Layered anisotropic CCP stacking of the Blackfoot 3-C,3-D survey

Peter W. Cary and Han-xing Lu

SUMMARY

The most important development in the processing of 3-C data in recent years is the realisation that layered, anisotropic effects must be taken into account in the processing of the horizontal components. The 1995 Blackfoot 3-C, 3-D survey was reprocessed to see what impact this previously neglected effect would have on the final image. Present methods for determining the effective Vp/Vs ratio, which controls the behavior of the anisotropic conversion-point binning process, depend on the existence of dipping events for the analysis. A fault that exists in the deep part of the southeast portion of the Blackfoot survey has enough structure associated with it to reliably indicate that the effective Vp/Vs ratio in this part of the image is about 70% of the vertical Vp/Vs ratio. This implies that far-offset traces were mis-stacked by about 200m (6.6 bins) in the original processing of this part of the CCP stack. It is more difficult to pick the effective Vp/Vs ratio in other parts of the stack in an objective manner because of the lack of dipping events.

INTRODUCTION

In November 1995, a 3C-3D seismic survey was conducted over the Blackfoot field located near Strathmore, Alberta, Canada (T23 R23 W5M). The vertical component was processed by conventional methods. The radial component was processed by asymptotic and depth-variant binning and stacking methods as well as by converted-wave DMO. The shot and receiver locations for this survey are shown in Figure 1.

Since these data were processed (with the implicit assumption of isotropy), it has become common knowledge that anisotropic layering, or even layering without anisotropy, should not be ignored in converted-wave processing (Thomsen, 1999). The basic effect of anisotropic layering is to move the conversion point of P-S reflections closer to the source-to-receiver midpoint than for a single isotropic layer, as analysed by Tessmer and Behle (1988). The purpose of this study was to determine how important this effect is at Blackfoot.

TAKING LAYERED ANISOTROPY INTO ACCOUNT

The Vp/Vs ratios that were originally used to process the radial component data were obtained by correlating events on the P-P and P-S stacks, and comparing their vertical travel-times. In other words, these Vp/Vs ratios were a measure of the vertical velocity ratio function, γ_0, which is defined as

$$\gamma_0 \equiv \overline{V_P} \Big/ \overline{V_S} \,,$$

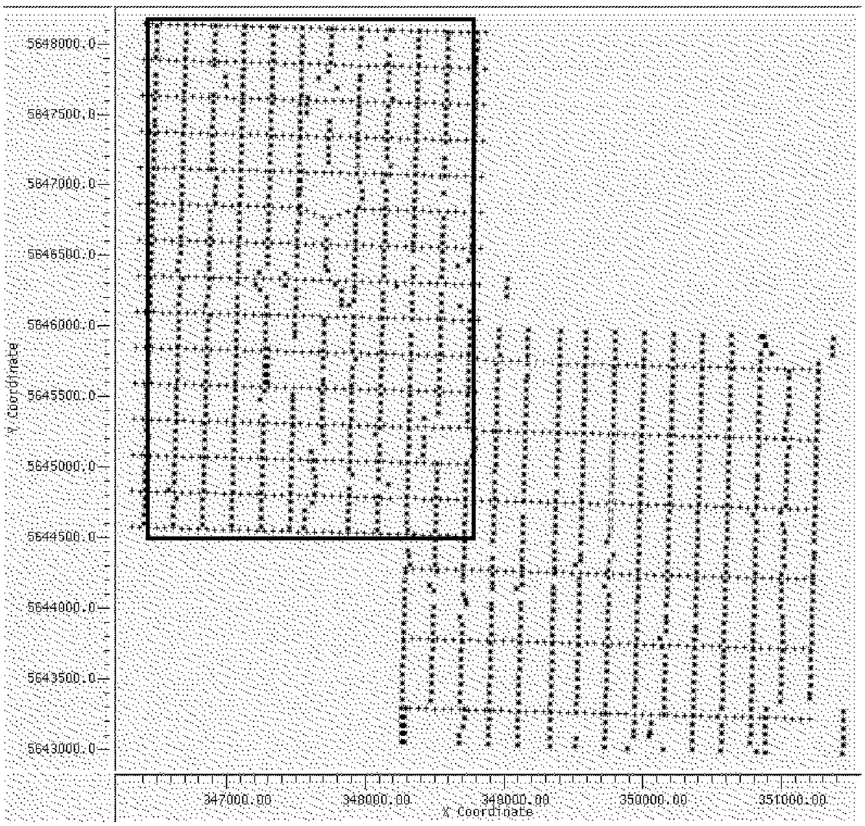

Fig. 1. The locations of the shots and receivers in the 1995 Blackfoot 3C-3D survey.

and the bar indicates that the velocity is averaged. The ratio of the distance of the asymptotic conversion point from the source, x_{c0}, to the source-to-receiver offset, x, assuming isotropy, is given by

$$\frac{x_{c0}}{x} = \frac{\gamma_0}{1+\gamma_0},$$

and the depth-variant formula is the solution of a fairly complicated quartic equation, given in the appendix of Tessmer and Behle (1988).

