CHAPTER 2 AMPLITUDE RESPONSE ANALYSIS, WELL-SEISMIC TIE AND INTERPRETATION PITFALL

The next step after understanding the seismic rock physics is to do amplitude response analysis. When well data available, this step normally done together with well-seismic tie so the analysis can be focused on the target interval.

The prime objective of amplitude response analysis is to deduce the geological information from the amplitude. Types of geological information can be very varying depend to the type and quality of the seismic amplitudes. For a good quality of post-stack seismic amplitude data, it is often possible to deduce the information on the depositional environment, facies, lithology, relative porosity, and pore fluids.

2.1. Polarity and Phase

This book follows the Society of Exploration Geophysicists (SEG) definition on the polarity: *"The onset of a compression from an explosive source is represented by a negative number or a downward deflection when displayed graphically. A reflection indicating an increase in acoustic impedance or a positive RC also begins with a downward reflection. For a zero-phase wavelet, a positive reflection coefficient is represented by a central peak, normally plotted black on a variable density display"*. This convention is called positive standard polarity and the reverse convention is negative standard polarity or reverse polarity (Sheriff, 2002) as illustrated in Figure 2.1.

In an extremelysimplified way seismic pulses displayed on seismic sections can be grouped into two main types: minimumphase and zero phase (Figure 2.2). A minimum-phase pulse has its energy concentrated atits front, and mostly associate with explosive source. The pulse is said to be "front loaded," with itsonset at the acoustic-impedance boundary. Zero-phase pulses consist of a central peakand two side lobes of opposite sign and lesser amplitude.Here the boundary is located at the central peak and notat the wavelet onset as is the case for minimum-phasepulses.

Although a zero-phase pulse is theoreticaland is not physically realizable since it requires that particle motion begin before the wave-front reaches thesurface of the impedance contrast, this type of pulse offers the following advantages for structural interpretation (Figure 2.3):

1. Given the same amplitude spectrum, a zero-phase signal is always shorter and always has greater amplitude than the equivalent minimum-phase signal; ittherefore has a greater signal/noise ratio.

2. The maximum amplitude ofzero-phase signals alwayscoincides with the theoretical reflectivity spike. Themaximum amplitude of a minimum-phase signal isdelayed with reference to the reflectivity spike.

Correct determination of polarity type is very important in geological interpretation of seismic responses. When polarity information is not available, some references which can be used to determine it are the markers in log data or any horizons we certain about their reflection-coefficients values such as positive R of the sea-bed or gas-water contact (Figure 2.4).

2.2. Forward Amplitude Modelling

Seismic interpretation always involves forward and backward modeling processes. The common forward modeling for instances is in the generation of synthetic amplitude response models based on a known geology information; while the common backward modeling is the generation of geological model (for example rock type, facies, porosity, etc.) from seismic data (Figure 2.5). Modeling which constrained by well data will give more objective results.

When the polarity and phase are given, forward modeling of amplitude response of simple geology model with known rock physics and elastic properties can be done as illustrated in Exercise 2.1.

Exercise 2.1. Simple Amplitude Modeling

1. *Figure 2.6 shows several gas-fill reservoir models. Using normal polarity and zero-phase draw manually the amplitude response on top of reservoir and at gas-water contact (gwc) by following example in Figure 2.6a.*
2. *Figure 2.7 shows a model of reservoir ROCK-2 saturated by gas, oil and water. ROCK-1 is shale with porosity 0%. V_p matrix are 2500 m/s for sandstone, 2000 m/s for shale and 4000 m/s for limestone. Matrix density is 2.2 g/cc for sandstone and shale, and 2.7 gr/cc for limestone. The fluid's V_p values are 1500 m/s for water, 1300 m/s for oil and 300 m/s for gas. Gas and oil densities successively are 0.8 g/cc for oil and 0.001 g/cc for gas. ρ_w is water density of 1.0 g/cc. Density gas is 0.001 g/cc, density water is 1.0 g/cc, oil is 0.8 g/cc. Using Willye's approach and normal polarity zero phase calculate the V_p, density, Reflection Coefficient (RC) and draw amplitude responses at points 1, 2, 3, 4 and 5 for the following cases:*
   a. *Reservoir ROCK-2 is sandstone whose porosity ϕ is 30%*
   b. *Reservoir ROCK-2 is limestone whose porosity is 10%*

