Source-receiver offset ranges for P-SV seismic data

Don C. Lawton

ABSTRACT

Modelling studies have shown that the ratio of incident angles for P-SV and P-P reflections is about 1.3 for a common receiver location. This means that for a given source-receiver offset, pre-critical P-P reflections may be recorded with post-critical P-SV reflections. This has serious implications for the P-SV stack, which requires that the phase for all reflections in the gather be stationary if the integrity of the stack is to be maintained. Long source-receiver offsets for P-SV acquisition are therefore not recommended. This requires that a major effort in multicomponent surface seismic data acquisition must be directed at attenuating source-generated noise and extracting useable reflection signal in the mid-offset range.

INTRODUCTION

In the design of converted-wave (P-SV) reflection seismic surveys, it has generally been accepted that longer source-receiver offsets are required than those used for conventional (P-P) reflection surveys (Garotta, 1987). This is due to the fact that no converted waves are recorded at zero-offset (normal incidence). Also, because most multicomponent surveys are recorded using single receivers rather than geophone groups, the near to mid-offset ranges of conventional spreads tend to be saturated with shot-generated noise, and visible reflections in shot gathers are limited to far offset traces (Lawton and Harrison, 1990; Miller, et al., 1990).

An important aspect of the interpretation of multicomponent seismic data is the correlation of reflection events between P-wave and S-wave stacked sections (Anno, 1987). While this process is valid between P-P and SH-SH sections, there has been considerable discussion about P-SV stacked sections because of the lack of a physical meaning of a zero-offset P-SV event (for flat reflectors). However, the P-SV stacked section contains inherent information about the average P-SV reflectivity over the range of incident angles dictated by the recording geometry. This paper re-examines the common-conversion point (CCP) stack and proposes that the P-SV recording aperture should actually be less than the P-P recording aperture.

INCIDENT ANGLES

Figure 1 shows the raypath geometry for P-P and P-SV reflections from the base of a single, homogeneous layer. Using the asymptotic approximation (Fromm et al., 1985), the location of the conversion point, x_{ps}, is given by:

$$x_{ps} = \frac{r}{1 + Vs/Vp} \qquad (1)$$

where Vp and Vs are the P-wave and S-wave velocities of the layer, respectively, and r is the source-receiver offset. In Figure 1, the angles i_{pp} and i_{ps} are the incident angles for the P-P and P-SV raypaths, respectively. It is obvious that $i_{ps} > i_{pp}$ for all values of r, and the raypath geometry in Figure 1 also shows that:

$$\frac{\tan i_{ps}}{\tan i_{pp}} = \frac{2x_{ps}}{r} \qquad (2)$$

Invoking the asymptotic assumption and using equation (1), it is straightforward to show that:

$$\frac{i_{ps}}{i_{pp}} = \frac{2}{1 + Vs/Vp} \qquad (3)$$

For the common approximation that Vp/Vs = 2, equation (3) then results in the ratio i_{ps}/i_{pp} being approximately equal to 1.3. Hence, the ratio between the magnitudes of the incident angles for P-SV and P-P reflections will be at about 1.3 for deep reflectors (with respect to the source-receiver offest), and less for shallow reflectors where the asymptotic approximation is no longer valid. This ratio is significant because it indicates that the incident angle could exceed critical incidence for P-SV events while remaining sub-critical for P-P events for the same source-receiver offset. For any particular spread length, the range of incident angles subtended by P-SV events will always be greater than that subtended by P-P events. If the spread aperture for P-SV acquisition is increased beyond that for P-P acquisition, then the P-SV incident angle range will be increased even further.

An example of the ratio between incident angles for P-SV and P-P events, as a function of source-receiver offset, is shown in Figure 2. This example is the case for a single, homogeneous, isotropic layer with Vp/Vs = 2. In the near-offset range (offset to depth ratio of less than 0.5), the incident angle ratio is 1.33, as predicted by equation (3). This ratio decreases, although only slightly, with increasing source-reciever offset, to a value of 1.27 at an offset-to-depth ratio of 2. For an offset-to-depth ratio of 1 (typical maximum for conventional P-P acquisition), the incident angle ratio is still 1.32.

