Comparison of an Estimated Shear Wave Log with a Measured Shear Wave Log*

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Abstract

This study presents a work flow for quantitative interpretation of sonic and seismic data. Measured data collected at the point of logging can be fraught with errors that can lead to wrong interpretation. Examples of such data are the shear wave velocity, and the compressional wave velocity.

The measured shear wave and compressional wave velocity log may contain errors that are due to drilling conditions, mud invasion, etc. They may also contain cycle skips and might have a lot of missing data and information. It is the poor quality of this type of log that has often made well log analysis companies and log interpreters neglect the measured shear wave log and subsequently generate or create an estimated shear wave log which they use for interpretation and modeling to check how the amplitudes vary with increasing offsets, among other uses.

The work flow presented in this study considers the effect of working with the measured data, a reprocessed shear wave log and a locally estimated shear wave log. Specific correction procedures for invasion of the logs was done and synthetic seismograms were created for each type after correction for comparison to 3D seismic data.

The results of this study suggest that oil-based mud invasion can cause significant problems to sonic logs. It also suggests that, if a shear wave log is of low or bad quality, a reprocessed shear wave log would be better for interpretation and modeling rather than a locally calibrated shear wave log or an estimated shear wave log using global predictions. The conclusion is evident from the synthetics generated using the measured shear wave data and the estimated shear wave data.

Figure 1 shows the origin of the problem to be solved. It is evident that the shear wave velocity (Vs) is of a poor quality while the compressional wave velocity (Vp) is of a good quality. However, the above shear wave velocity log was reprocessed to obtain a better Vs and this “better Vs”, hereafter refered to as the “Measured Vs”, is compared with another Vs which is generated from the Vp, after correction of the Vp for invasion. The Vs generated in the latter case is hereafter refered to as the “Estimated Vs”. Answers to the following questions would enable us to distinguish between two kinds of shear waves that are used in industry.

Questions:

- Why are there gaps in the measured Vs?
- Should we discard it even if it appears to be good over the reservoir zone?
- Have the logs been invaded, and if so, what is the extent of invasion?
- What is the difference between the original Vs and the reprocessed Vs?
- How can we estimate a Vs from the Vp and what constants must be used?
- Which is better and which would give a true representation of the subsurface? Is it the Measured (Reprocessed) or Estimated Vs ?

Problem of Invasion

The density, gamma and sonic logs cannot indicate whether or not there was invasion of the sandstones by the oil-based mud which was used for drilling. Hence, the resistivity log was used to determine the possible invaded zones. The resistivity log is very useful for estimation of water and hydrocarbon saturation, and it is the main key to detecting the zones of invasion. It is very important that the effect of invasion is considered when correcting sonic and density logs.

Figure 2 shows how the invading fluid sweeps away the reservoir fluid during drilling. This invasion is caused by relative pressure difference between the borehole pressure and formation pressure. The effect is to change resistivity, density, electric potentials, sonic velocities, and other logs which may be reading the invaded zone.

Oil based mud (OBM) filtrate invasion correction is more difficult than water based mud (WBM) filtrate invasion correction due to the fact that one cannot easily determine the type of invasion profile. Also one needs to consider the type of saturation in the water sands because we have a case of OBM filtrate with brine, unlike brine filtrate with brine in WBM. The oil based mud filtrate does not completely mix with the formation brine, so one may assume a kind of “patchy saturation” for which treatment is different from the “effective fluid behavior” (Mavko et al., 2003).

In a recent study by Carr et al. (2004) on oil based mud invasion, they showed the possible kinds of invasion profiles (see Figure 3) which may be present in both hydrocarbon saturated sandstones and water or brine saturated sandstones. Rxo and Rt are the resistivities measured in the shallow and deep zones respectively. Sw is computed from Rt, and Sxo is computed from Rxo; Swirr is the irreducible water saturation, which is always present in the pores of the sandstones.

