GC Synthetic Seismograms for PS Seismic Data*

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General Statement

Over the last few years, several articles on multicomponent seismic data have appeared in Geophysical Corner by Bob Hardage and his co-authors describing various aspects of processing and interpretation of such data:

Simultaneous-Source High Fidelity Vibroseis System Cuts Time and Cost, Search and Discovery Article #40688.

Recording Shear-Wave Data in P-Wave Seismic Programs, Search and Discovery Article #40701.

Fracture Identification and Evaluation Using S Waves, Search and Discovery Article #40792.

Multicomponent Seismic Augments Seismic Stratigraphy Interpretation, Search and Discovery Article #40888.

In this article, we address an important question about correlation of synthetic seismograms with converted wave PS seismic data. When a seismic wave (compressional or P-wave) impinges on a rock interface at oblique incidence, the contrast in the elastic parameters it encounters results in compressive and shear stresses. As a result, partitioning of energy takes place at the interface. This means that besides the reflection and refraction of the incident P-wave, there is P to S energy conversion. Thus an incoming P-wave gives rise to a reflected P-wave, a transmitted P-wave, a reflected S-wave and a transmitted S-wave as we show in Figure 1.

The partitioning of energy of the incident wave that takes place at the interface into different components is dependent on the angle of incidence as well as the elastic parameters, which can all be derived from the P-velocity, S-velocity and density of the two media defining the interface. The angular relationships between the different wave components are governed by Snell's Law (which we all studied in high school) and the amplitude relationships between the incident wave and the reflected, transmitted and converted-wave components are described by Zoeppritz equations, which we have referred to in our earlier articles:

[An ‘Elastic Impedance’ Approach, Search and Discovery Article #41082.]()

[Prestack Impedance Inversion Aids Interpretation, Search and Discovery Article #41664.]()

Synthetic Seismogram Generation

What we have stated above is that conversion of energy (P to S) takes place at oblique incidence of the incident waves. We may emphasize this aspect as normal for the incident wave – there will be no conversion of energy, and for angles of incidence less than 10 or 12 degrees, there is no detectable conversion. This PS data, when acquired and processed, may not show any visible amplitudes corresponding to such small angles of incidence. This is a consequence of the fact that PS waves follow asymmetric illumination ray paths at the reflecting surface, compared with the symmetric ray paths for the PP waves as seen in the conventional survey geometry (common mid-point reflection).

Synthetic seismograms are usually generated from well log data for identifying reflection events on stacked seismic data corresponding to different subsurface rock interfaces. The sonic and density log curves are used for generating an impedance log and the reflectivity derived therefrom is convolved with a wavelet to produce a synthetic trace at the location of the well. The wavelet used can be a mathematical wavelet of an appropriate frequency such as a Ricker wavelet, or it could be extracted from seismic data in the broad zone of interest using a statistical process, or it could be extracted by making use of well log data and seismic data.

Whatever method is used for generating the wavelet, it generates the synthetic trace, which is compared with the seismic data and interpretation made thereof. Such a simplistic process for synthetic seismogram generation assumes normal incidence of the seismic waves, which is what is implied for stacked seismic data as well as the well log data.

For PP seismic data interpretation this works well. This is not to say that every time we correlate a synthetic seismogram with real seismic data, we end up getting a good match. This could serve as a topic of discussion for another article, wherein reasons for commonly observed mismatch of well ties could be enunciated.

For PP stacked seismic data, the synthetic seismogram generation described earlier will serve well. But for PS stacked converted wave data, the above process may not be accurate, as the reflectivity is zero for normal incidence and thus the convolution of a normal incidence reflectivity with a wavelet makes no sense.

Pseudo Density

So, how do we correlate PS stacked seismic data with well log data? There are a couple of ways to address this question. One way to compute the PS-reflectivity is to use an approximation to the Zoeppritz equations (Aki and Richards) with use of P-velocity, S-velocity and density information. Once the PS-reflectivity is computed, it can be convolved with a statistical wavelet extracted from the PS seismic data to obtain a PS synthetic seismogram. As PS reflectivity is a function of the angle of incidence, and the amplitude information on the near-offset traces is not optimum, in practice PS synthetic seismograms are computed over a range of angles (usually 10 to 25 degrees), with each correlated with the PS stack data. The PS synthetic seismogram that gives maximum correlation with PS stack data is then selected. This works well.

