Geophysical Tutorial: Thin Beds, Tuning, and AVO

Wes Hamlyn, Ikon Science Canada

In this tutorial we will explore two topics that are particularly relevant to quantitative seismic interpretation – thin-bed tuning and AVO analysis. Specifically, we will examine the impact of thin beds on prestack seismic amplitudes and subsequent effects on AVO attribute values.

The code used to generate results and figures presented in this tutorial can be found in two Python scripts at http://github.com/seg/tut Each script is self-contained and allows the user to investigate the impact of layer and wavelet properties on poststack and prestack seismic amplitudes.

Tuning refers to the modulation of seismic amplitudes due to constructive and destructive interference from overlapping seismic reflections. This phenomenon commonly occurs when a downgoing wave is reflected from multiple closely-spaced interfaces. If the resultant upgoing reflections overlap, the reflected seismic energy will interfere and alter the amplitude response of the true geology.

Let's examine this phenomnon using a zero-offset synthetic wedge model created using the `tuning_wedge.py` script (Figure 1). This model is generated using a 30 Hz Ricker wavelet and varying the thickness of Layer 2. For thicknesses greater than 40 m, we see that the amplitude response of the wedge is a constant value. This indicates that there are discrete reflections from the top and base of the wedge with no interference.

Below a thickness of 40 m, the effects of constructively interfering wavelet side lobes becomes apparent (i.e. amplitude increase due to tuning). Below approximately 18 m thickness we start to see destructive interference from overlap of the central wavelet lobes. Interpreting the geological meaning of these tuned seismic amplitudes is clearly more complex than the case of non-overlapping seismic reflections.

The wedge model is a standard tool in the interpreter's arsenal. It is routinely used to gain insight to the geological meaning of seismic amplitudes below the tuning thickness of a particular reservoir. The same tuning phenomenon that impacts zero-offset seismic data also affects prestack seismic amplitudes and prestack analysis techniques such as AVO.

Let's reconsider our initial wedge model. Instead of examining only the zero-offset case we now investigate a synthetic angle gather to assess the impact of thin-bed tuning on angle-dependent reflectivity.

Figure 2 is created using the `tuning_prestack.py` script. This Figure shows a synthetic angle gather and associated amplitude versus angle of incidence curves corresponding to the 18 m thick trace from our wedge model. Notice in this figure that there are two amplitude curves for the upper interface reflectivity, one corresponding to the convolved amplitude and another coresponding to the exact Zoeppritz P-to-P reflectivity. Explicitly, one is what we expect to record in the field (i.e. convolved amplitudes) and one is what we theoretically

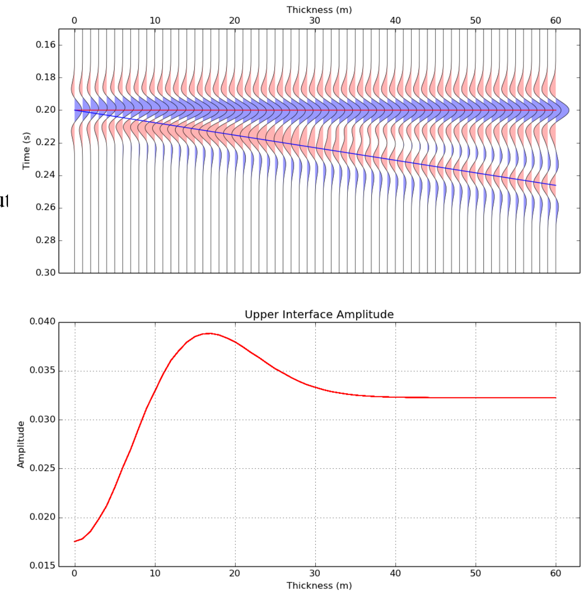

Figure 1: (top) Zero-offset synthetic seismogram for a 3-layer wedge model, displayed in normal polarity; (bottom) amplitude of wedge model extracted along top of layer 2

anticipate for a given V_P, V_S, and density model (i.e. Zoeppritz reflectivities).

Quite clearly there are differences in the reflectivities computed using Zoeppritz equations and the convolved synthetic. As previously discussed for the zero-offset case, an 18 m thick model will result in constructive interference along the upper interface. As expected, the convolved amplitudes are larger than the exact Zoeppritz reflectivities, but only for angles of incidence less than 27°. For angles of incidence larger than 27°the convolved amplitudes become smaller than the exact Zoeppritz reflectivities (i.e. destructive interference). This indicates that tuning due to thin beds is also dependent on incidence angle.

Let's now consider the impact of thin bed tuning on the AVO attributes, normal incidence reflectivity (R_0) and gradient (G) calculated for the top of our wedge.

We calculate R_0 and G attributes by fitting Shuey's equation,

$$R(\theta) = R_0 + G\sin^2\theta, \tag{1}$$

to the amplitude values for the upper interface. These attribute values are summarized in Table 1.

For our 18m thick wedge there is a significant difference between R_0 and G values computed from the convolved synthetic and exact Zoeppritz amplitudes. As AVO is an amplitude based analysis technique, tuning caused by thin beds will manifest similar errors when inverting for other AVO attributes.