Thomsen (1999) has shown that in the presence of anisotropic layering, the conversion point location is actually controlled by the effective velocity ratio function, γ_{eff}, which is given by

$$\gamma_{eff} = \gamma_2^2 / \gamma_0,$$

where γ_2 is the moveout velocity ratio function, defined as

$$\gamma_2 \equiv V_{p2} / V_{s2} \,,$$

and V_{p2} is the RMS P-wave moveout velocity, and V_{s2} is the RMS S-wave moveout velocity.

In this case, a very good approximation to the ratio of the distance of the depth-variant conversion-point from the source, x_c, to x is given by equation (26) in Thomsen (1999):

$$\frac{x_c(x,t_{c0})}{x} = c_0 + c_2 \frac{\left(x / t_{c0}V_{c2}\right)^2}{\left(1 + c_3\left(x / t_{c0}V_{c2}\right)^2\right)},$$

where

$$c_0 = \frac{\gamma_{eff}}{1+\gamma_{eff}},$$

$$c_2 = \frac{\gamma_{eff}}{2\gamma_0} \frac{\left(\gamma_{eff}\gamma_0 - 1\right)\left(1+\gamma_0\right)}{\left(1+\gamma_{eff}\right)^3},$$

and

$$c_3 = c_2 / (1 - c_0) \,.$$

In these equations, t_{c0} is the two-way converted-wave zero-offset time, and V_{c2} is the converted-wave RMS moveout velocity.

These formulae, taken directly from Thomsen (1999), were implemented in 2-D and 3-D CCP stacking ProMAX modules and applied to the radial component of the Blackfoot 3-D dataset. A complete treatment of anisotropic effects would include nonhyperbolic moveout velocities. However, only hyperbolic velocity analysis and moveout was performed here. Taking nonhyperbolic moveout velocities into account will have a relatively minor effect on the final stack, since in most cases it only allows a slightly milder mute to be applied.

RESULTS

Determining the best value of γ_{eff} for CCP stacking is like the problem of determining the best velocities for migration. Stacking up the data with a number of different γ_{eff} values, and examining them all in a dynamic fashion by flipping between bit-planes on a computer screen makes it easy to see events go in and out of focus as γ_{eff} changes, in a similar way to varying velocities for migration.

In the case of the Blackfoot data, the images after CCP stacking were all very noisy, and the signal too unfocused, to determine the best one. A more effective method for determining the best γ_{eff} was to apply 3-D fx-decon after CCP stacking, and then to apply 3-D poststack migration to each of the noise-attenuated stacks. The comparison of migrated images was much easier to evaluate than the comparison of CCP stacks.

Figures 2(a) to 2(g) show the results of this procedure for seven values of γ_{eff} as seen on a line passing through the fault that is deep in the section, in the southeast portion of the 3-D survey. The values of γ_{eff} that were used for CCP binning and stacking were varied as fractions of the vertical Vp/Vs, γ_0, which were picked from event correlations between P-P and P-S stacks. For poststack migration, velocities that are fractions of the P-S stacking velocities were used. Notice that if $\gamma_{eff} = c\gamma_0 = \gamma_2^2 / \gamma_0$, then $\gamma_{eff} = \sqrt{c}\gamma_2$, so if the data were stacked with γ_{eff} equal to $0.7\gamma_0$, then the migration was performed with 83.67% of the stacking velocities.

The results for this portion of the survey indicated that setting γ_{eff} equal to about 0.7 γ_0 yielded the best image (γ_0 varies between about 1.9 and 2.1 for this data). This result is in accordance with the usual observation that the effective Vp/Vs is less than the vertical Vp/Vs. Since the original processing was essentially performed with $\gamma_{eff} = \gamma_0$, it is fair to say that a good deal of resolution was lost in the original processing by neglecting the effects of layered anisotropy. Using the asymptotic approximations, the original processing mis-stacked the far offsets by about 200m, or roughly 6.5 bins.

Figures 3(a) to 3(g) show results that focus on the zone-of-interest in the Glauconite (northwest) part of the survey. There are no large structural features in this part of the data, so it is difficult to know which image is correct. There are some substantial changes in the events as γ_{eff} changes. Determining which value is correct becomes much more of an interpretation exercise in this situation, so it should not be performed by the processor alone.

In principle, it should be possible to produce stacks for positive and negative offsets for 2-D or 3-D data, and determine the correct value of γ_{eff} based on the correlation of the two images (Herrmann et al., 1998), or to pick γ_{eff} based on a measure of semblance across all offsets (Bagaini et al., 1999). Notice, however, that if events are perfectly flat, no change in the image is expected, so these types of diagnostics are ineffective for data with little structure. This is the situation for much of the Blackfoot survey. When seeing the events change with γ_{eff}, it is virtually impossible for the unbiased eye to know which image is more correct. The same horizon can vary as γ_{eff} changes from being smooth and coherent to rough and incoherent, or from singlets to doublets, but this does not tell you which one is right.