In this article, we describe another approach that was first described by Valenciano and Michelena, and presented at the 2000 SEG Meeting. They demonstrated that PS normal incidence reflectivity can be approximated by introducing a quantity called “pseudo density,” which is a function of the medium density and ratio of P- and S-velocities.

Using the dipole sonic and density curves, we derived the pseudo density curve, in blue, as shown in Figure 2. The measured density curve is shown in red. The synthetic seismogram generated in Figure 2 using reflectivity derived with S-velocity and measured density is shown in Figure 2d. The equivalent synthetic seismogram derived using the reflectivity from pseudo density is shown in Figure 2f.

Notice, as indicated with yellow arrows and in the highlighted zone, there are differences in the reflection coefficients and hence the amplitudes. In each case the same wavelet derived within the time zone marked with orange bars was used and shown on the top right. Such differences may appear small, but can make appreciable differences going forward when reservoir properties are derived with the use of the PP and PS seismic data, or the confidence imposes in zones with mismatches.

Registration Process

For making use of PP and PS seismic data, one of the first steps to follow is to correlate the seismic reflections on the two sections, a process called “registration.” This is usually done manually, though some other existing methods could also be adopted with varied degrees of success.

As the travel times of the reflection events on the two datasets are different (P-waves travel faster than S-waves), PP and PS synthetic seismograms are generated for correlation with the respective stacked datasets. Besides the stacked datasets, prestack PP and PS data are also used for deriving elastic reservoir properties such as with the use of prestack joint inversion. This necessitates the careful processing of PS prestack data and the subsequent correlation with modeled PS gathers.

For modeling prestack seismic data, usually the travel time as a function of offset is calculated using a ray-tracing technique, and Zoeppritz equations are used for generating amplitude information. Together, the composite information defines the prestack gather for a given geometry, which is chosen similarly to the geometry of the real seismic data for which the gather is being modeled. This way gathers are modeled for both PP and PS seismic data.

The data example shown is from northwest Alberta, Canada, where the Devonian Duvernay Shale has been the source rock for many of the large Devonian oil and gas pools in Alberta, including the early discoveries of conventional hydrocarbons near Leduc. This fine-grained and silica-rich shale unit is overlaid by the Ireton (calcareous) and Winterburn shale units, and over which lays the Wabamun limestone unit. The Duvernay unit is underlain by a thin carbonate-rich shale layer that overlies the Swan Hills reefal unit.

The stratigraphic column shown to the left of Figure 3 illustrates these units. In the same figure we show the correlation of P-velocity, S-velocity and density curves (seen in Figure 3a) with stacked data (Figure 3b). Also shown in the figures are the equivalent correlation of PP modeled elastic gather (Figure 3c) with the real PP raw processed gather (Figure 3d), and its conditioned version (Figure 3e). Notice the differences in the gathers and the stacked data at the locations indicated with pink and purple arrows. The reasons for such mismatches need to be explored. In our exercise these points of mismatch lie outside of our zone of interest and thus were left alone.

For comparison, in Figure 4 we show the equivalent PS seismic data correlation. Notice the following prominent differences, apart from some others:

- The difference in the travel times of the PP and PS data.
- The first two traces on the PS gather showing very weak amplitudes as mentioned earlier.
- The difference in quality of the PP and PS prestack seismic data. PS data is usually noisier.

Conclusion

We thus conclude that the PS synthetic seismograms should be calculated accurately using one of the available methods. We have described a method wherein pseudo density is first calculated to approximate the normal incidence PS reflectivity, which is then used for generating a PS synthetic seismogram.

Acknowledgement

We thank Arcis Seismic Solutions, TGS, Calgary for permission to present this work.

