# On the Scattering Effect of Lateral Discontinuities on AVA Migration

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**ABSTRACT**
We have carried out numerical simulations to examine the transition from the specular reflection regime to the scattering regime in amplitude versus angle imaging. Theoretical AVA curves are compared with AVA curves extracted from migrated common image gathers using wave equation AVA migration. Care has been taken in order to obtain true amplitude gathers when the migrated waveforms are of specular nature. Our results show that when the lateral size of the anomaly becomes smaller than the dominant wavelength, the scattering regime will commence to dominate the common image gather. At this point, the classical specular reflector model, commonly used in AVO and AVA, brakes down.

## Introduction

Two types of attenuating phenomena affect seismic wave propagation. One is intrinsic attenuation, which is caused by anelastic absorption, and the other is apparent attenuation originating from scattering. Correction terms should be included in seismic data processing since attenuation can distort the amplitude of seismogram distinctly from the model deduced by elastic wave theory (Adriansyah and McMechan, 1998). By far much work has been done on the effects of scattering caused by thin layers (Shapiro, et al (1994), Widmaier (1996), Shapiro and Hubral (1996), Wapenaar, et al (1999)). However, AVA effects generated by lateral discontinuity have not gained much attention. The general AVA properties of complex structure are shown by Adriansyah and McMechan (1998) where they observed the mixture of effects produced by the lateral and vertical media complexity. In this paper, we will focus on the relationship between the extension of lateral discontinuities and the AVA behavior by carrying out numerical experiments.

## Ideal Formula For Specular Acoustic Wave Reflections

Following Berkhout's deduction (1980), the angle dependent reflectivity for a specular acoustic reflection is:

$$r(\alpha) = \frac{\rho_2 c_2 \cos\alpha - \rho_1 \sqrt{c_1^2 - c_2^2 \sin^2 \alpha}}{\rho_2 c_2 \cos\alpha + \rho_1 \sqrt{c_1^2 - c_2^2 \sin^2 \alpha}} \quad (1)$$

where $\alpha$ is the incident angle, $\rho_1, \rho_2$ are the densities of the two layers, $c_1$, $c_2$ are the velocities of the two layers. If $c_1 = c_2$, above formula becomes:

$$r(\alpha) = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \quad (2)$$

Therefore, if we accept the aforementioned condition (constant velocity), the reflectivity will be independent of the incident angle. We use a two-layer model as the ideal reference model (see *Fig. 1*). The CIG (common image gather) for midpoint position x=4000 is shown in *Fig. 2*. After wave equation AVA migration; we picked the AVA response (*Fig. 3*) and corrected it with Jacobian term (see later explanation) to get true amplitude estimates. The amplitude is not constant for all angles because of frequencies and aperture limitations.

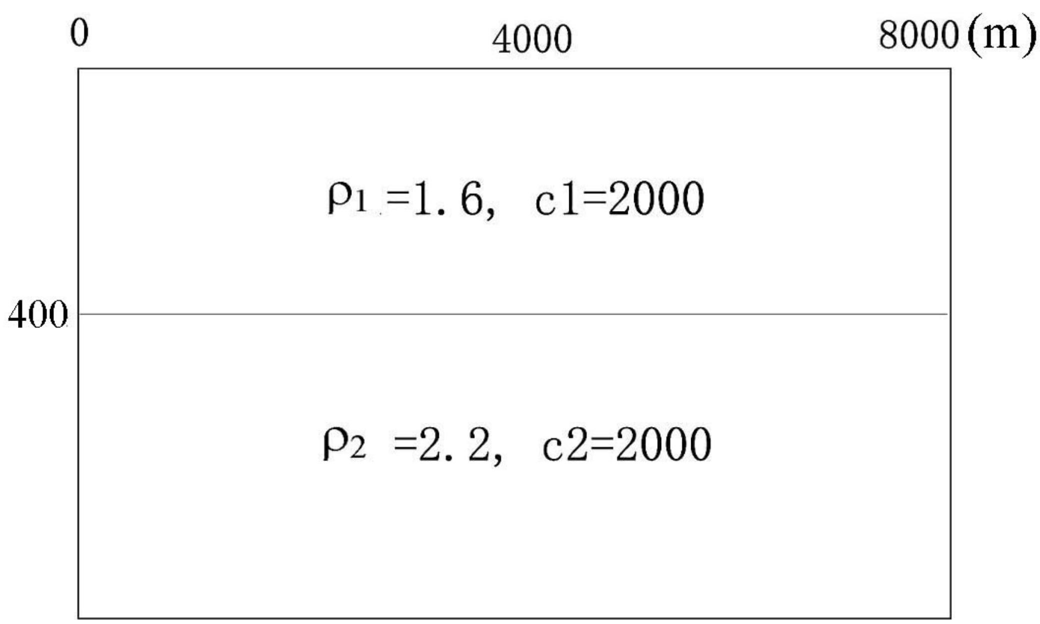


*Fig. 1. Geometry for the reference model ($\rho_1$, $\rho_2$: densities, g/cm, $c_1$, $c_2$: velocities: m/s)*