CONCLUSIONS

Layered anisotropy is an important factor to take into account in the converted-wave processing at Blackfoot. The original processing of the 1995 3-C, 3-D survey did not take layered anisotropy into account, and therefore were poorly resolved because the far-offset traces were misplaced with respect to the near-offset traces during CCP stacking. Values of Vp/Vs for CCP stacking that are roughly 70% of the values used in the original processing were found to produce the best image in the one part of the survey that has enough structure to determine the valid velocity ratio for imaging.

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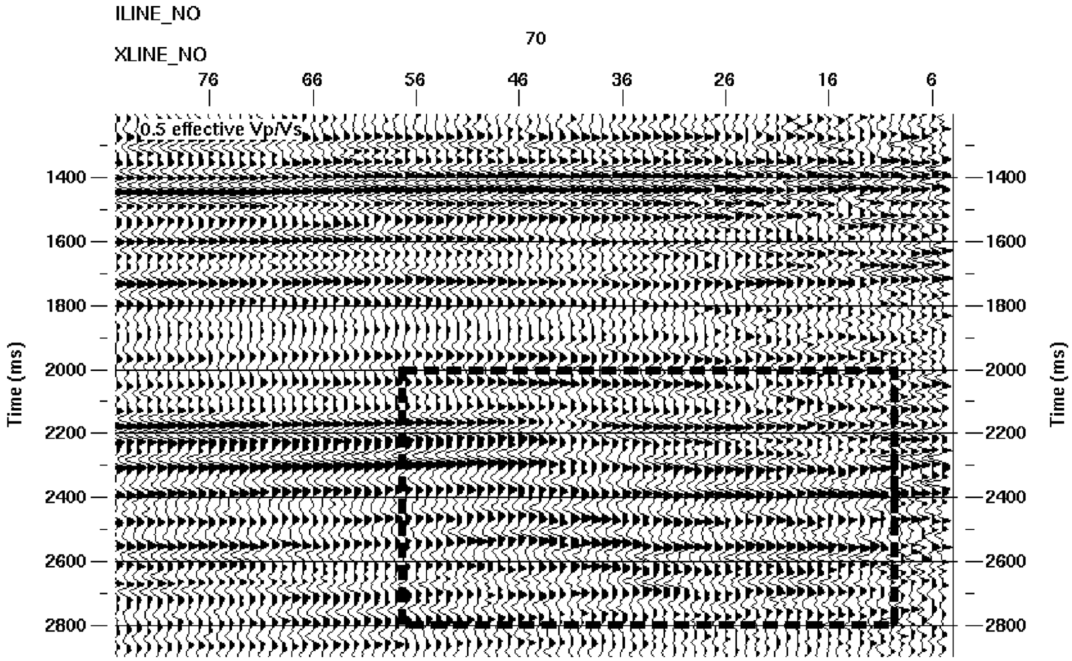


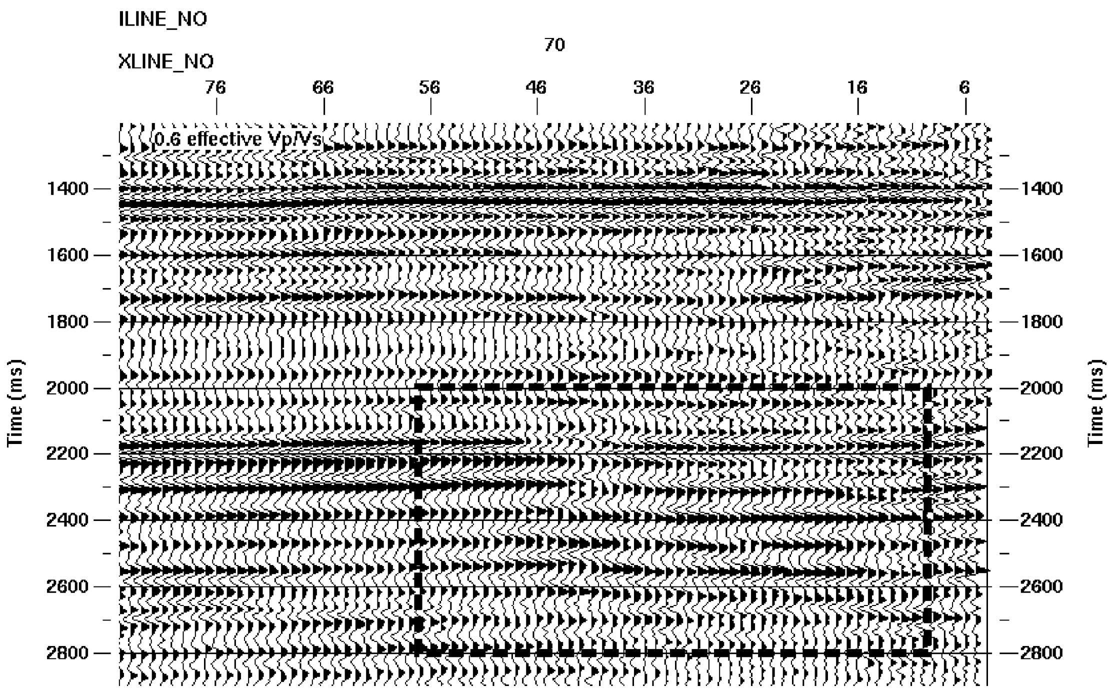


Fig. 2. Migrated data with effective Vp/Vs equal to (a) 0.5 and (b) 0.6 times vertical Vp/Vs.

