured amplitude below about 55 m is characterized by two tuning maxima, indicating that the source wavelet has a central peak and at least two negative side lobes.

Shown in Fig. 9 are the absolute amplitude to background amplitude ratio (A/B) maps for BS4 before detuning (a) and after detuning (b). A/B maps are known to better represent petrophysical properties of reservoirs than the simple amplitude maps (Lee, 1993). The amplitude of BS4 was detuned or corrected, assuming that the bright spots associated with BS4 are due to the presence of hydrocarbons. The height of the oil/gas column decreases not only locally but also toward the periphery of BS4, acting as the thinning bed. Detuning can be done only where the true bed thicknesses are known because the amplitude calibration is a function of bed thickness, which in turn is subject to the interference below the tuning thickness. Thus, the change of the height of oil/gas column below the tuning thickness was estimated from the trend and nature and the bright spots associated with BS4.

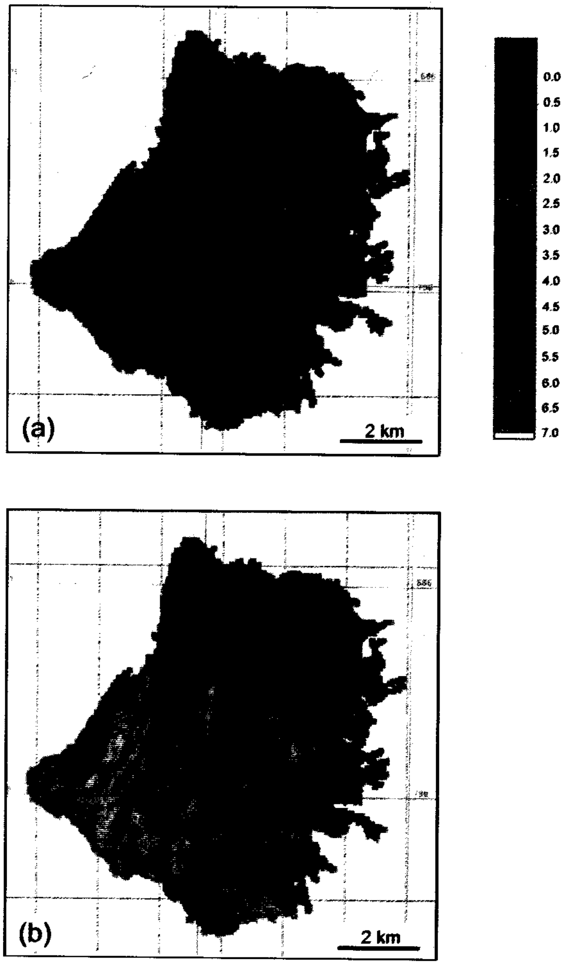

Fig. 9. Absolute amplitude to background amplitude ratio (A/B) maps for BS4 before detuning (a) and after detuning (b). Note that the area with A/B greater than 2.5 is reduced in size after detuning.

Overall, the A/B without detuning is greater than the A/B after detuning, indicating that the large part of BS4 is less than 50 m thick. The western part of BS4 is brightest (A/B > 2.5), exhibiting NE-trending channel-like features. In the northern Gulf of Mexico slope, hydrocarbon accumulations commonly have A/Bs of greater than 2.0 - 3.0 (Lee, 1993). Thus, the channel-like features in BS4 is a prospect for hydrocarbon accumulations. These bright features become reduced in size after detuning. Assuming that the hydrocarbons accumulated in BS4 are oil, the volume of recoverable oil in BS4 is estimated from the tuned and detuned A/B maps (Table 1) using the following equation (Laudon, 1996).

$$
\begin{aligned}
\text{Recoverable oil} &= \\
&= \text{rock volume} \cdot \frac{7,758 \cdot \phi \cdot S_{oil}}{FVF_{oil}} \cdot \text{recovery efficiency} \\
&= \text{rock volume} \cdot \text{recovery factor}
\end{aligned}
$$

Rock volume is from an isopach map, or some area times a thickness. The area of BS4 containing oil is outlined by A/B of 2.5. Most commercial 3D interpretation applications automatically compute the rock volume from an area and an isopach map. 7,758 is a conversion factor from acre · feet to barrels; ϕ is the porosity; S_{oil} is the oil saturation. FVF_{oil} is the formation volume factor for oil to account for the decrease of the volume of oil after traveling from reservoir conditions to surface conditions. Recovery efficiency is an educated estimate. Recovery

Table 1. Rock volumes and recoverable volumes of oil estimated from the A/B maps of BS4 before detuning and after detuning. The recovery factor of 500 barrels/acre · feet is assumed.

	Rock Volume (acre feet)	Recoverable Oil (million barrels)
Volumetrics without Detuning	73,620	24.5
Volumetrics with Detuning	49,050	36.8

factor is a number in barrels/acre · feet including the conversion factor, porosity, oil saturation, formation volume factor and recovery efficiency. Empirically, the recovery factor for the Plio-Pleistocene turbidite sands in the northern Gulf of Mexico slope range from 300 barrels/acre · feet to 750 barrels/acre · feet.

The rock volume (49,050 acre · feet) of BS4 with oil, computed from the detuned A/B map, is much smaller than that (73,620 acre · feet) computed from the A/B without detuning (Table 1). Assuming the recovery factor of 500 barrels/acre · feet, the volumes of the recoverable oil from the A/B without detuning and from the detuned A/B are 36.8 million barrels and 24.5 million barrels, respectively. Thus, the volumetric estimation based on an amplitude map without detuning can result in a significant overestimation, which in turn can lead to costly drilling especially for marginal prospects that otherwise would not have been drilled.

4. Summary and Conclusions

When the thickness of a reservoir interval is close to or below the tuning thickness, tuning effect can cause amplitude anomalies regardless of the fluid type in the reservoir. The tuning effect can be removed by comparing the reservoir amplitude in seismic data with the response of wedge or thin-bed models and calibrating the reservoir amplitude using the tuning curves from the model. The tuning curve for amplitude for the minimum-phase Ormsby wavelet is better predictable than that for the zero-phase Ormsby wavelet. The tuning curve for bed thickness, on the other hand, is more erratic for the minimum-phase wavelet than for the zero-phase wavelet. The tuning thicknesses for the minimum- phase wavelet estimated from snap horizon picking and manual horizon picking are $\lambda/2$ and $3\lambda/8$, respectively, greater than the theoretical resolution limit ($\lambda/4$). The tuning thickness for the zero-phase wavelet is $\lambda/5$.

Hydrocarbon volumes estimated from conventional amplitude maps are usually greater than those from detuned amplitude maps. Volumetric estimation for any amplitude plays, therefore, must be based on detuned amplitude maps that ideally reflect only variations in the acoustic properties of the reservoir rocks.

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