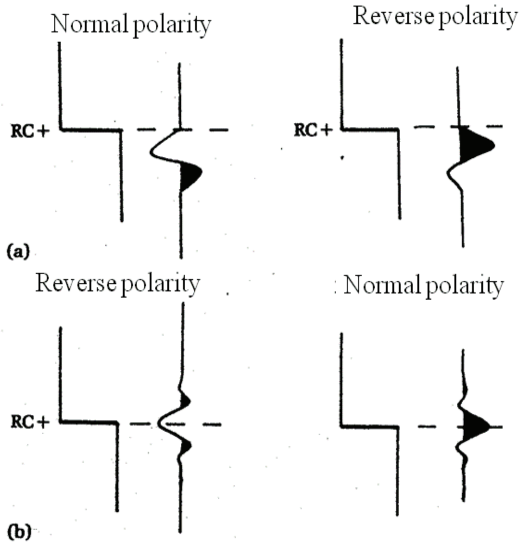


Figure 2.1 SEG standard polarity for (a) minimum-phase and (b) zero-phase wavelet (Sheriff, 2002).

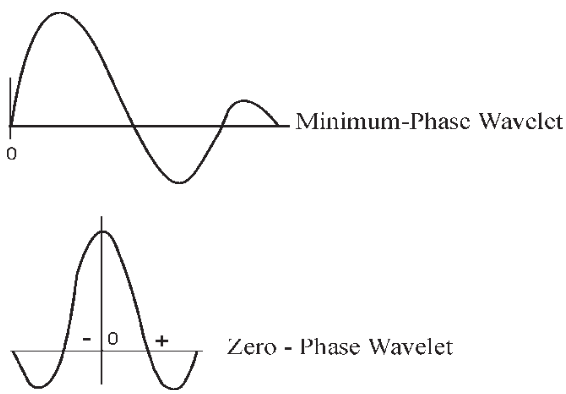


Figure 2.2 The minimum and zero phase wavelets

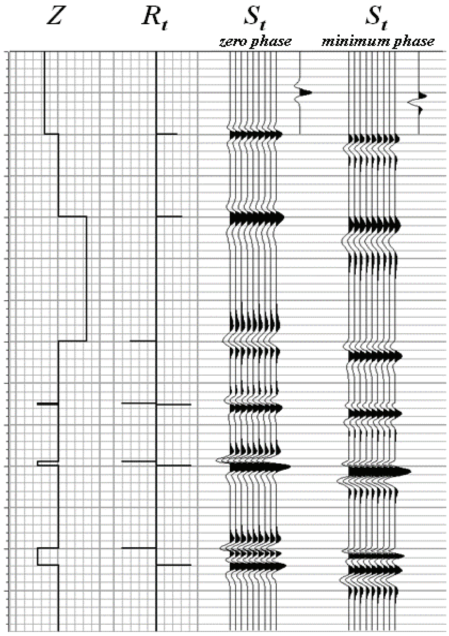


Figure 2.3 Illustration showing the effect of minimum and zero phase wavelet in seismic response. *Which wavelet is better for picking the associated R?*