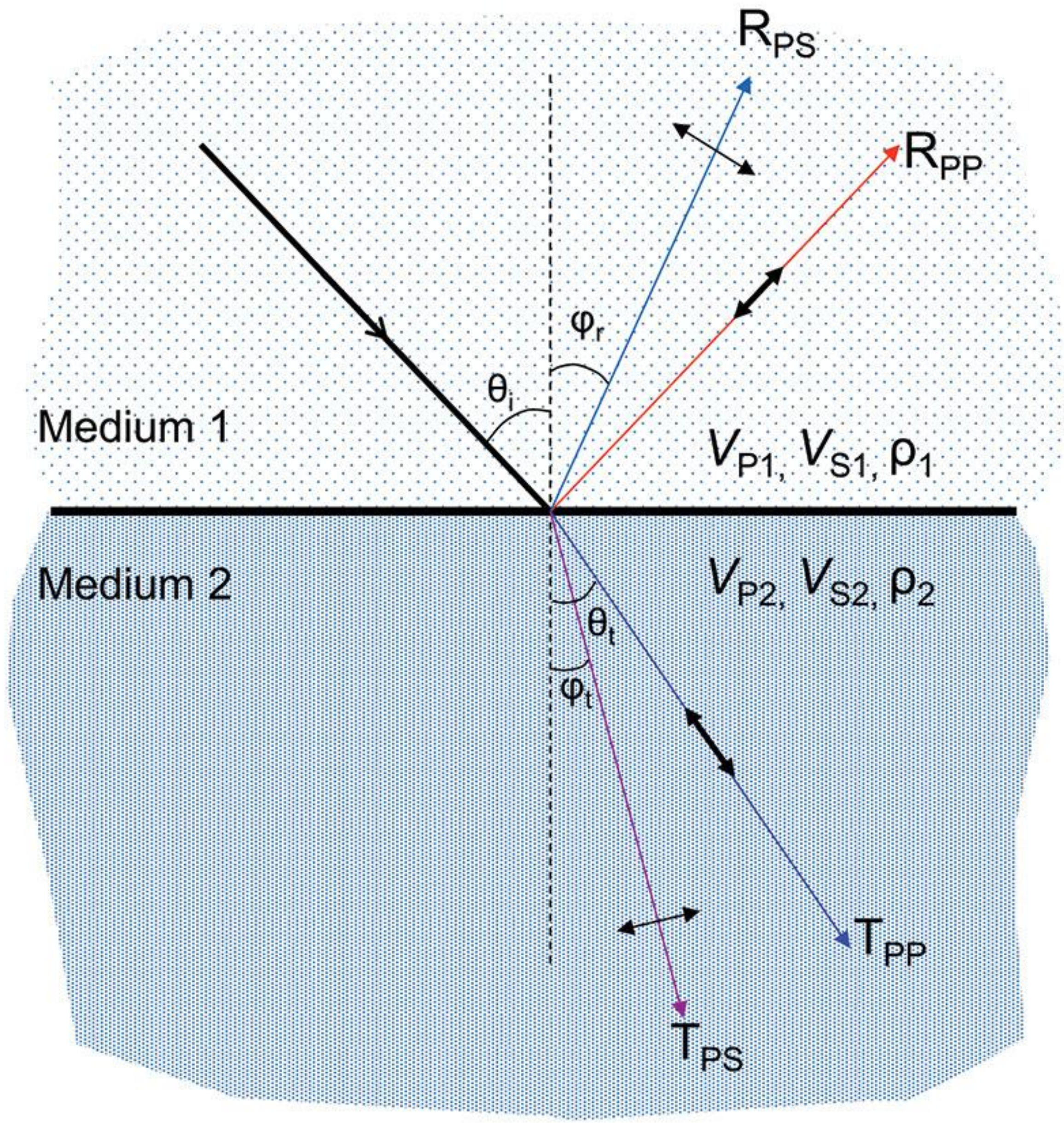

Figure 1. Ray paths for a seismic wave that is incident on an interface and splits up into four separate components. The particle motions are shown schematically for the individual waves.