From the resistivity log which was provided and the processed log showing the computed Sxo and Sw, we notice that Sxo is lower than Sw in the water saturated sandstones because OBM and brine have different resistivities, whereas in the oil sandstones Sxo is about the same as Sw because OBM and natural oil have very high resistivities.

Methodology for Models

Two main models were considered namely the "Measured Shear Wave Model" and the "Estimated Shear Wave Model". For both models, the extent of invasion of the density and sonic log was not known initially. Also from the resistivity log provided, we confirmed that there was indeed invasion in the oil and wet sandstones. However, the density log has more probability of reading invaded values than the sonic log. This is because the depth of investigation of the density tool is less than that of the sonic. Because we cannot easily measure the extent of invasion of both logs, we make a general assumption that the logs were *partially invaded*.

Before correcting the velocities, the density log was also corrected for invasion, and this was done in two steps:

1) Calculation of porosity - from the measured density log which was assumed to be invaded.
2) Fluid substitution, i.e. obtaining the density of the *in situ* state, hereby referred to as the "Corrected Density".

<u>Measured Shear Wave Model</u>

- Import Measured Shear Wave Velocity log and Measured Compressional Wave (Vp) Velocity log and use the measured Vp and Vs, and the Corrected Density to calculate the Shear and Bulk moduli of the initial fluid saturated sandstones.
- Perform fluid substitution using Gassmann's relations to obtain the saturated bulk moduli of the new fluid saturated states, i.e. oil in Oil-saturated sandstones and brine in Brine-saturated sandstones.
- Calculate the corrected Vp from the new bulk modulus.
- Calculate the new Vs (corrected Vs) from the new shear modulus.
- Using the corrected density, Vp and Vs, create synthetics for the "Measured Model" for comparison with the real seismic data.

Estimated Shear Wave Model

- Import the Measured Compressional Wave Velocity (Vp) log, without any Vs.
- Use the modified form of Gassmann's relations to obtain the P-wave moduli of the initial fluid saturated sandstones.
- Perform fluid substitution in order to get the corrected Vp of the respective fluid saturated states, i.e. oil or brine.
- A crossplot of the original Vp and Vs is used to generate "fitting" constants.
- Use the "fitting" constants to estimate a Vs using the Greenberg-Castagna algorithm.
- Using the Corrected Density, corrected Vp and estimated Vs, create synthetics for the Estimated Model for comparison with the real seismic data. Finally compare the synthetics from both models to choose the best fit.

Results and Conclusions

In the figures below, it should be noted that "*in situ*" represents the nature of the subsurface prior to drilling and it is a section of the subsurface extracted from the seismic data. Here, we have assumed that the processed seismic data is a true representation of the subsurface.

Simmons and Backus (1994) showed that primaries-only Zoeppritz modeling of thin layers can be very misleading and that synthetic seismograms obtained by use of a linearized approximation (Aki and Richards, 1980) to the Zoeppritz equations to describe the reflection coefficients are more accurate than those obtained by use of the exact Zoeppritz reflection coefficients.

Using the Aki and Richards algorithm, still in the same reservoir zone on the Measured Shear Wave Model, we obtain what is shown in Figure 5. The long offset reflection events on the Aki-Richards gather look more like the *in situ* gather than do those on the Zoeppritz gather.

The conclusion can be drawn that the measured S-wave log, properly corrected, is closer to the truth than the estimated log in the case of oil-based mud. There seems to be no reason why this conclusion should not be the same for water-based mud. Another conclusion is that it is better to use Aki and Richards than Zoeppritz in AVO modelling.