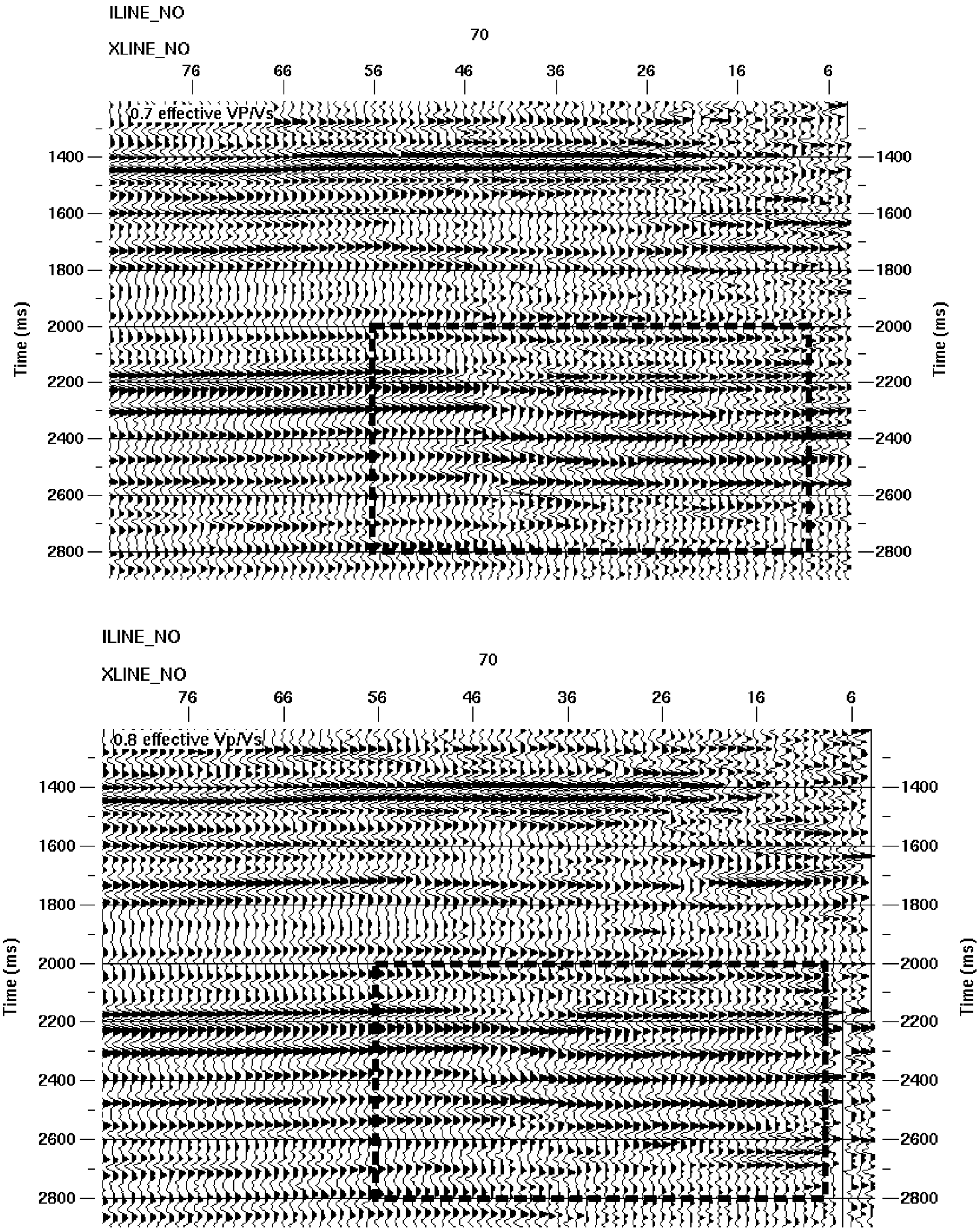


Fig. 2. Migrated data with effective Vp/Vs equal to (c) 0.7 and (d) 0.8 times vertical Vp/Vs.

