GC Enhancement of Multicomponent Seismic Data*

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General Statement

Our seismic industry has witnessed many revolutions, starting from refraction to reflection imaging (1919), analog to digital recording (1963), the introduction of the common depth point (CDP) technique (1952) and the transition from 2-D to 3-D P-wave seismic data in the 1980s. Thereafter, the application of repeated 3-D seismic surveys over time helped monitor reservoir properties during the productive lives of different fields. This came to be known as time-lapse or 4-D seismic, and viewed by many as an extension of 3-D seismic technology.

Multicomponent seismic technology was experimented with in the 1960s and 1970s, with different types of sources and processing of the acquired S-wave data thereafter. It is considered the next big revolution, though it made its entry slowly and is gradually emerging as a very useful technology.

If we consider some of the challenges that we face with regard to the applied geophysics, we may be able to list them as follows:

1. Distribution of faults and fractures.

2. Understanding of subsurface stress regimes.

3. Description of reservoir rock type and the fluid content.

4. Imaging of the subsurface in complex geological setups, e.g. deep water, sub-salt or gas zones.

5. Quantitative saturation and pressure changes.

The use of P-wave seismic data alone may not be enough to help us address the challenges stated above, which probably require an improved technology or approach that can bring a shift in the conventional interpretation and, hence, the drilling plans made from that interpretation.

Being three-dimensional in nature, when a seismic wave propagates in the subsurface, it causes the rock particles or fabric to oscillate about their mean positions in different directions. The P-wave causes the rock particles to oscillate in the direction of the propagation wavefront. When a P-wave arrives at subsurface rock interfaces at non-normal angles of incidence, a mode conversion of P-wave energy takes place into two different types, i.e. P to SV and P to SH modes. Both SV and SH waves cause the rock particles to oscillate perpendicular to the direction of the propagating wavefront. The directions of the SV and SH waves are orthogonal to each other as well. These three different components of the seismic reflected wavefront can be recorded with sensors that recognize their particle motions (P-, SV and SH).

Geophones used for conventional seismic data acquisition are constrained to respond to just one component, i.e. the vertical P-component. But the three-component (3-C) geophones have the motion sensing elements arranged in a single casing and are used for recording the 3-C seismic wavefield. Such 3-C geophones are good for recording multicomponent seismic data on land.

Conventional marine seismic data are acquired by using hydrophone streamers towed behind boats. The hydrophones consist of some piezoelectric material that responds to pressure variations in the water caused by the reflected seismic wavefield. As shear waves do not propagate in water, hydrophone streamers cannot record shear waves emanating from P-wave sources and getting converted at subsurface rock interfaces. To record shear waves in marine environments, ocean-bottom cable was developed which can be placed on the sea floor and can capture converted shear waves.

For improving the recorded data quality, a vertical geophone and a hydrophone at each sensor location were summed and came to be known as a "dual sensor technique." This was followed by upgrading the geophones to three components so that now the 4-C (hydrophone and three-component geophone) technique is successfully used for recording converted shear waves, in addition to the P-wave data. Thus multicomponent seismic data are now acquired, both on land and offshore areas, processed and interpreted to address many of the challenges listed above.

Spectral Balancing of PS Data

In our prior article Joint Impedance Inversion Transforms Aid Interpretation, Search and Discovery Article #41667, we described the joint impedance inversion technique for using PP and P-SV seismic data, which yields P- and S-impedance data. These attribute volumes can be used to derive different reservoir properties.

In this article we discuss how the preconditioning of P-SV (henceforth referred to as just PS) data can lead to more meaningful joint inversion results, as applied to 3-D seismic data from the Kaybob area of northwest Alberta, Canada, where the Devonian Duvernay Shale Formation is an emerging shale liquids play. Once the 3-D multicomponent seismic data are processed, for carrying out any consistent analysis the first step is to carry out an accurate PP and PS time correspondence, a process referred to as "registration." This is accomplished by tying the processed

PP and PS data with PP and PS synthetic seismograms respectively, generated over the same range of frequency bandwidth as the input reflection data.