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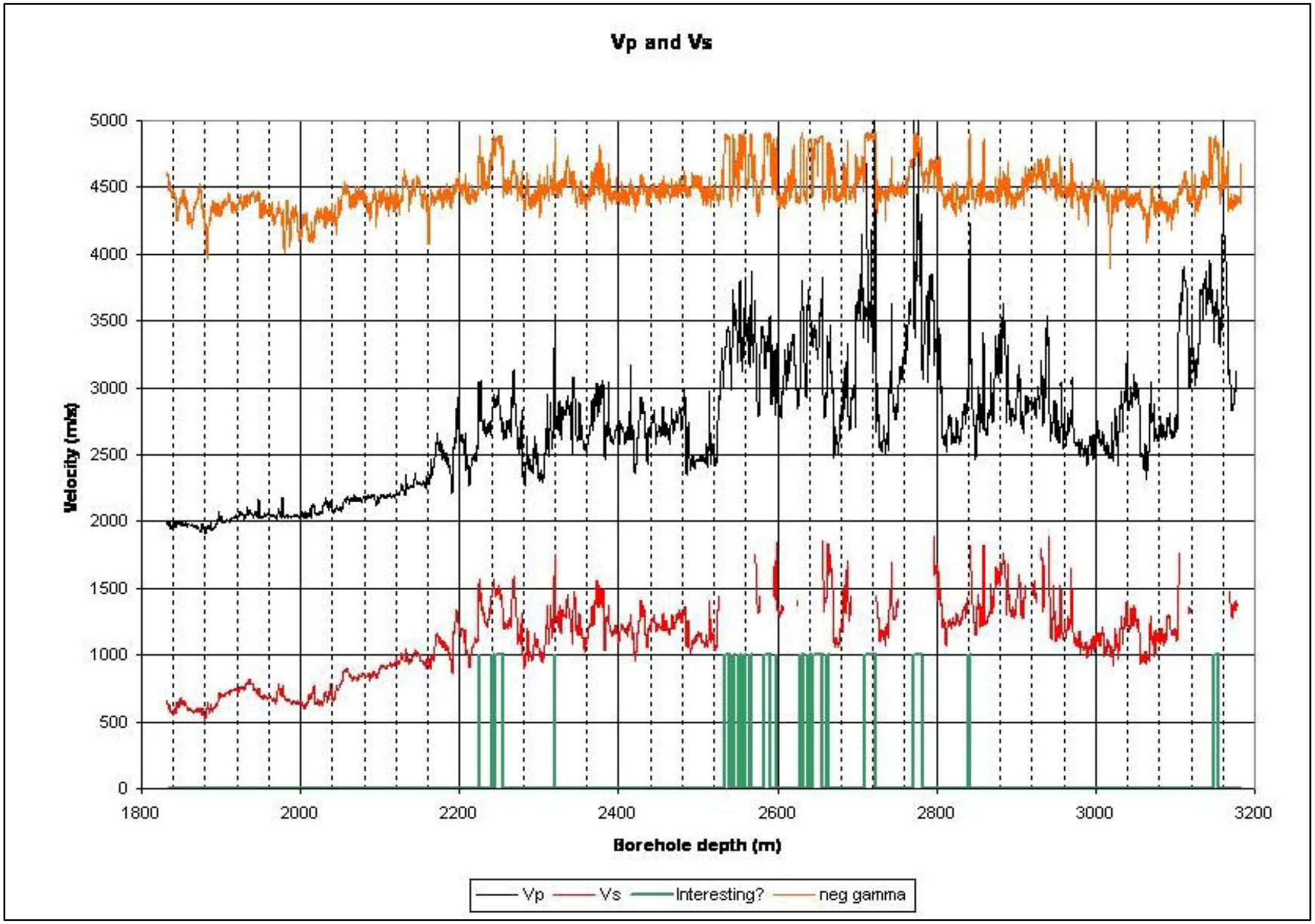

Figure 1. Original sonic logs collected from well site.