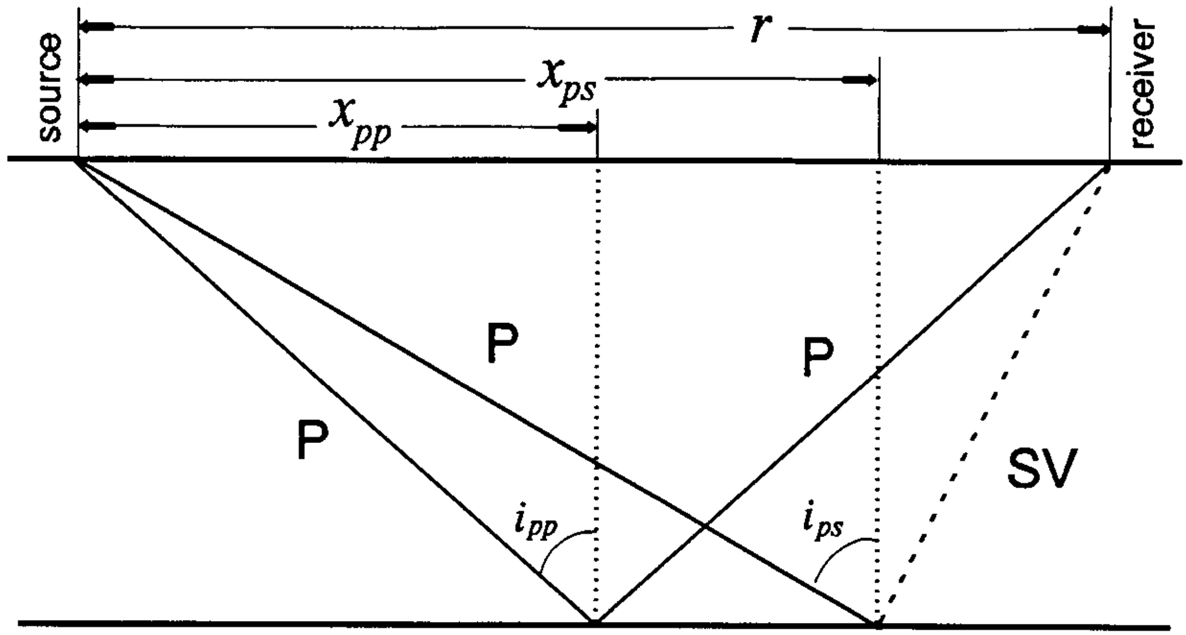

FIG. 1. Raypath geometry for P-P and P-SV reflections from the base of a single, isotropic layer.

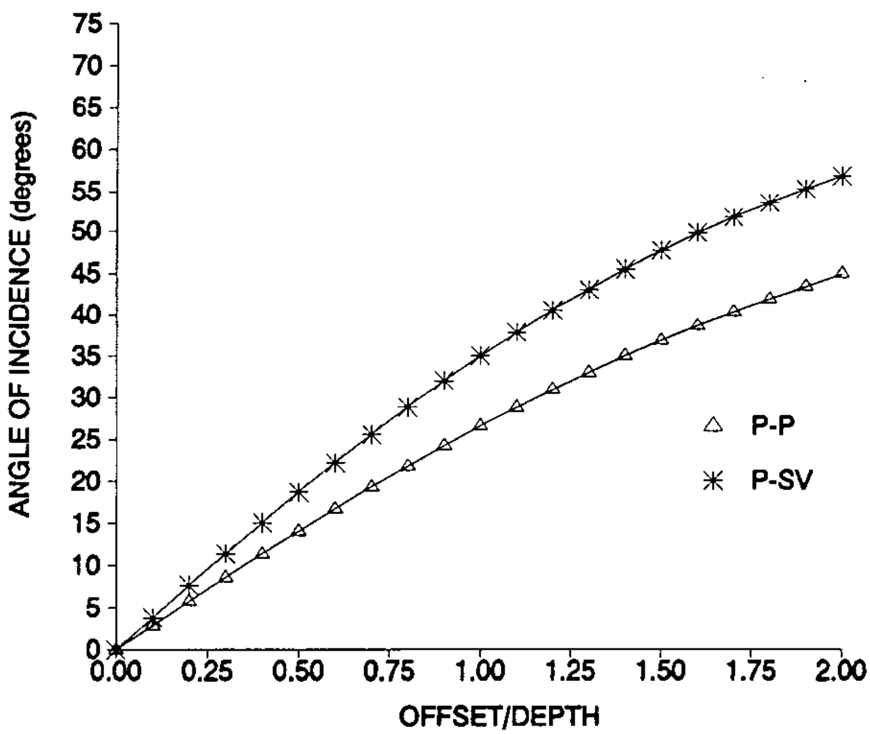

FIG. 2. Angles of incidence for P-P and P-SV reflections as a function of source-receiver offset.