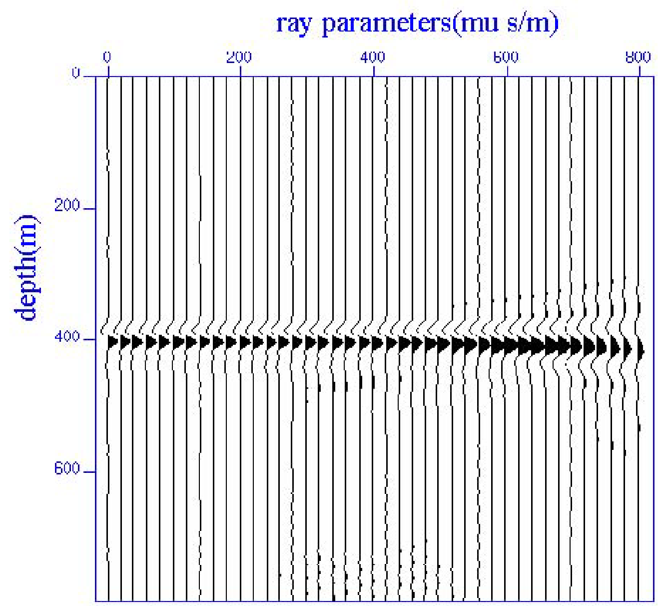


*Fig. 2 Common image gather for the reference model at x=4000m.*

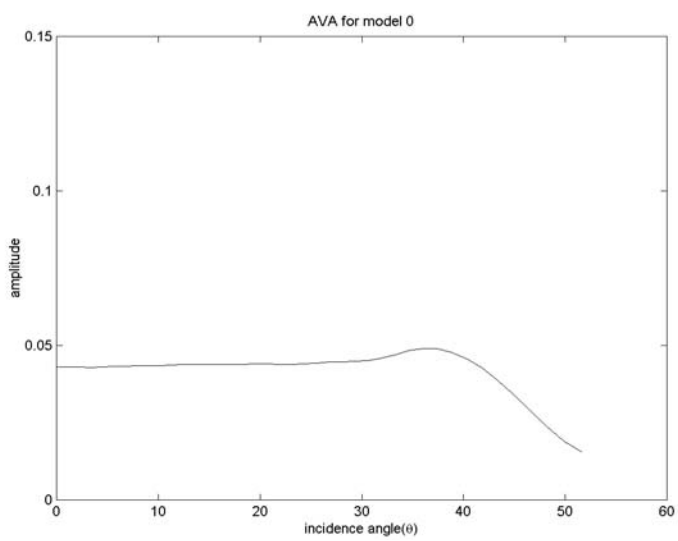


*Fig. 3 AVA for reference model 0*

**AVA Testing Procedure**

To find the relationship between the trend of AVA curve and the lateral discontinuity of geological body, we devise a processing flow for models in *Fig. 4*.

*(1) Data preparation*

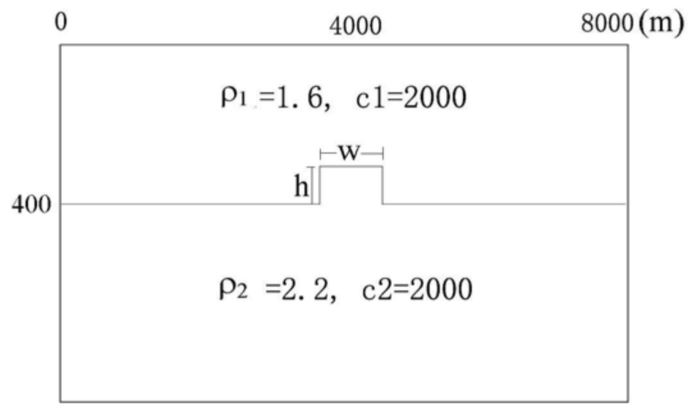


*Fig. 4 geometry for model 01-07, h=200m, w=200,160,120,80,40,24,16m for models 01-07, respectively*

We use the 2-D finite-differencing tools of the Seismic Unix software to synthesize seismograms for models described in *Fig. 4*. All these models consist of two layers. The upper one has smaller density of 1.6 $g/cm^3$, and the lower has density of 2.2 $g/cm^3$. The velocities are constant for both layers. This velocity structure simplifies our tests since the amplitude should be independent of incident angle if the wave obeys the acoustic reflection rules. Shot spacing is 20 meters; 201 shot are produced for each model, and each shot has 91 receivers (offset varies from 0 to 1800 meters). A Ricker wavelet with 30 Hz peak frequency is used to synthesize seismic traces. Each trace has 401 samples with a sampling rate of 0.004 second. Synthesized data are band-pass filtered (f1=1 Hz f2=10 Hz, f3=50 Hz, and f4=60 Hz) and sorted in midpoint numbers. Direct arrivals and refractions were muted.