In Figure 1, we show the synthetic seismograms generated and correlated with PP (in PP time) and PS data (in PS time). One can notice the lower frequency content of the PS data than the PP data. In Figure 2, we show data extracted along an arbitrary line from the PP and PS data volumes, which again exhibit the different frequency content of the two volumes. Such differences in the frequency content imply differences in amplitude and phase of the PP and PS reflection events, which in turn result in mismatches during registration and thus has a negative effect on the reservoir properties determined therefrom.

If the spectral content of the PS data was somehow balanced with that of the PP data, the problem could be mitigated. For doing this we make use of the *amplitude-friendly* spectral balancing method we described in Spectral Balancing Aids Seeing Faults More Clearly, Search and Discovery Article #41594. In this method, the data are first decomposed into time-frequency spectral components. The spectral magnitude is averaged over all the traces in the data volume spatially and in the given time window, which yields a smoothed average spectrum. Next, the peak of the average power spectrum is also computed. Both the average spectral magnitude and the peak of the average power spectrum are used to design a single time-varying spectral balancing operator that is applied to each and every trace in the data. As a single scalar is applied to the data, the process is considered as being amplitude friendly.

In Figure 3, we show the application of amplitude-friendly spectral balancing to the PS data. We note the bland reflection zones in between the marked horizons as seen in Figure 3a, exhibiting more reflection detail (Figure 3b) that seems to correlate with the impedance curves overlaid on the section. The overall enhancement in the frequency content of the PS data (in PS time) after spectral balancing can be gauged from the frequency spectra alongside Figure 3. The PS data with enhanced frequency content was next put through the process of registration, wherein the apparent bandwidth further increases. This data is then put through joint inversion which was described by the authors in Joint Impedance Inversion Transforms Aid Interpretation, Search and Discovery Article #41667.

In Figure 4 we show a comparison of the V_P/V_S sections before and after spectral balancing. As indicated on the figures, the definition of the many reflection events looks crisp and detailed, which can aid the interpretations made therefrom.

Conclusion

We thus conclude that appropriate spectral balancing of the PS seismic data before carrying out its registration with the equivalent PP seismic data can lead to more detailed and meaningful attribute volumes that are derived, and consequently result in more accurate interpretation.