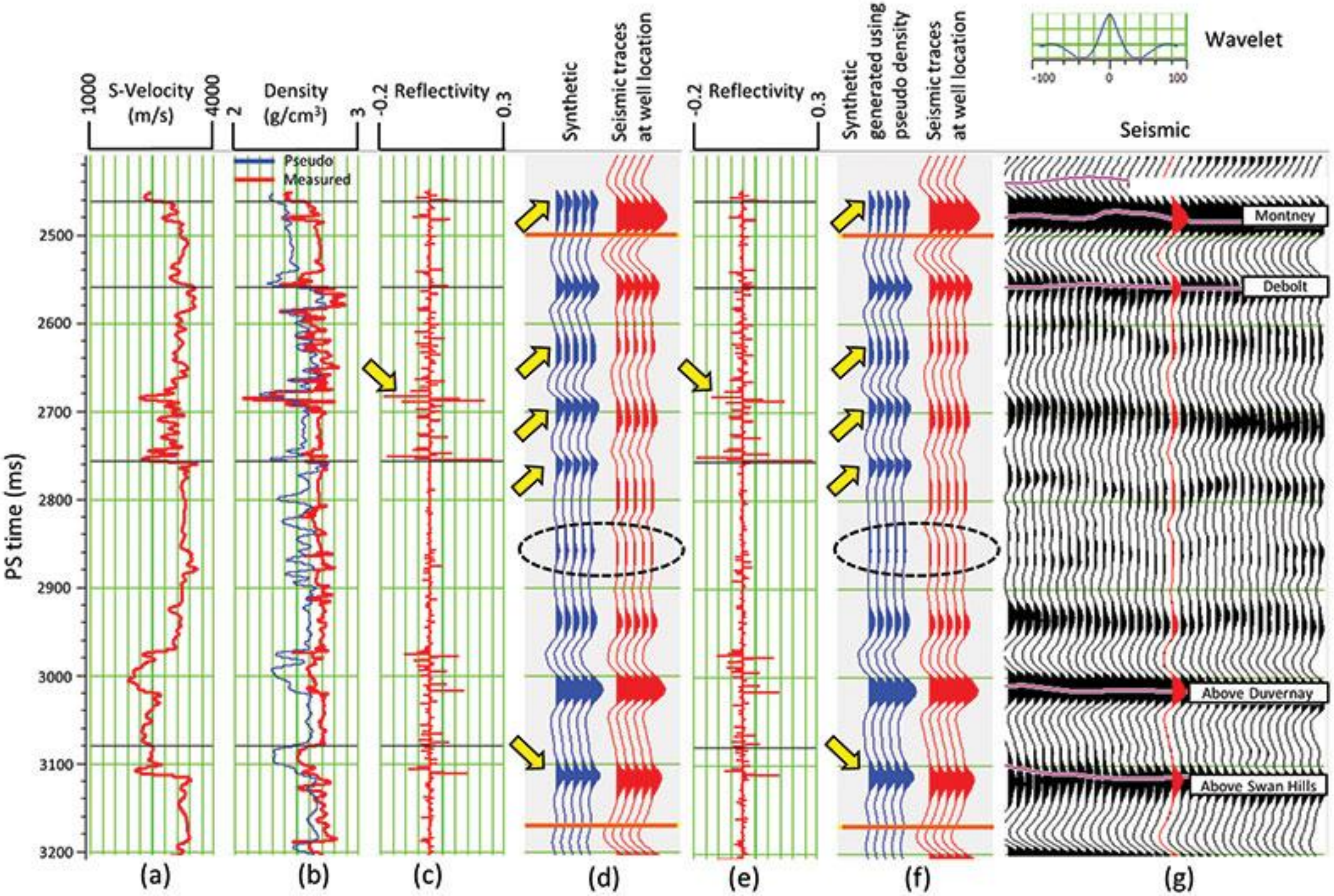

Figure 2. Well to seismic tie for PS data. (a) S-velocity well log curve, (b) the measured density curve in red, the estimated pseudo density curve in blue, (c) reflectivity derived from these two curves. (d) The blue traces are the synthetic traces derived from the reflectivity and using the wavelet shown on the top right. The red seismic traces are the PS data at the location of the well. Most of the reflection events seem to correlate well on the blue and the red traces, except at the locations marked with yellow arrows. (e) Reflectivity calculated from the pseudo density and S-velocity, which in turn is used for generating the blue synthetic traces in (f). The PS seismic data is shown in (g). Notice the differences between the reflection amplitudes indicated with the yellow arrows. The correlation with pseudo density reflectivity seems to be better as indicated by the correlation coefficient increase from 76 percent with (d) and 78 percent in (f). Data courtesy: Arcis Seismic Solutions, TGS, Calgary.