SOUTHERN ALBERTA EXAMPLE

Sonic log data from a well in southern Alberta was used as an example to examine spread geometry for P-SV surveys. The well (6-1-13-19W4) is located in the Retlaw area and penetrated a good channel-sand reservoir of the Lower Cretaceous Glauconitic Formation at a depth of 1030 m. The well bottomed in carbonates of the Mississippian Livingstone Formation at a depth of 1080 m; Figure 3 is a portion of a conventional P-P seismic section which ties the well and the channel anomaly is clearly evident at 0.7 s. The P-wave sonic log and a zero-offset synthetic seismogram generated from this log are shown in Figure 4. The velocity log shows that there is a steady increase in velocity with depth in this well, typical of the Cretaceous of southern Alberta. The channel-sand anomaly has a trough-peak signature, tuned at the 10-60 hz bandwidth.

Synthetic P-P and P-SV stacks were created from the P-wave sonic log from the 6-1 well. These gathers and stacks were generated using software described by Howell et al. (1991). Because of the general increase in P-wave velocity with depth, the incident angles of P-waves illuminating reflectors will be greater that those for the straight-ray assumption (Figure 2). Incident angles for P-SV and P-P reflections from the top of the channel (1030 m depth) were computed by raytracing a layered model over a source-receiver offset range from 0 to 2 km; i.e. an offset-to-depth range from 0 to 2. A constant Vp/Vs = 2 was assumed for the model. These incident angles are plotted in Figure 5 and show that refraction of the downgoing energy results in incident angles considerably greater than those generated for a straight-ray assumption. This effect, particularly for P-SV data, was noted previously by Garotta (1987). For an offset-to-depth ratio of 1, the P-P and P-SV incident angles have increased by 17% and 18% respectively versus straight-ray values (Figure 2). This result exacerbates the problem of P-SV rays exceeding critical incidence.

The P-P and P-SV synthetic gathers and stacks from the 6-1 well are shown in Figures 6 and 7. In the modelling, it was considered that 20 traces over the offset range (2 km) were sufficient to provide a robust stack. Ricker wavelets with peak frequencies of 35 Hz and 25 Hz were used for the P-P and P-SV modelling respectively. Both gathers were corrected for normal moveout (NMO), with P-SV data being corrected using the time-shifted hyperbolic equation presented by Slotboom, et al. (1990). Figure 6 shows unmuted gathers and stacks for P-P modelling (upper) and P-SV modelling (lower). For the P-P record, it is clear that the most significant offset-dependant effect is NMO stretch, whereas for the P-SV record, the data have been flattened well, but there are significant phase variations with offset over the far offset range of traces. This effect is particularly significant for the Mississippian event (1.15 s) where a phase reversal at trace 12 results in cancellation of this event after stacking.