Acknowledgement

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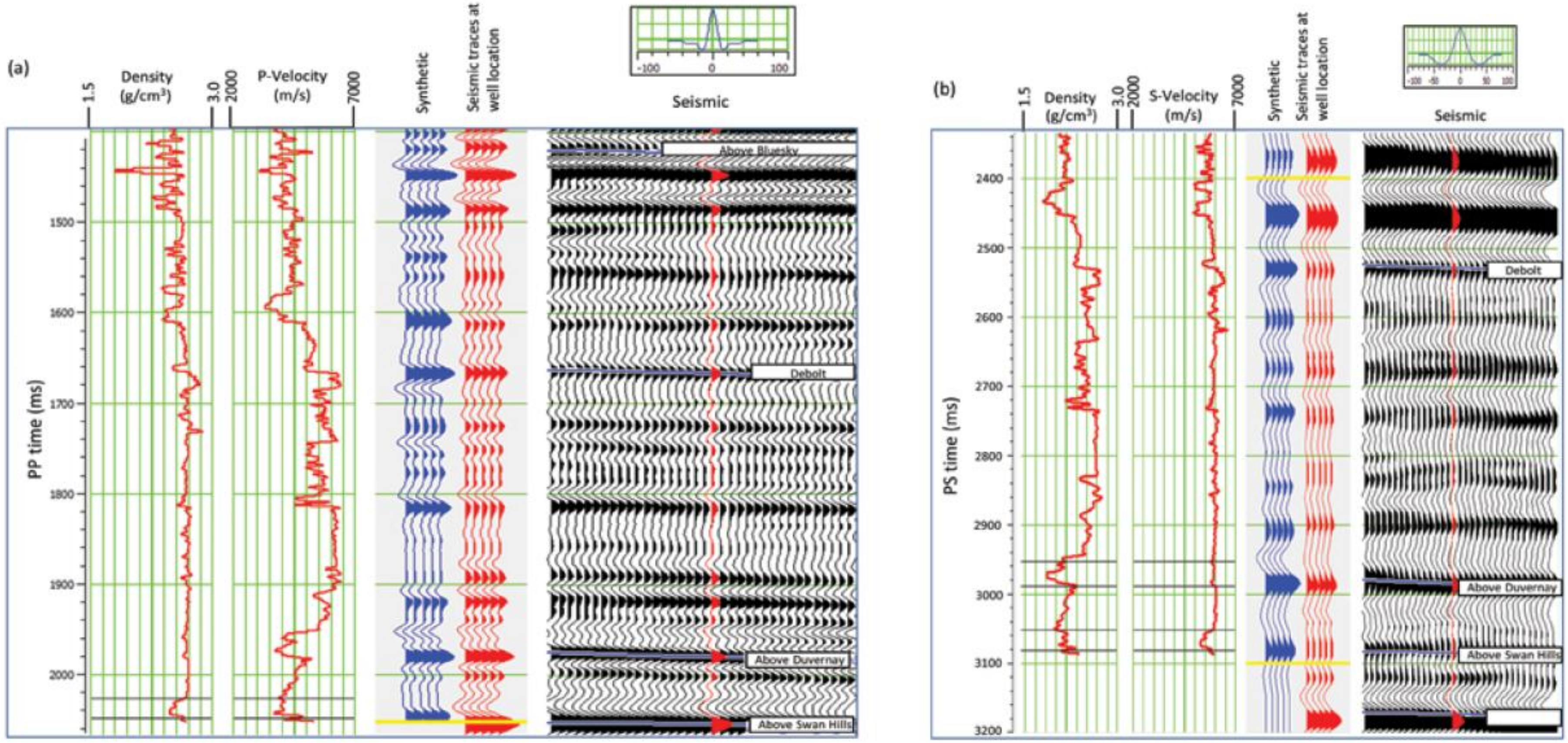

Figure 1. Well to seismic tie for (a) PP data, (b) PS data. The synthetic traces are in blue generated using the reflectivity from the log curves and the wavelet shown alongside to the right. The red traces are the seismic traces at the location of the well. A good correlation is seen between both the PP and PS data and the log curves. Data courtesy of Arcis Seismic Solutions, TGS, Calgary.