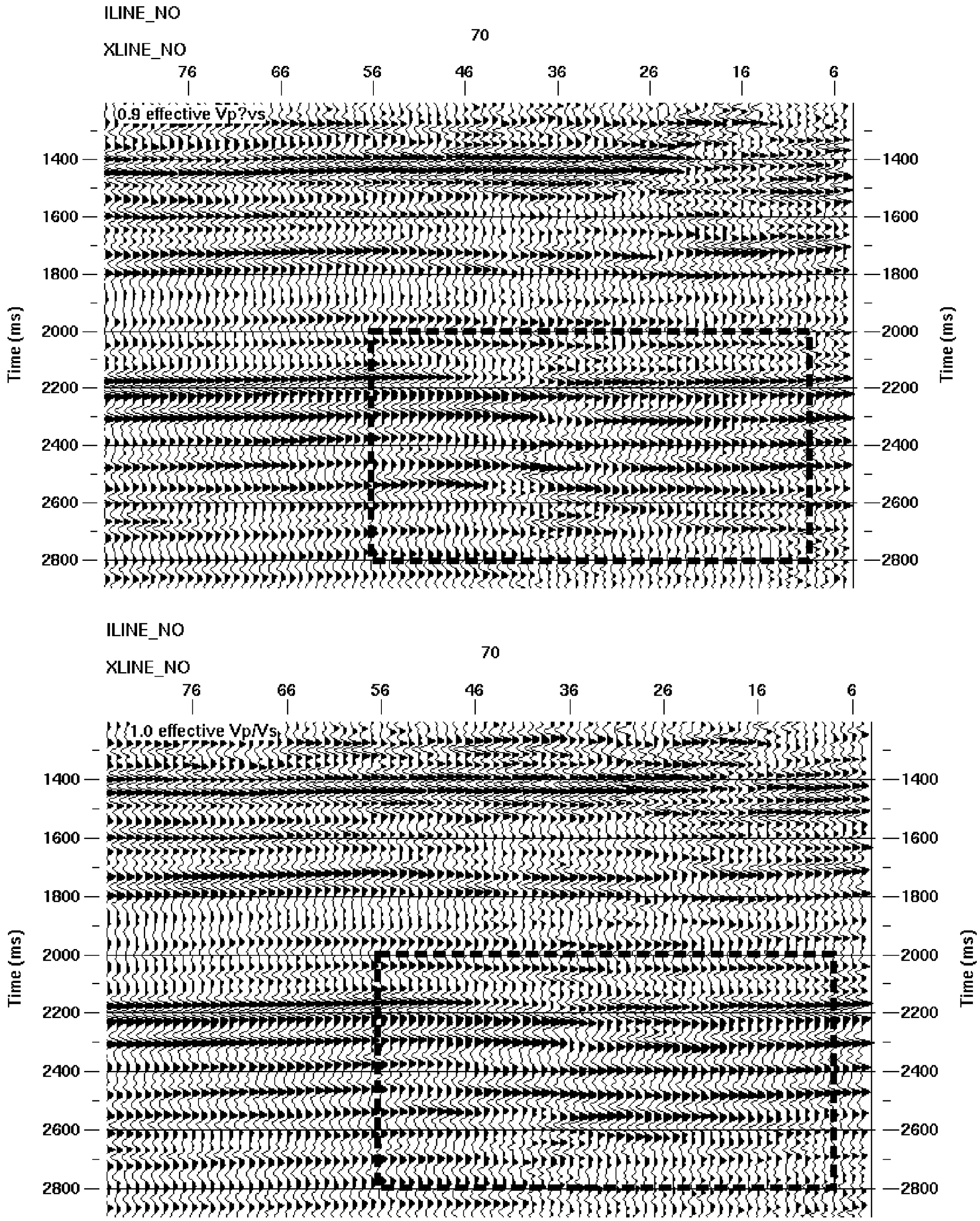


Fig. 2. Migrated data with effective Vp/Vs equal to (e) 1.0 and (f) 1.1 times vertical Vp/Vs.