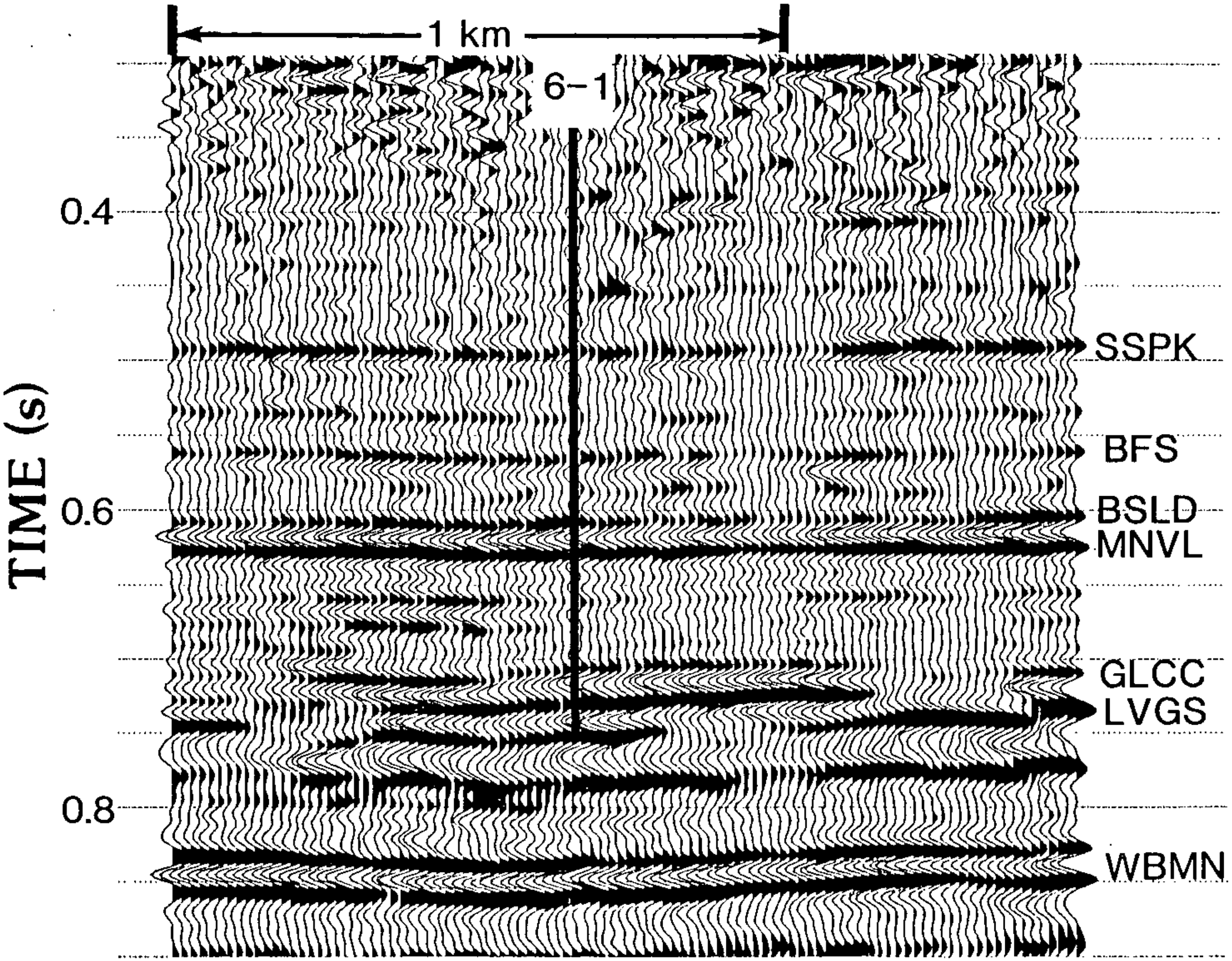

FIG. 3. Stacked seismic section of a Glauconitic channel anomaly in the Retlaw area of southern Alberta