*(2) Migration and AVA correction*

We use DSR AVP migration method (Kuehl and Sacchi, 2001) to produce CIGs in ray parameter domain datasets. Then change to angle domain using the following relationship:

$$\sin\theta = \frac{c(y,z)p_h}{2\cos\varphi} \qquad (3)$$

where $\theta$ is the incident angle, $\varphi$ is the dip angle (here it is equal to zero), $p_h$ is the offset ray parameter, and c is the acoustic velocity in the medium.

For efficiency, we use the Jacobian correction instead of least-squares inversion to get true amplitude. When the interface is horizontal, the weighted factor is (Wapenaar et al., 1999 ):

$$J^{-1} = \frac{2\cos\theta}{c} \tag{4}$$

**Synthetic Data Results**

The picked AVA for the same event on the top of the  anomaly (x=4000 m) are shown in *Fig. 5*.

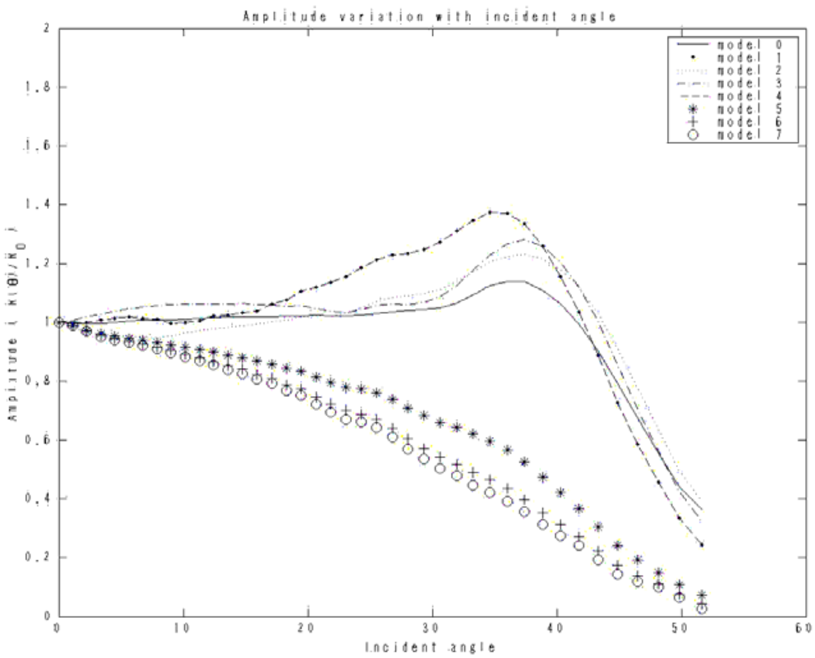


*Fig. 5. AVA profiles for model 0 ~ model 07. ( model 0 (solid line) is the reference model. )*

The amplitude for model 0 through model 4 is almost constant when the incident angle is less than 30°. When the angle increases, the amplitude increases and then decreases sharply. Since limited offsets and frequencies during data acquisition and migration account for the unavoidable AVA dispersion effect visible at large angles, we can say that the amplitude curve is consistent with the specular assumption.

The amplitude curves for model 5, 6 and 7 show a different trend. The amplitude decreases steadily with angle. *Formula 2*, which is derived using specular acoustic reflection assumption, breaks down.

What may have caused the transitions in the AVA responses? The eight models differ only in the width of the geological anomaly. When the width is larger than 80 meters (width of model 5), the amplitude is constant up to 40 degrees. On the other hand, if it is less than 40 meters (width of model 4), we do not observe the constant-amplitude trend. We may conclude that the critical width should be between 40 meters and 80 meters. This is close to the dominant wavelength in the data:

$$\lambda = \frac{c}{f} = \frac{2000}{30} = 66.7m$$

Our numerical tests show that the minimum anomaly size allowing the validness of the specular reflection assumption is nearly equal to dominant wavelength.

## Conclusion

Numerical tests have been used to test the limit of the specular reflection assumption in AVA imaging. Lateral anomalies with width below the dominant wavelength in the seismic probe will produce distorted AVA gathers that cannot be interpreted using the specular reflection assumption.


## Acknowledgement

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