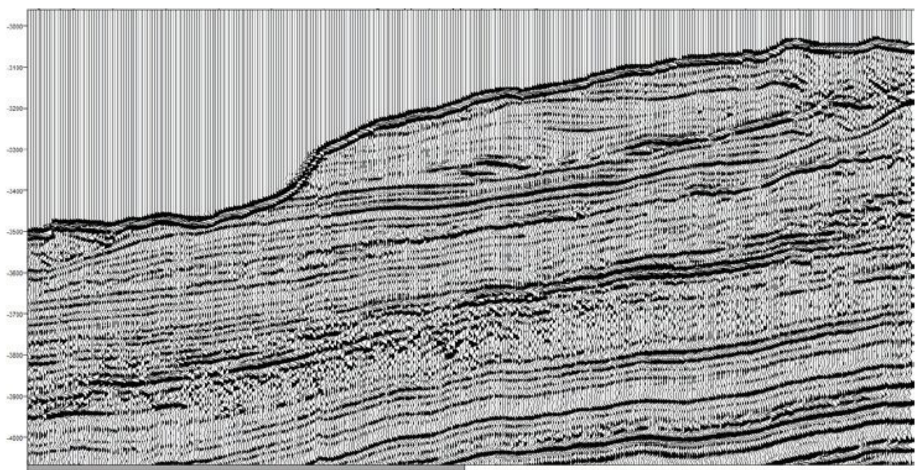


Figure 2.4 Example of marine seismic data. *What polarity and phase used in the display? If geology data says that the lithology is intercalation of sand-shale, could we identify the sand and shale in the section?*

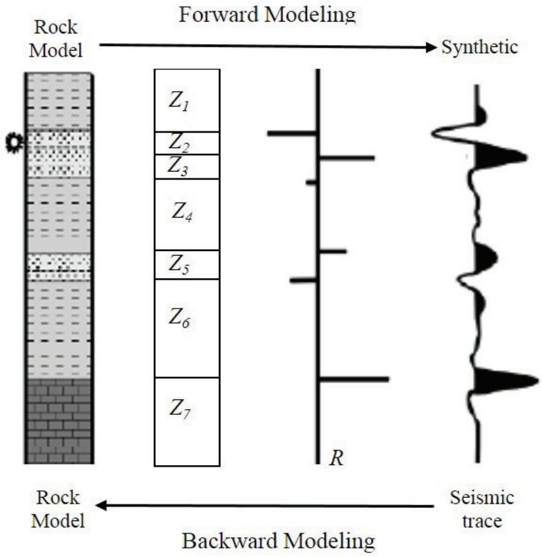
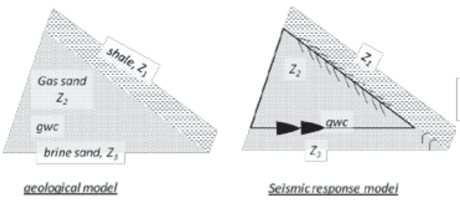
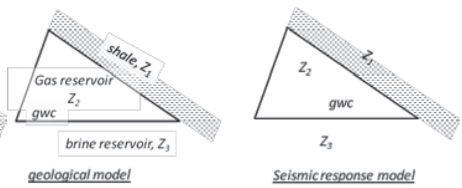


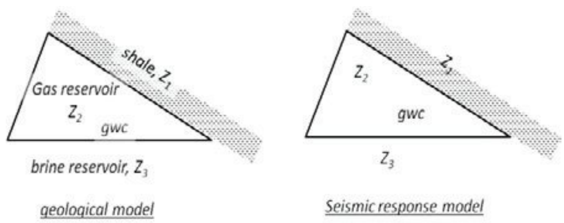
Figure 2.5 Illustration of forward and backward modeling



(a)



(b)



(c)

Figure 2.6 Gas-fill reservoir model for Exercise 2.1.1: (a) Reservoir: very porous sand ($Z_3 < Z_1$), (b) Reservoir: less porous sand or limestone (Z_3 is little bit bigger than Z_1), and (c) Reservoir: tight sand or limestone ($Z_3 >> Z_1$)