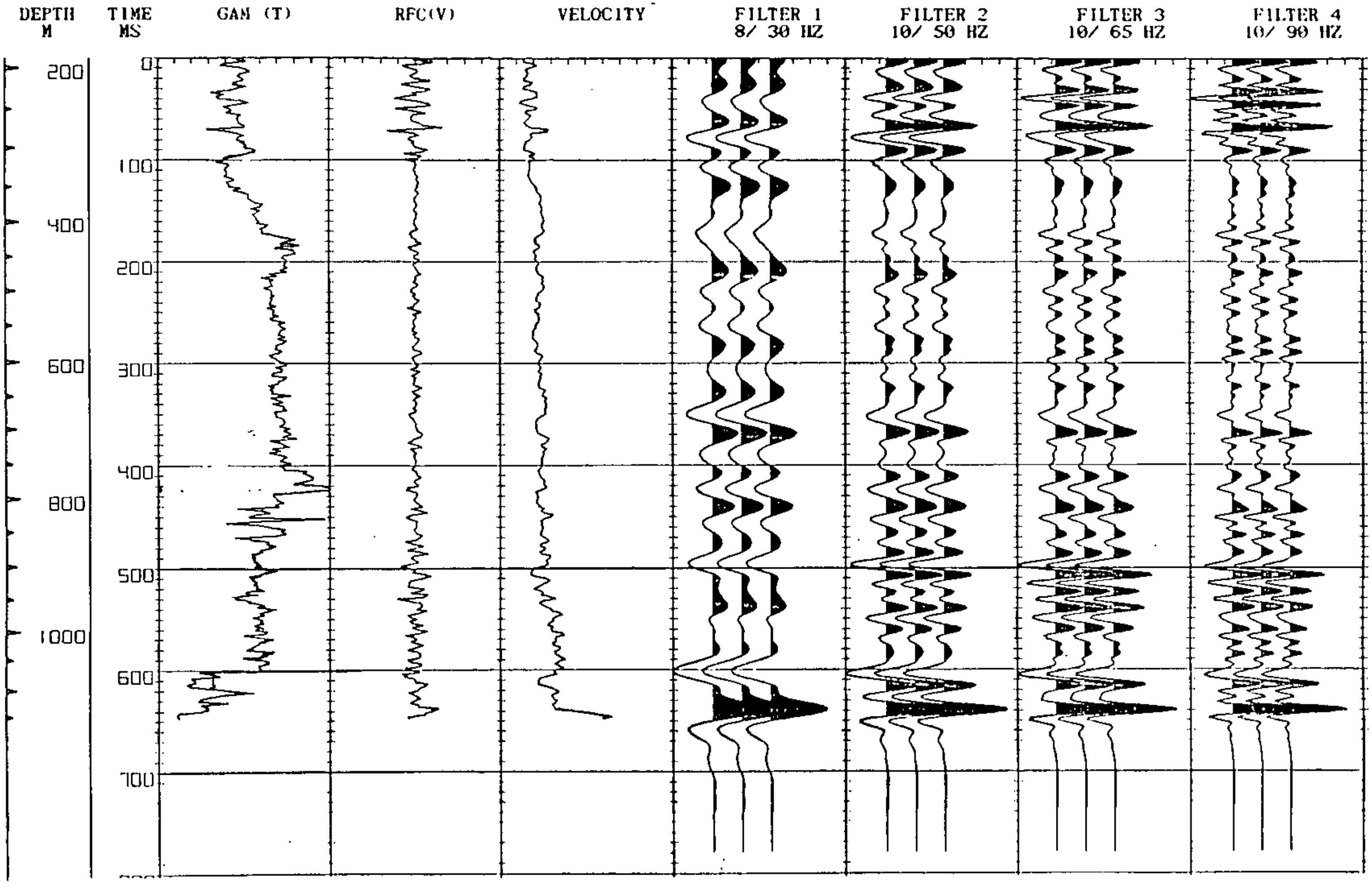

FIG. 4. Velocity logs and one-dimensional synthetic seismograms from the Retlaw well (6-1-13-19W4).

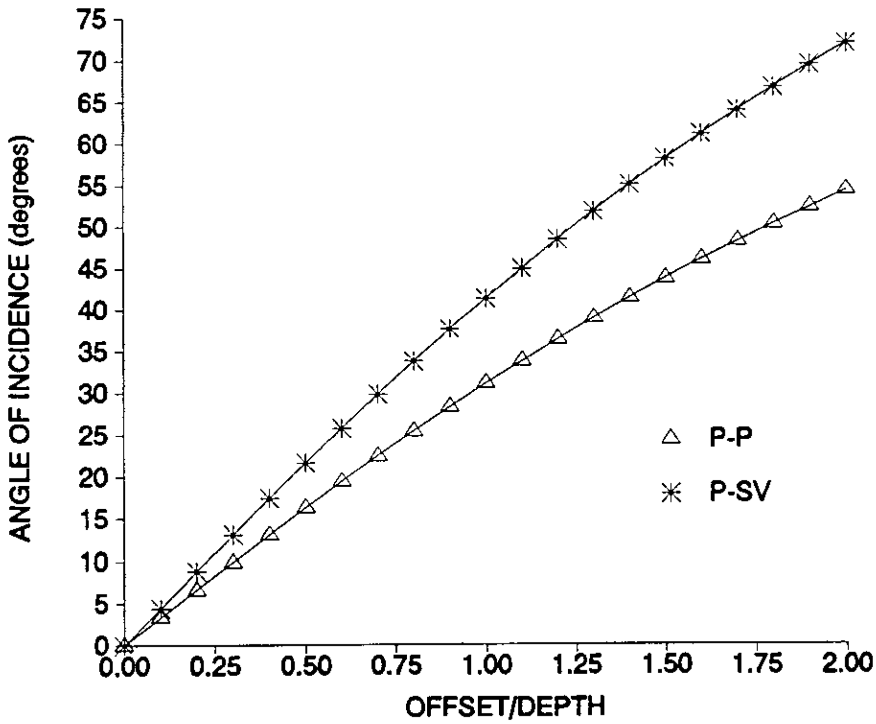

FIG. 5. Incidence angles of P-P and P-SV reflections from the top of the Glauconitic channel in a layered model based on the 6-1-13-19W4 well (depth of 1030 m), versus offset/depth ratio.