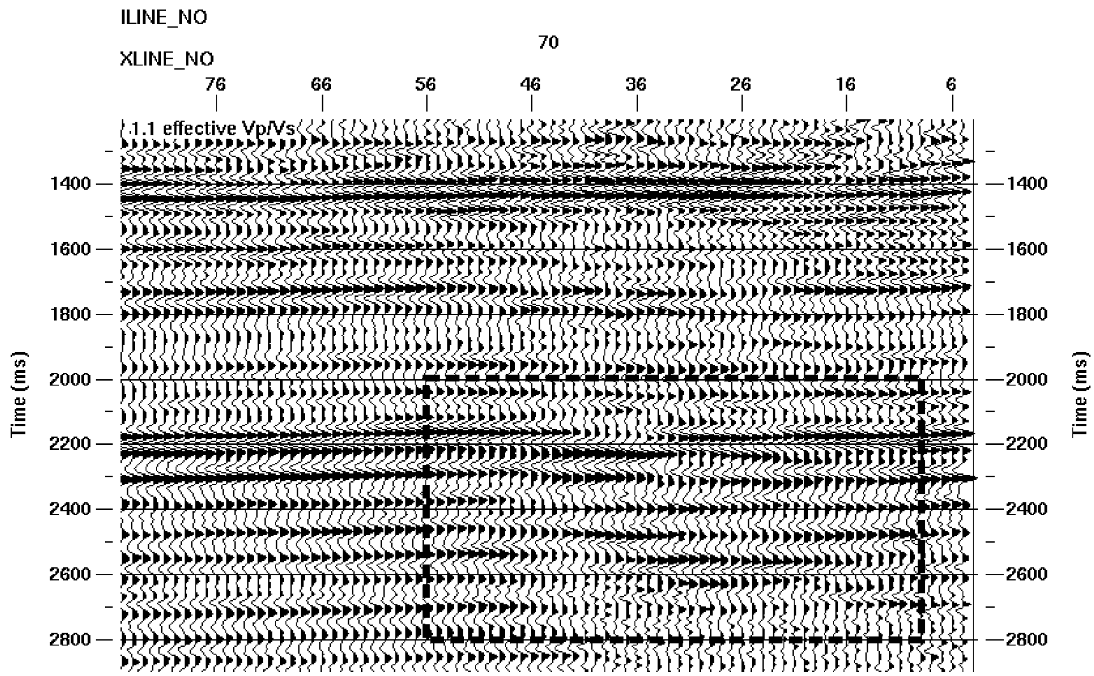


Fig. 2 (g) Migrated data with effective Vp/Vs equal to 1.1 times vertical Vp/Vs.

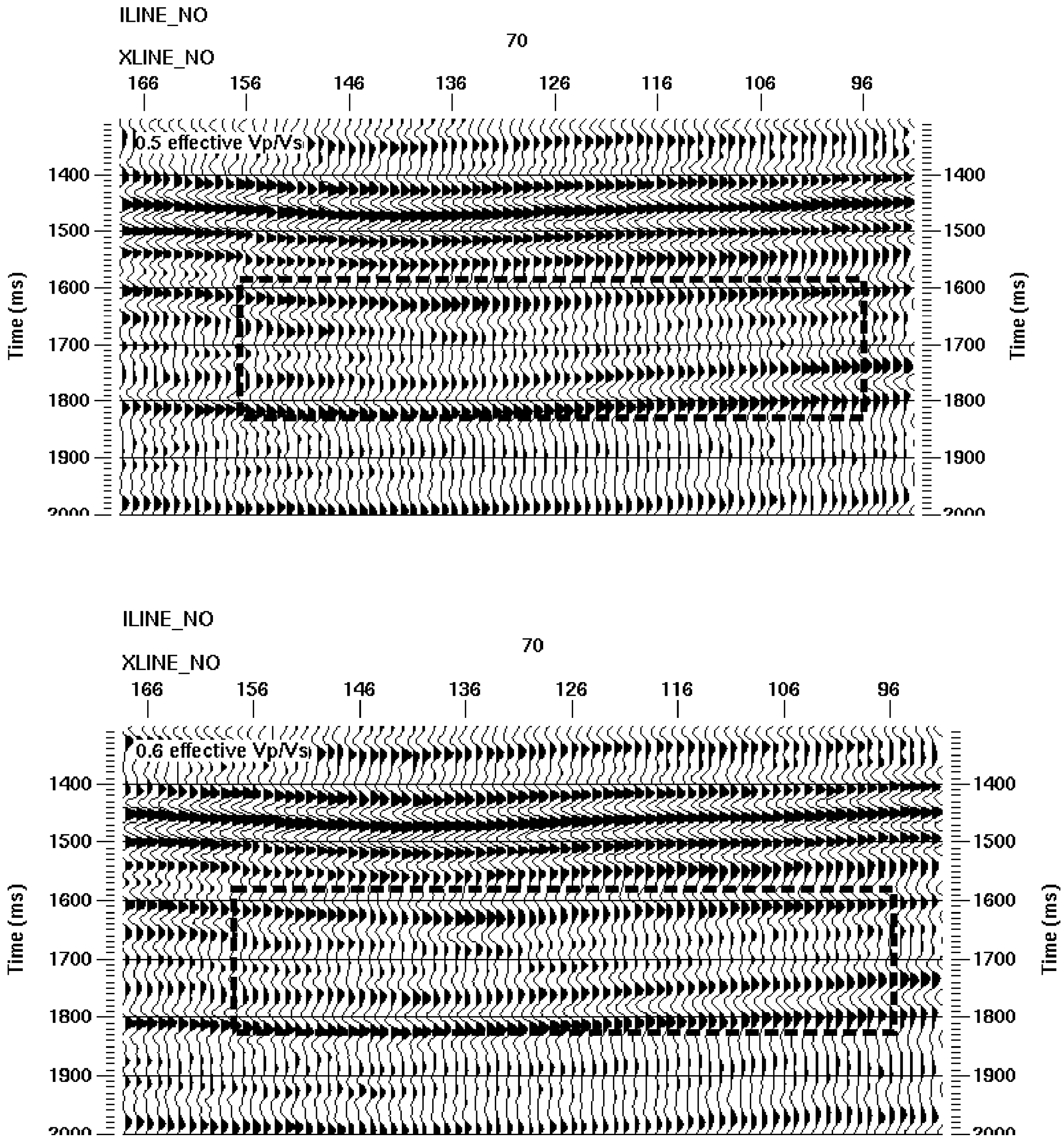


Fig. 3. Migrated data with effective Vp/Vs equal to (a) 0.5 and (b) 0.6 times vertical Vp/Vs.