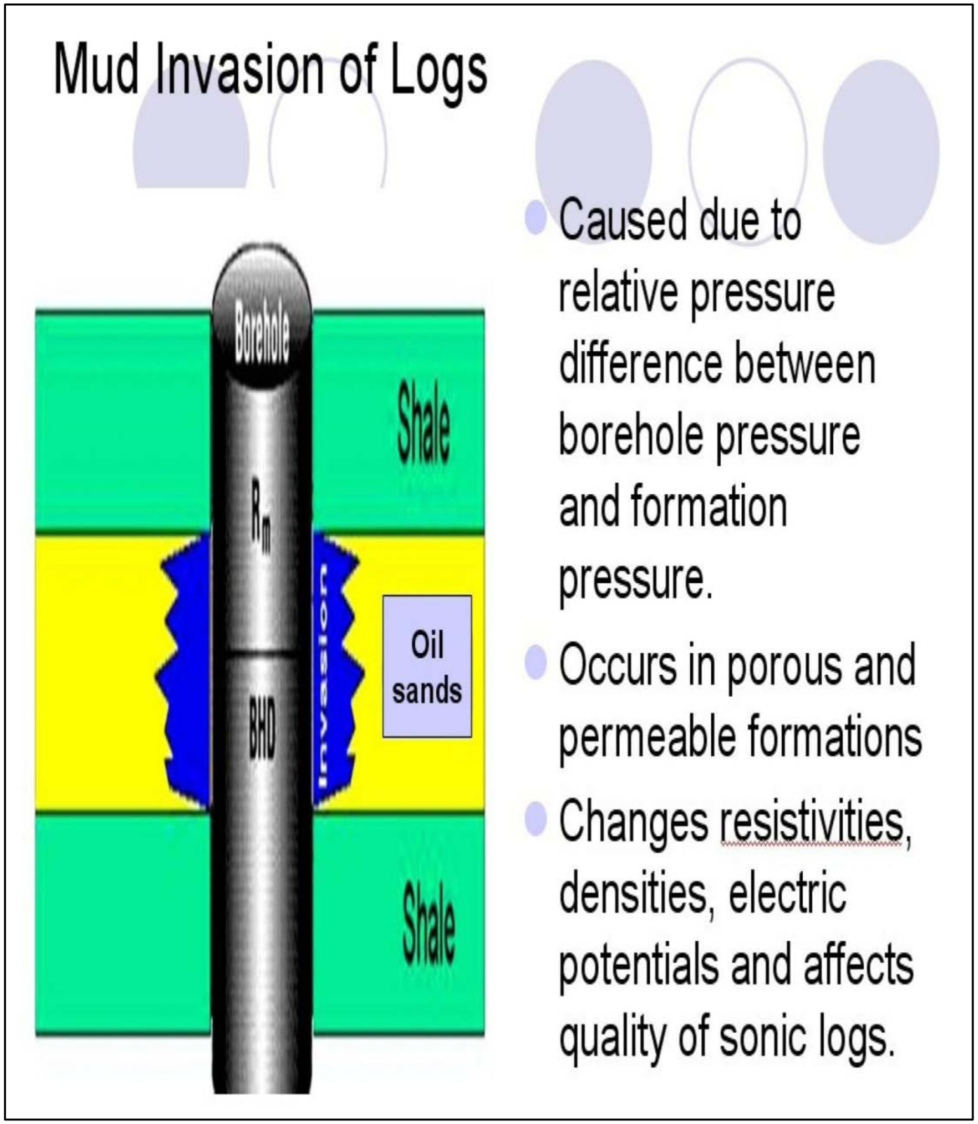

Figure 2. Mud invasion of logs (Walls and Carr, 2001).