In order to create a synthetic P-SV stack which is free of offset-dependent phase artifacts, a mute was applied and a new stack was created. The P-P gather was also muted to eliminate NMO stretch. The mutes applied were 1500 m/s and 2100 m/s for the P-SV and P-P gathers respectively, and the results are presented in Figure 7. These mute patterns are actually rather similar when viewed in terms of offset versus P-P traveltime. The offset-limited stacks are significantly different from the full offset stacks in both records of Figure 7. However, the relatively harsh mute applied to the P-SV gather was still insufficient to remove the phase variation with offset for the Mississippian event.

DISCUSSION

It is clear from the P-P and P-SV synthetic stacks in Figure 7 that there is no advantage in P-SV offset ranges being greater than P-P offset ranges. Stacking P-SV data over a large range of offsets may result in event cancellation due to reflection phase changes across the gather. The integrity of the P-SV stack will be lost and correlation between P-P and P-SV events, based in reflection character, will be jeopardised.

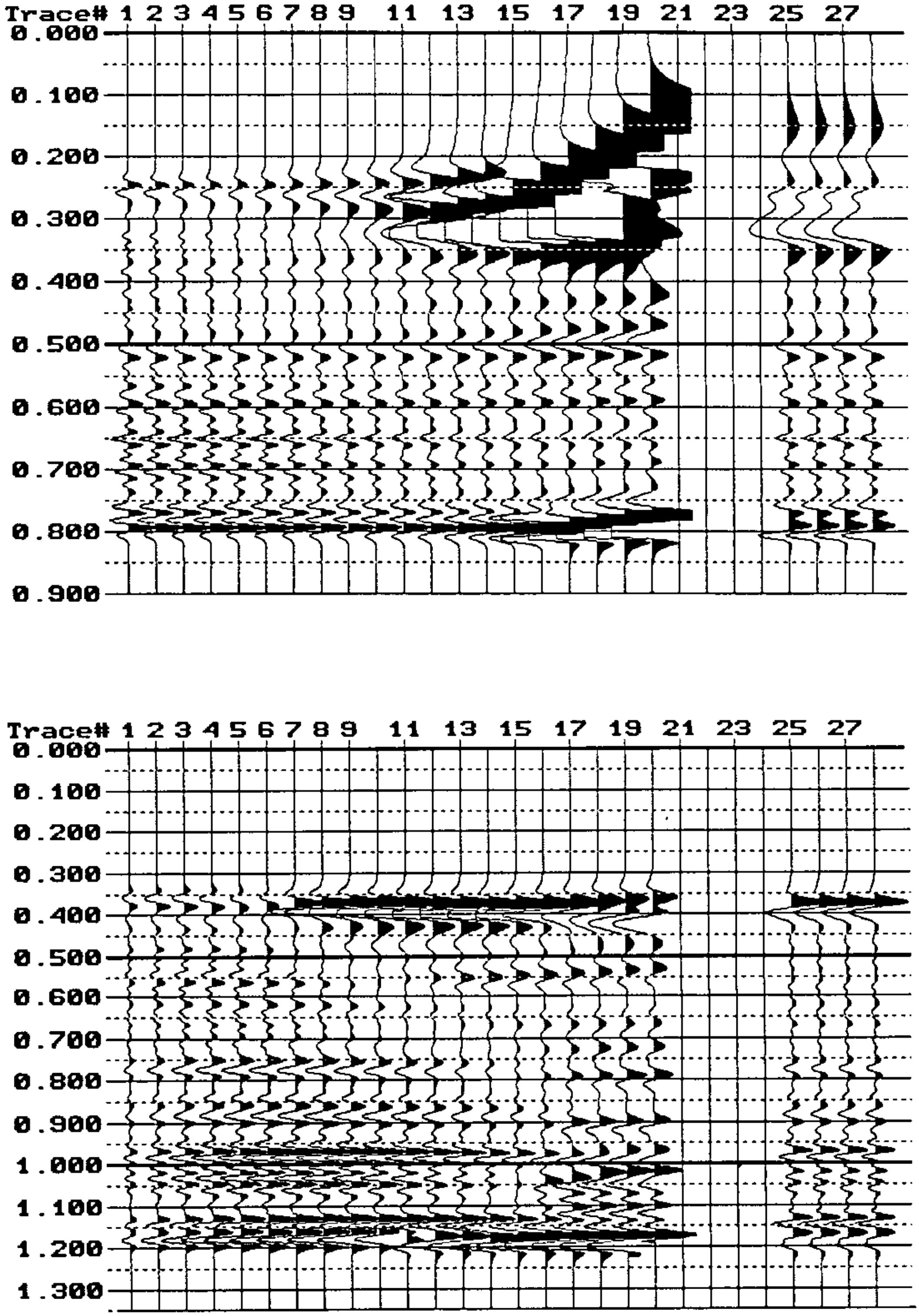

FIG. 6. P-P (upper) and P-SV (lower) synthetic stacks from the 6-1-13-19W4 well. The gather is shown on the left side and the stack on the right side of each figure. The maximum offset is 2 km.