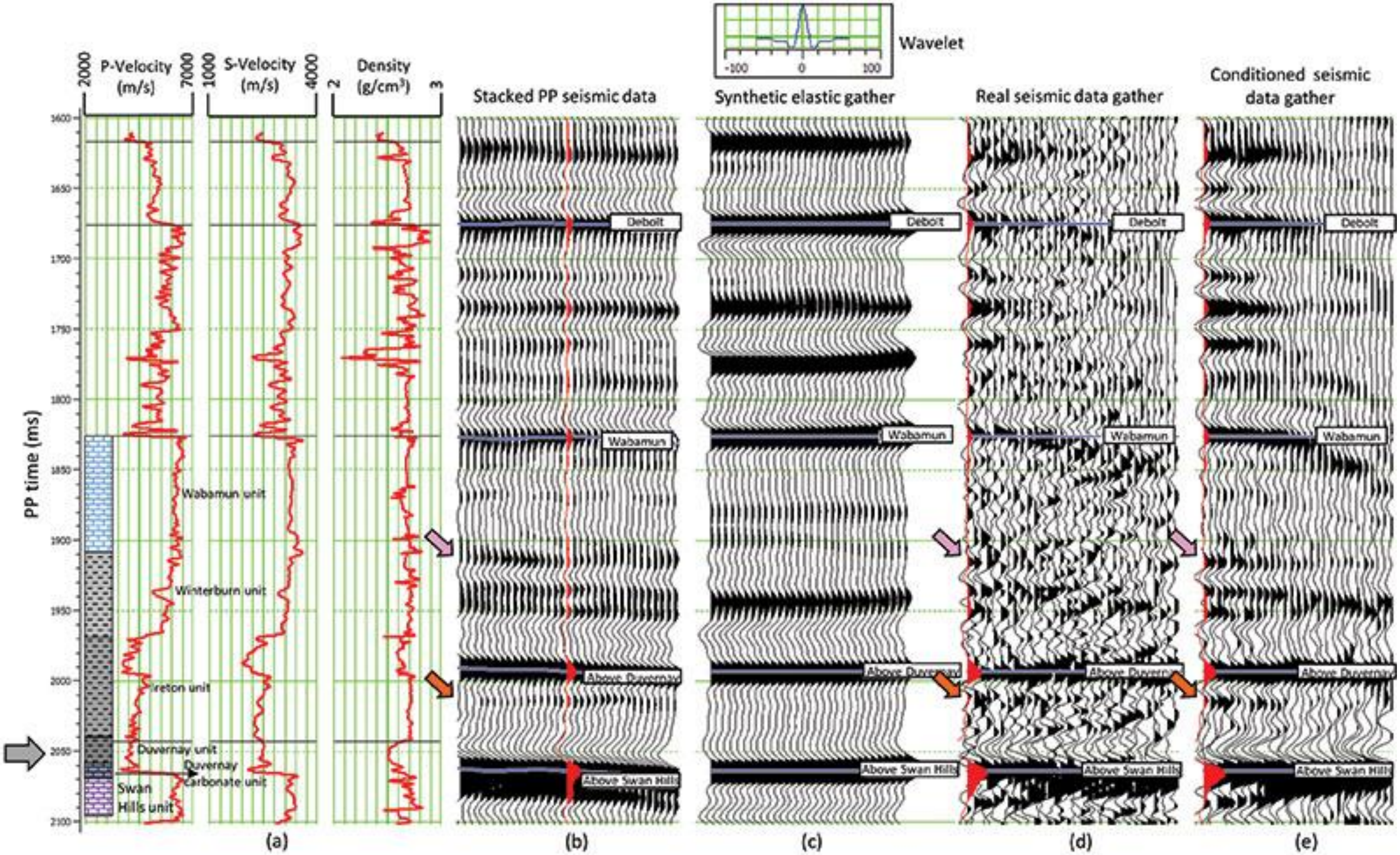

Figure 3. The P-velocity, S-velocity and density curves measured in a well are shown in (a), and are seen correlated with PP seismic data in (b). A synthetic elastic gather generated from the three curves is shown in (c). A real seismic PP gather at the location of the well is shown in (d). This data has not been conditioned for any amplitude analysis. The conditioned version of the gather in (d) is shown in (e). It is interesting to note the differences as indicated with the pink and orange arrows. Also, the stacked data and the prestack data correlation shows the similarities and differences that are open to interpretation.