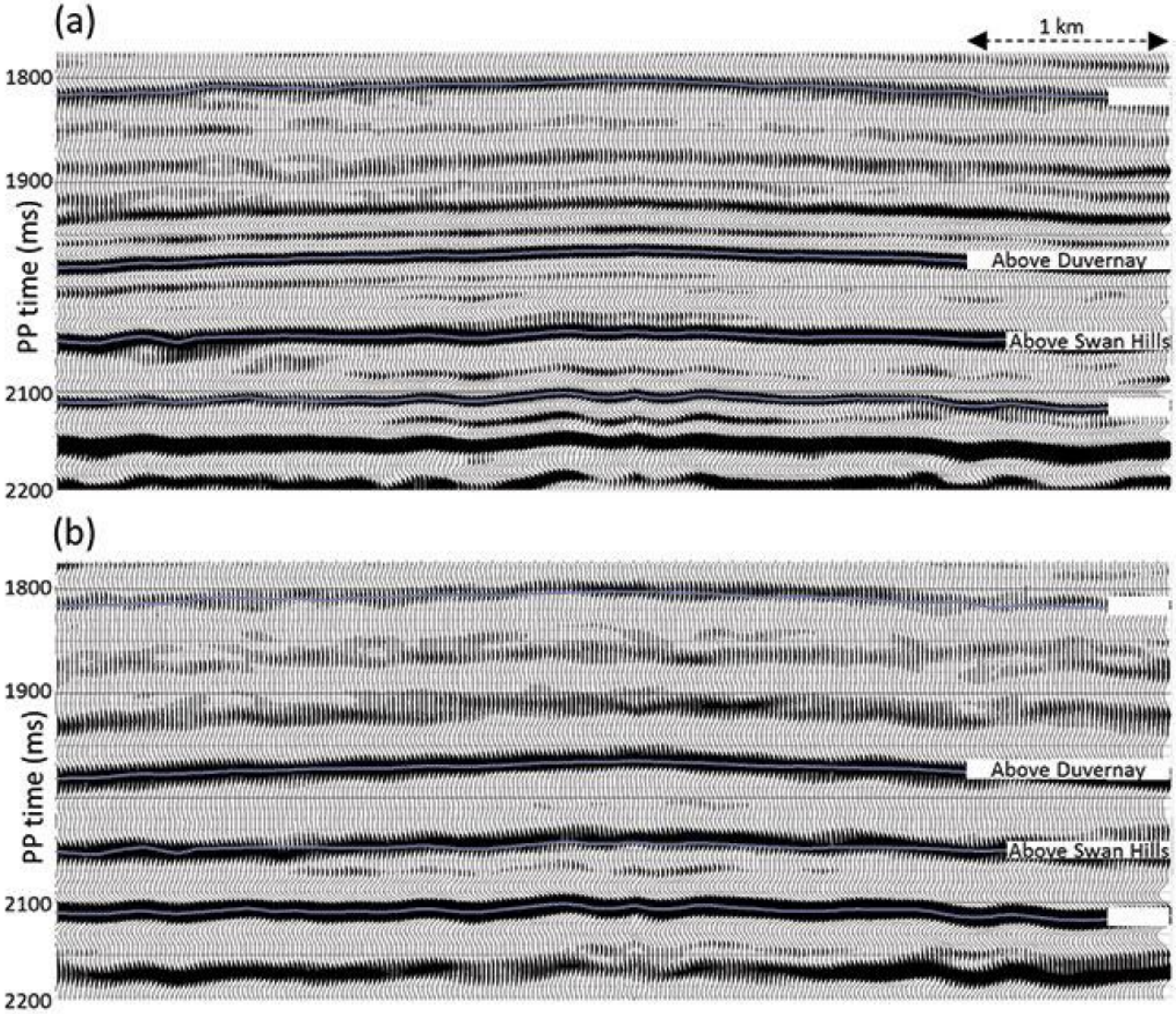

Figure 2. A segment of (a) PP- data section extracted from the data volume along an arbitrary line in PP time, and (b) equivalent PS- data section extracted along the same arbitrary line. Notice the good correlation of the marked events on both sections, but the frequency content of the PS- data is lower than the frequency content of PP data.