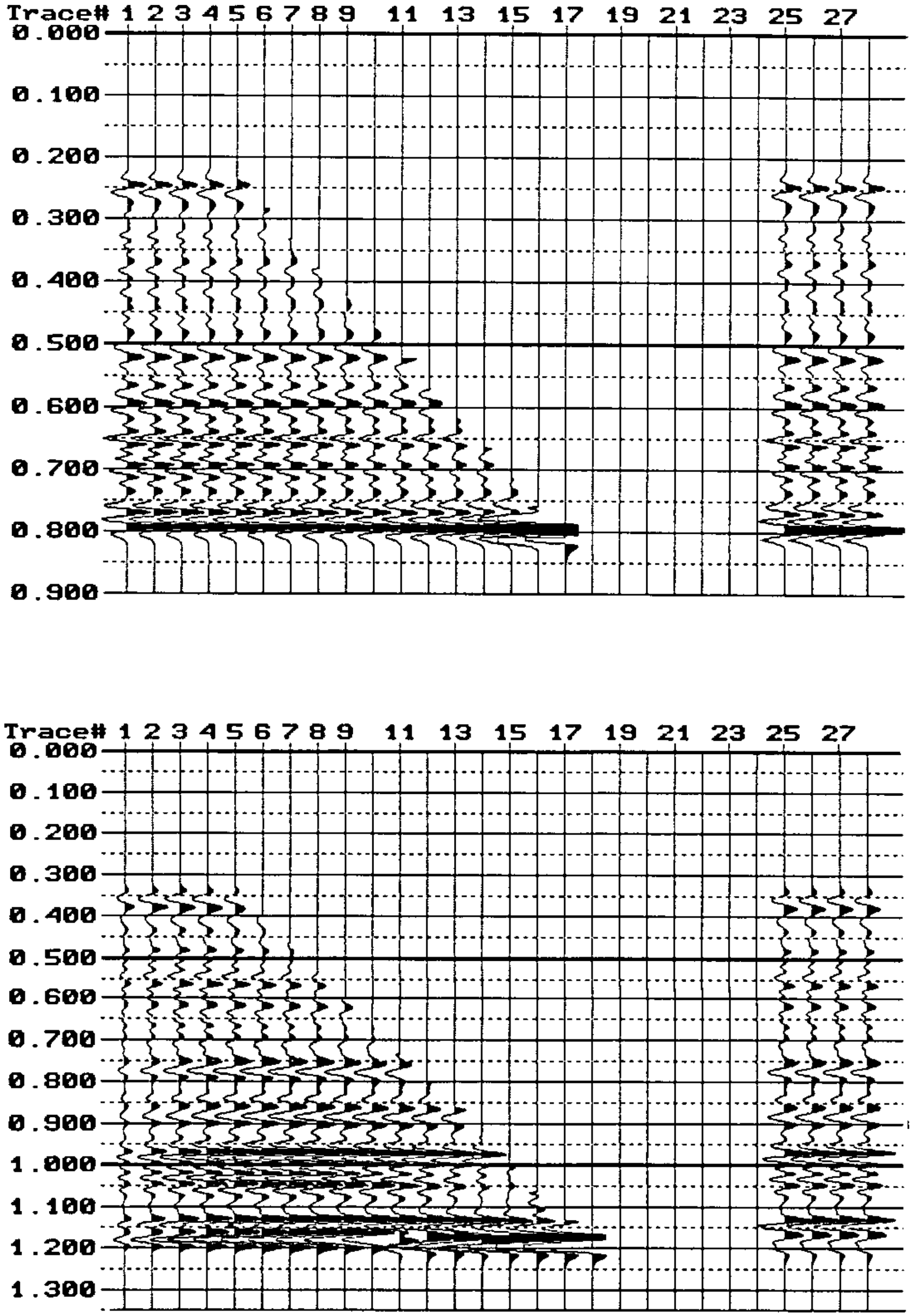

FIG. 7. As for figure 6 but after application of a mute.