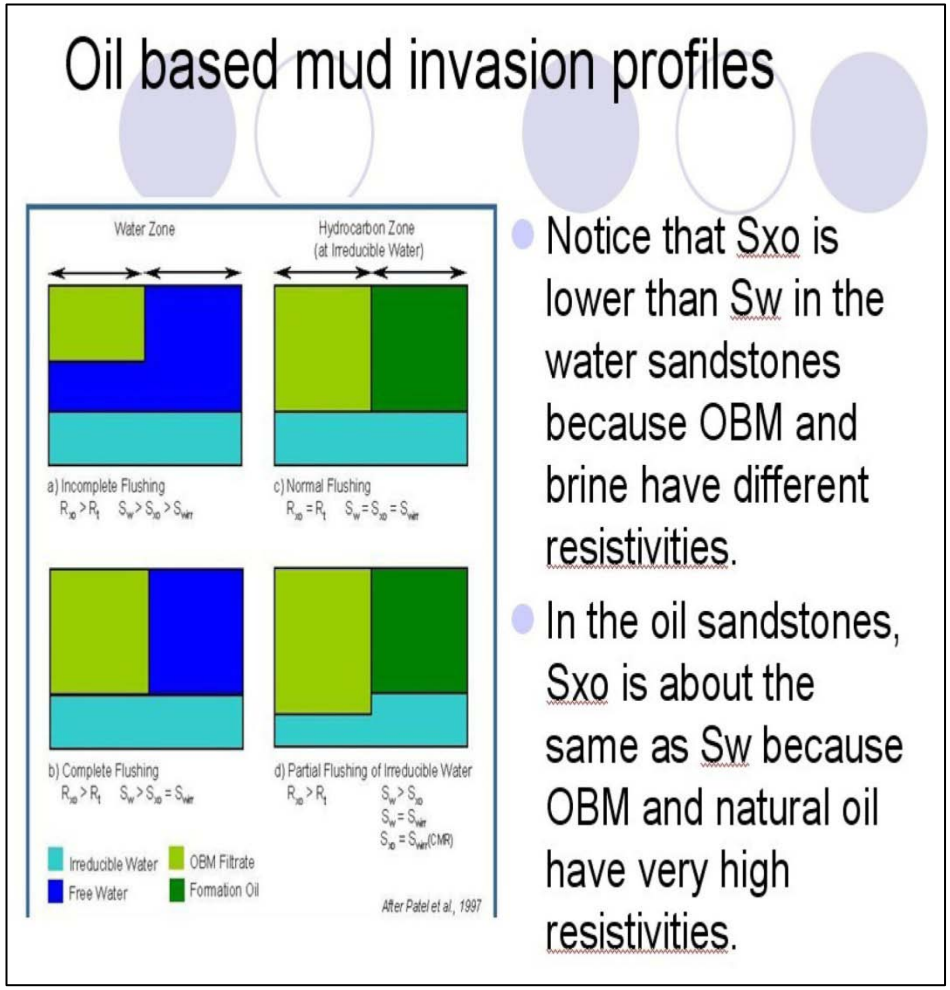

Figure 3. Oil-based mud invasion profiles (Carr et al., 2004).