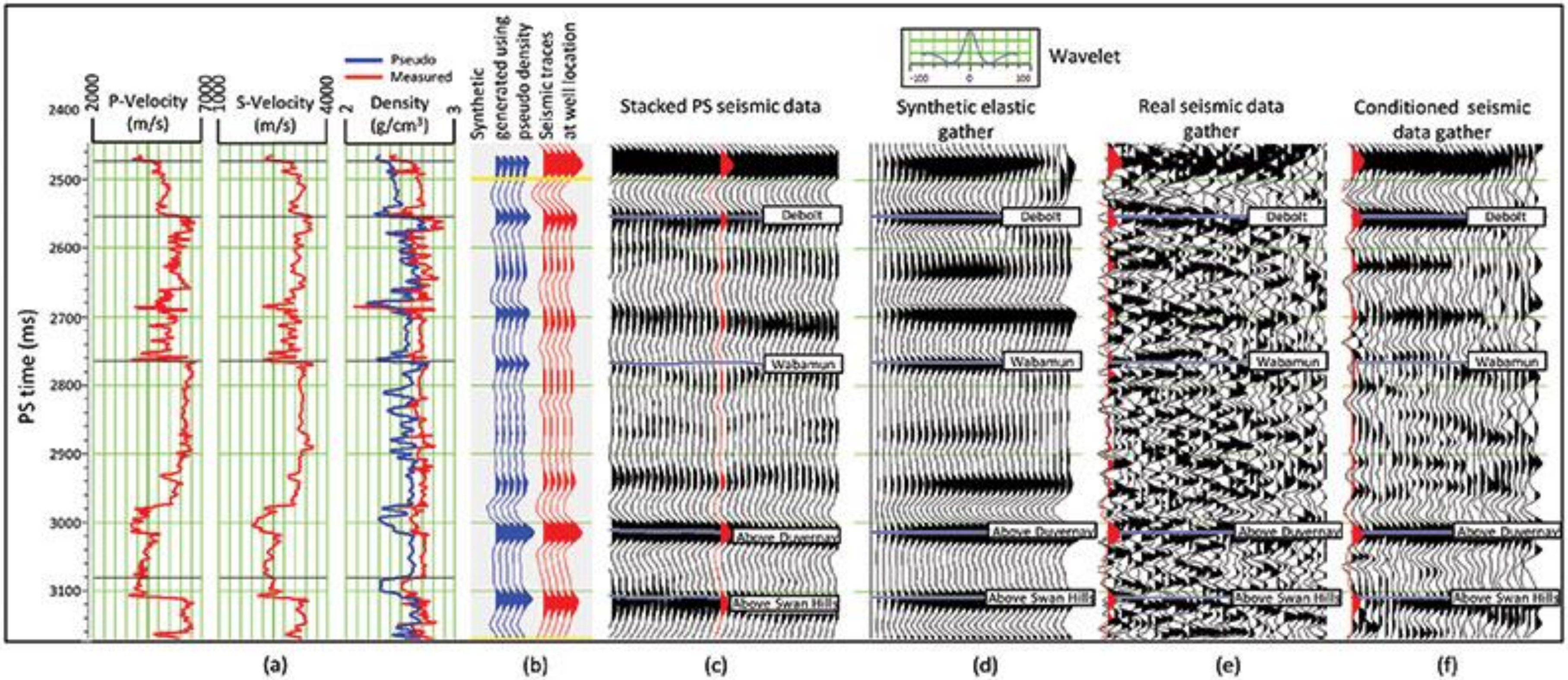

Figure 4. (a) The P-velocity, S-velocity and pseudo-density curves measured in the same well as shown in Figure 3. The PS synthetic seismogram (blue) generated from the S-velocity and the pseudo density curves is shown in (b) and with PS seismic data in (c). A PS synthetic elastic gather generated from the P-velocity, S-velocity and density curves is shown in (d). A real seismic gather at the location of the well is shown in (e). This data has not been conditioned for any amplitude analysis. The conditioned version of the gather is shown in (f). It is interesting to note the difference between the gathers in (e) and (f). Also, the stacked data and the prestack data correlation shows the similarities and differences that are open to interpretation.