The P-SV stack maps reflection amplitude-versus-offset (AVO) effects into zero-offset space. In order to undertake properly coupled P-P and P-SV AVO interpretation, both the P-P and P-SV data sets should span the same range of incident angles. Because of the asymmetry of the P-SV raypath (Figure 1), this requires that the maximum source receiver offset for P-SV acquisition should actually be less than the maximum offset for P-P acquisition. This concept is illustrated in Figure 8 which shows a unique maximum incident angle i_{max} related to maximum source-receiver offsets of r_{ps} and r_{pp} for P-SV and P-P acquisition, respectively, for a single, isotropic layer. If Vp/Vs is equal to 2, then r_{ps} should be approximately 75% of r_{pp}.

As discussed earlier, the main reason why short P-SV recording apertures have not been popular is the low signal to noise ratio observed on shot gathers. However, if the integrity of the P-SV stack is to be maintained, then the major effort in surface P-SV data acquisition and processing must be in the reduction of source-generated noise and the extraction of reflections in the mid-offset range. This may require extended dynamic range in the recording instruments, such as the 24-bit systems which are currently being developed by several manufacturers.

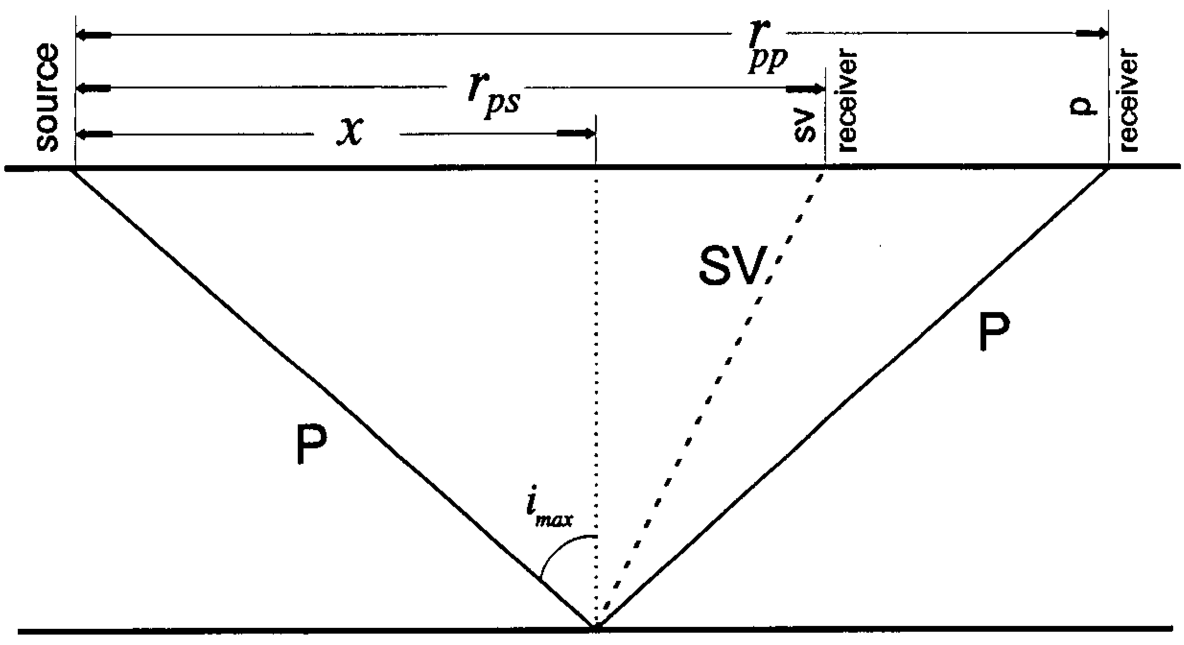

FIG. 8. Raypath geometry for P-P and P-SV reflections from the base of a single isotropic layer, with a common maximum incident angle i_{max}.

CONCLUSIONS

The following conclusions are drawn from this study:

(a) In the acquisition of P-SV reflection seismic data, long source-receiver offsets, greater than about 1.5 times the target depth, may degrade the integrity of the P-SV stack due to mixing of pre- and post-critical reflections.

(b) For Vp/Vs = 2, the ratio of incident angles for P-SV and P-P reflections is about 1.3, for common source-receiver offsets less than the reflector depth.

(c) For coupled P-P and P-SV AVO analysis, the P-SV offset range should be approximately 75% of the P-P offset range.

(d) The extraction of reflection signal from source-generated noise in the mid-offset range is the most important problem to be addressed in surface P-SV exploration seismology.

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