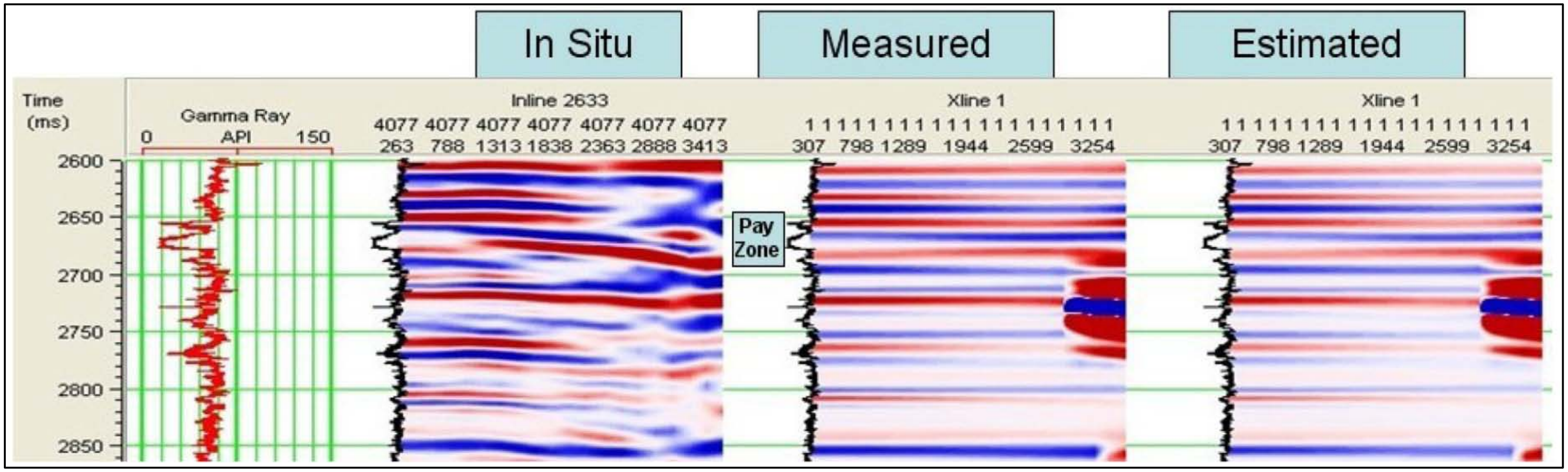

Figure 4. Comparison of synthetics from Measured Model and Estimated Model.

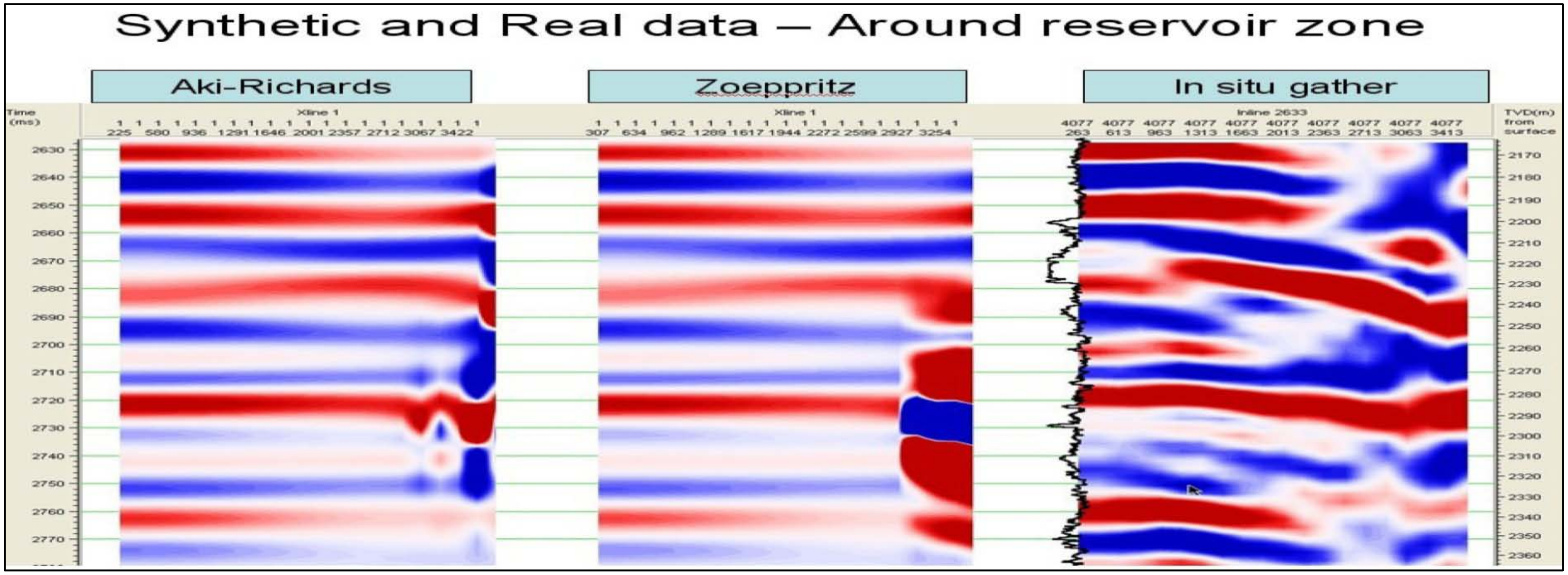

Figure 5. Two different synthetics of the Measured Shear Wave Model.