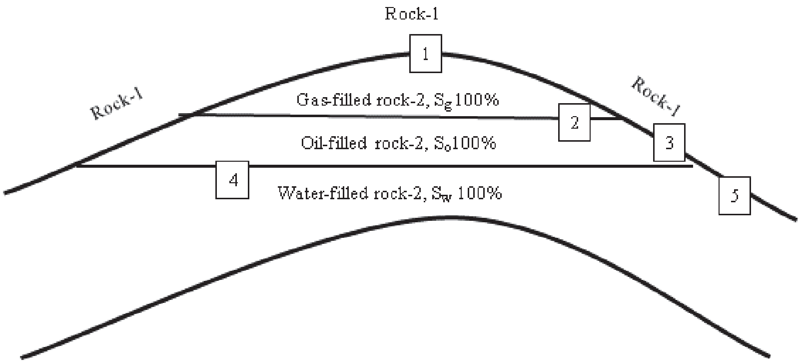


Figure 2.7 Model of anticline filled by hydrocarbon for Exercise 2.1.2.

A more quantitative way to forward model seismic response can be done by convolving the earth's reflectivity with a seismic wavelet which in the simplest form can be written as:

$$S_t = W_t * R_t \qquad (2.1)$$

where S_t = the seismic trace in time domain
W_t = a seismic wavelet in time domain
R_t =reflection coefficient in time domain

Matrix operation often usable to do the simple convolution process using zero-phase wavelet. In physical definition, the convolution describes behavior of how two energy wavelets combined. For example if there are two vectors [A] = [a_0 $a_1 a_2$ …] and [B] = [b_0 b_1 b_2…]. Their convolution are indicated by operator *, for example [C] = [A] *[B] which will produce the vector [C] = [c_0 c_1 c_2…]. The [C] element is given by:

$$c_i = \sum_{j=0}^{i} a_j b_{i-j} \qquad (3.2)$$

For example, if we want to convolute two vectors [A] and [B]. If the [A] = [a_0 a_1] and [B] = [b_0 b_1], so the first, second and third elements of the convolution result are :

$c_0 = a_0 b_0$, $c_1 = a_0 b_1 + a_1 b_0$, c2 = a1b1
or [A] *[B] = [C] = [a_0b_0 $a_0b_1 + a_1b_0$ a_1b_1]

Robinson and Treitel (1980) introduced a simple graphic method to do the two vectors convolution. For example the vector [A] = [1 3 5 7 2], while the vector [B] = [6 2 4], with the graphic way, the convolution can be written as :

$$
\begin{array}{c|ccc}
 & 6 & 2 & 4 \\
\hline
1 & 6 & 2 & 4 \\
3 & 18 & 6 & 12 \\
5 & 30 & 10 & 20 \\
7 & 42 & 14 & 28 \\
2 & 12 & 4 & 8
\end{array}
$$

Thus, [A]*[B] = [C] = [6 20 40 64 46 32 8]

Quantitative forward modeling very useful to predict the amplitude response associated with a certain geological model. Exercise 2.2 discusses the principle on how to do 1-D forward modeling to generate a single seismic trace using Excel to evaluate the amplitude responses of different lithology and pore-fluids, together with the effect of wavelet side-lobe used in the modeling.

Figures 2.10 shows an illustration on the fluid replacement modeling to predict the expected amplitude response. The principle of 1-D forward modeling can be extended for 2-D forward modeling as illustrated in Figures 2.11 where the purpose is to evaluate the change of the amplitude with the change of $S_{w.}$ The knowledge on how amplitude responses to a certain geological situation then used in the geological interpretation of the real seismic data, which basically is a back-ward modeling.

<u>Exercise 2.2. Forward Amplitude Modeling</u>
Using rock model given in Table 2.1 and wavelet in Figure 2.7 which simplified into W_t = {-20 70 -20}, construct the synthetic trace S_t using Robinson and Treitel (1980) approach and evaluate the effect of the wavelet side-lobe to the interpretation .