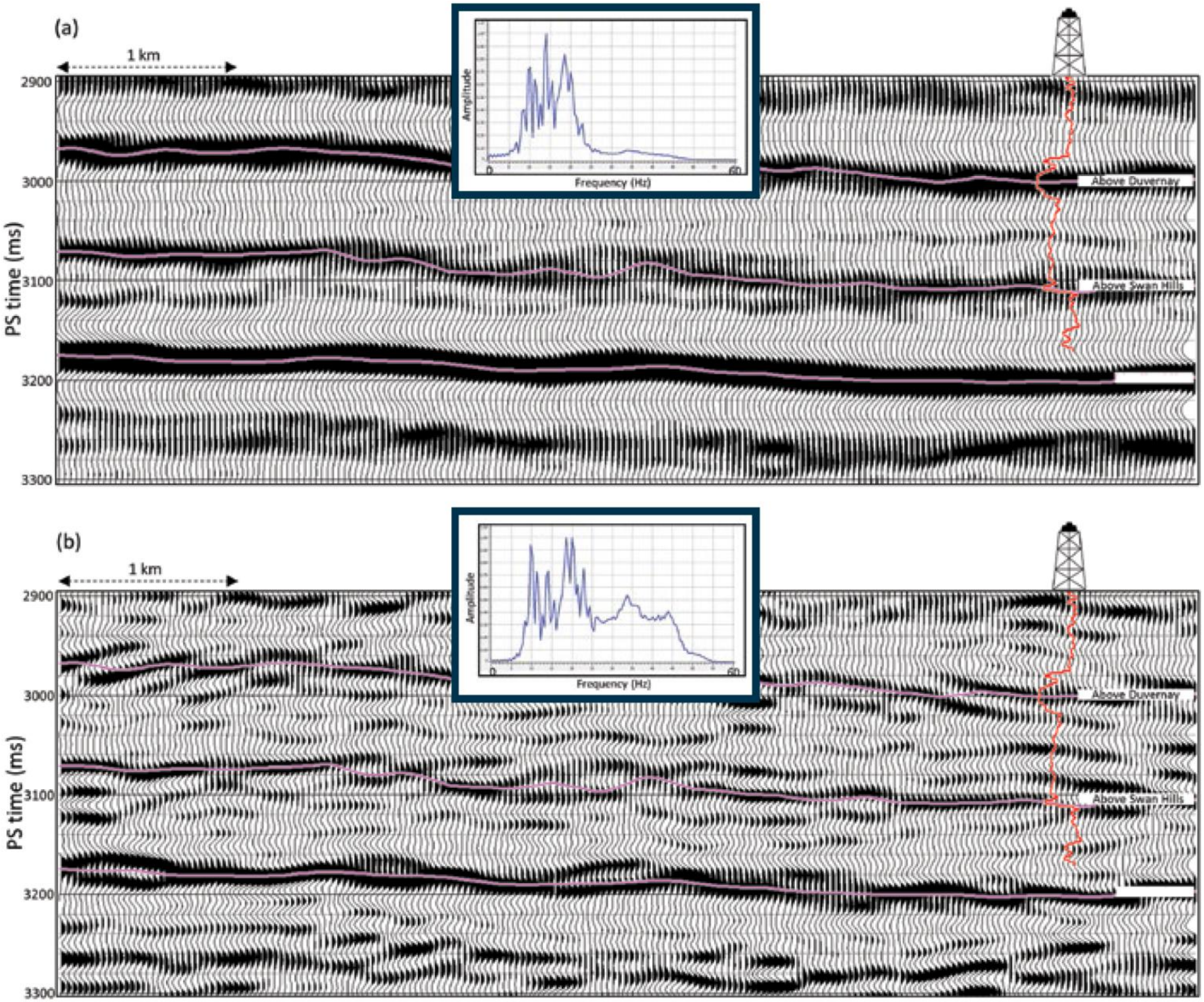

Figure 3. Segment of a (a) PS-wave seismic section from the Kaybob area in northwest Alberta, Canada, and an equivalent section from (b) spectrally balanced PS wave data volume. Notice the lower frequency content (< 25Hz) before has been enhanced with the frequency enhancement process. The bland zones within the marked horizons seen in (a) show more reflection events which seem to correlate with the impedance log curve overlaid on both sections.