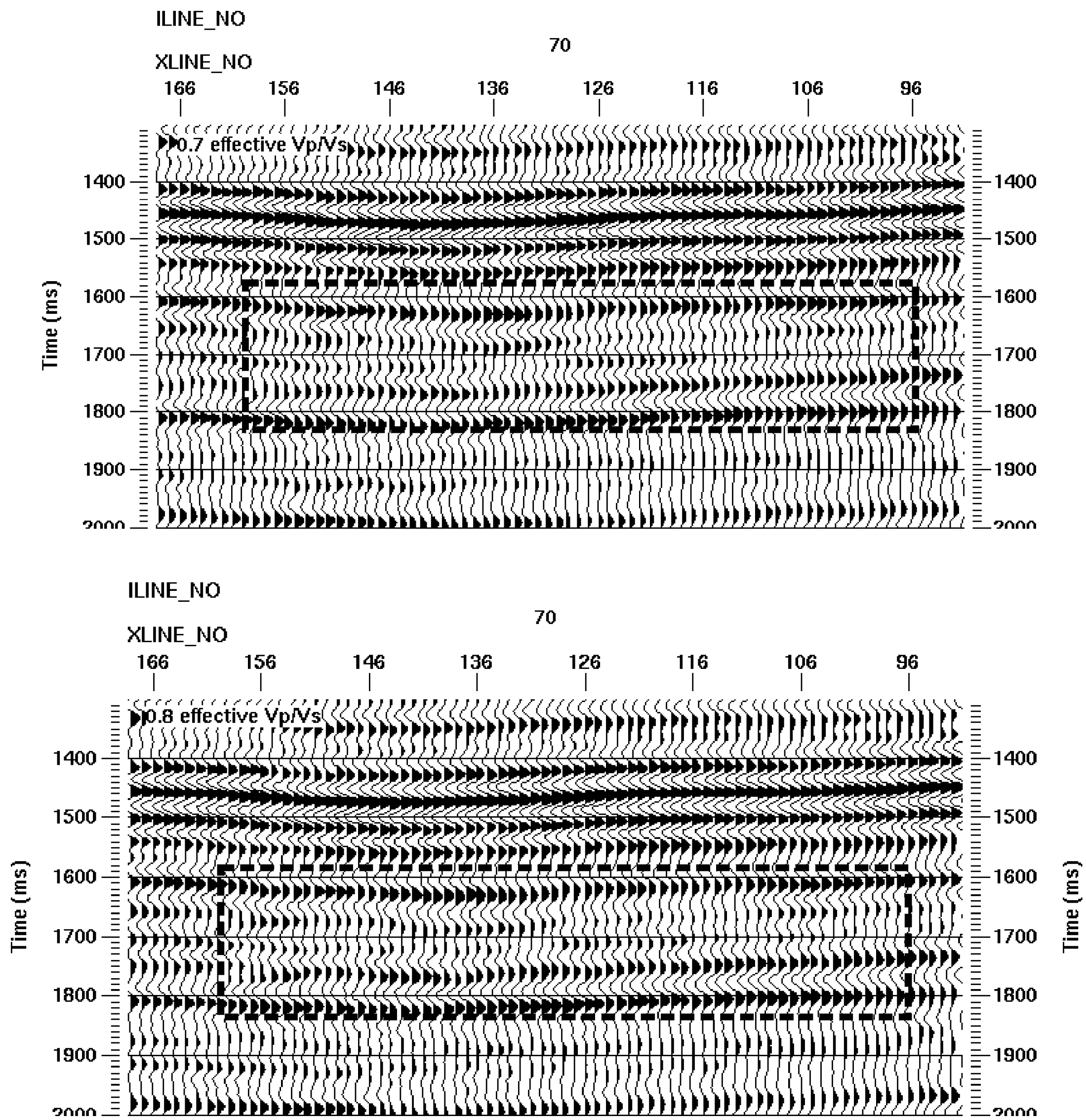
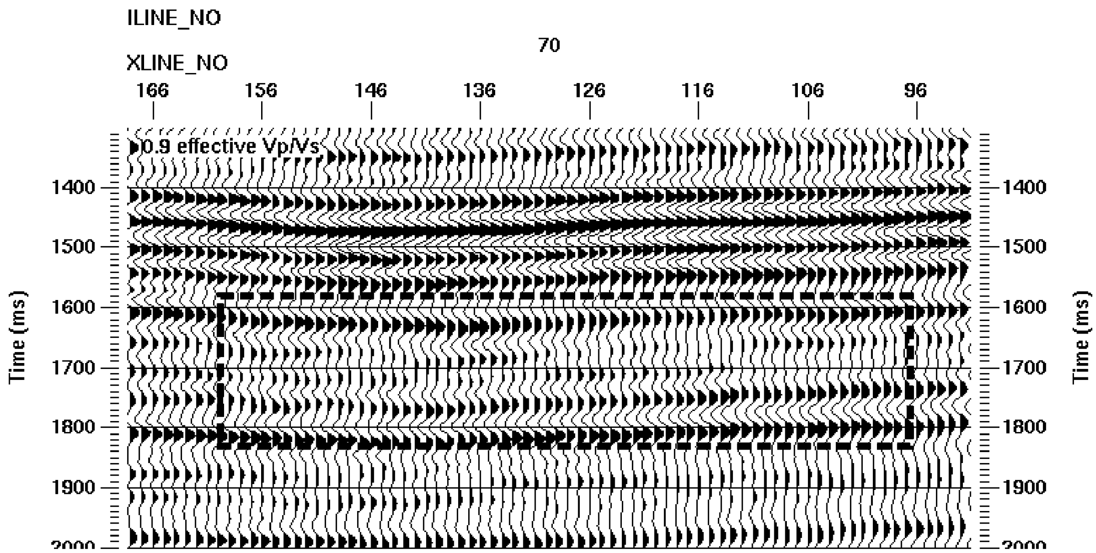