In summary, thin bed tuning affects both poststack and prestack seismic amplitudes. Simple synthetic modeling tools such as those presented in this tutorial allow you to gauge the impact of thin bed tuning on seismic amplitude interpretation and analysis techniques.

Table 1: AVO inversion of convolved and exact Zoeppritz reflectivities from the wedge model upper interface produce significantly AVO attribute values.

Reflectivity Curve	R_0	G
Zoeppritz	0.03168	-0.05671
Convolved	0.03797	-0.08555

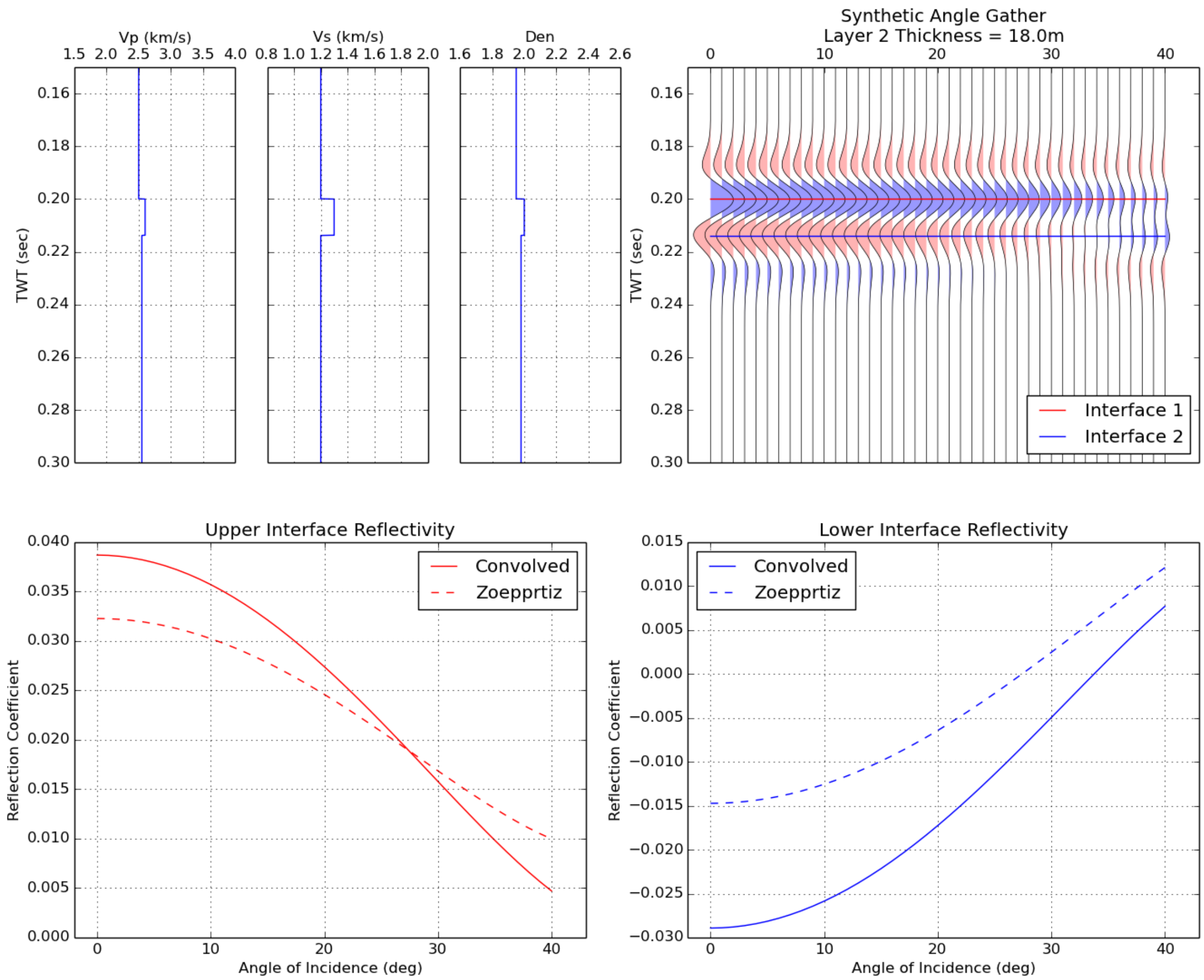

Figure 2: (top left) Input properties for synthetic model; (top right) synthetic angle gather for the 3-layer model, displayed in normal polarity; (bottom left) reflectivity amplitudes extracted along upper interface; (bottom right) amplitude of wedge model extracted along lower interface.

REFERENCES

Aki, K., and P. G. Richards, 2002, Quantitative seismology.

Chung, H.-M., and D. C. Lawton, 1999, A quantitative study of the effects of tuning on avo effects for thin beds: Canadian Journal of Exploration Geophysics, **35**, 36–42.

Mavko, G., T. Mukerji, and J. Dvorkin, 2009, The rock physics handbook: Tools for seismic analysis of porous media: Cambridge university press.

Widess, M., 1973, How thin is a thin bed?: Geophysics, **38**, 1176–1180.