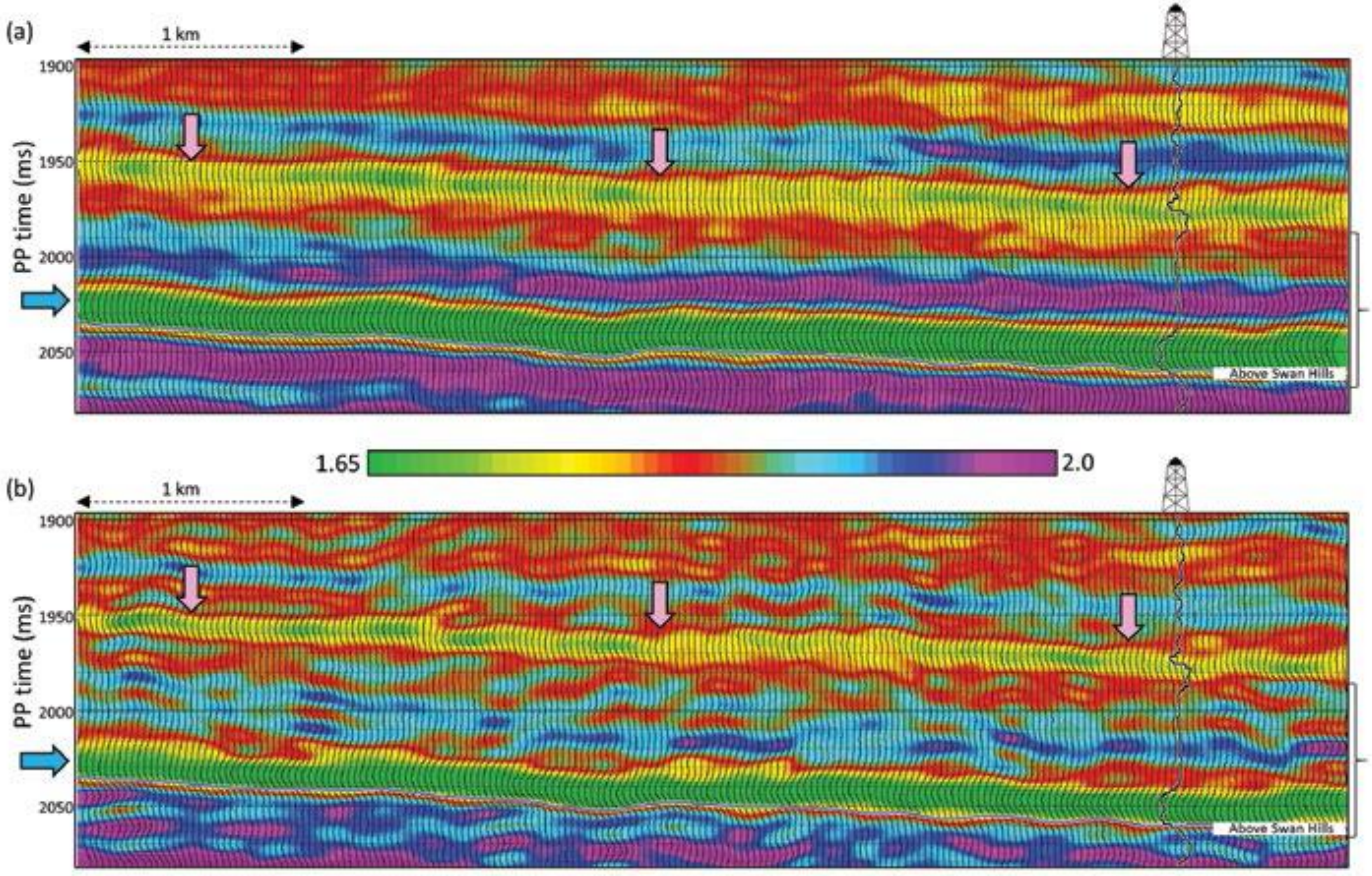

Figure 4. A portion of a section from VP/VS volume computed using post-stack joint inversion with (a) the PS-wave data as obtained after processing, and (b) using spectrally balanced PS-wave data. Notice the crisp definition of the event indicated with the pink arrows, and the enhanced resolution of the time zone marked to the right with a curly bracket (and in particular the blue arrow to the left).