Fig. 3. Migrated data with effective Vp/Vs equal to (c) 0.7 and (d) 0.8 times vertical Vp/Vs.



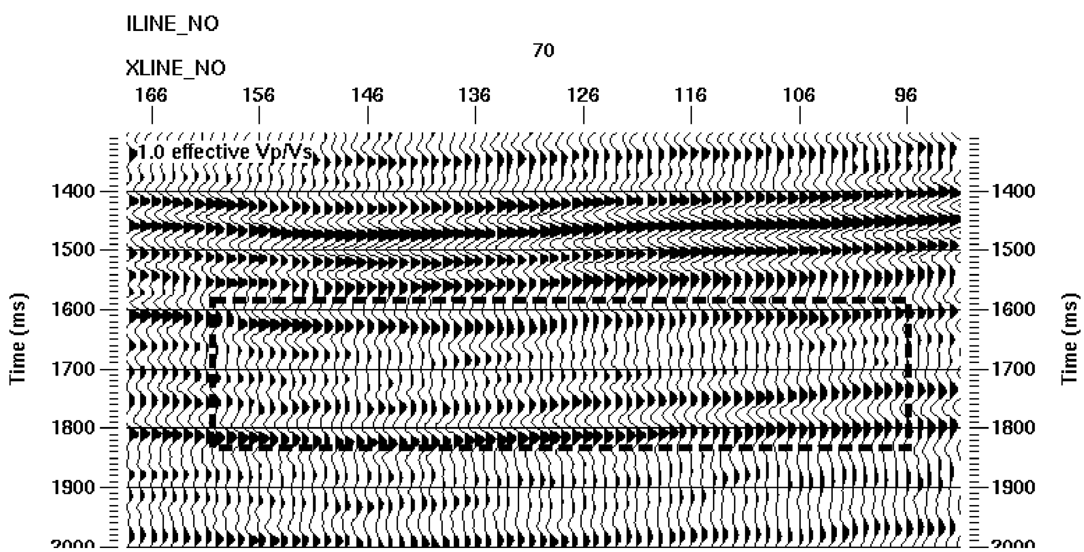


Fig. 3. Migrated data with effective Vp/Vs equal to (e) 0.9 and (f) 1.0 times vertical Vp/Vs.

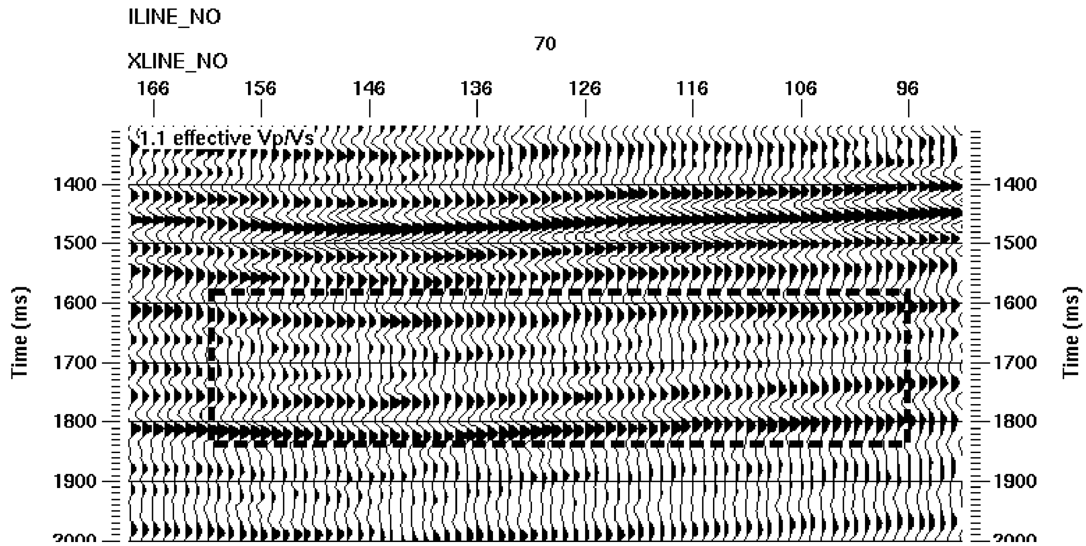


Fig. 3(g). Migrated data with effective Vp/Vs equal to 1.1 times vertical Vp/Vs.