The Wedge Model Revisited*

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Abstract

Several physical seismic models of simple wedges were built to assess amplitude and tuning effects commonly associated with the classic 'Widess' wedge. Rather than producing simple tuning at λ/4, 2D zero-offset seismic surveys over the physical models showed a surprising number of high amplitude dipping events corresponding to pure-mode, mixed-mode and doubly-converted wedge multiples. To examine these reflection events, finite-difference exploding reflector models using a numerical version of the same wedge velocity models were also produced. Migration of the physical model data was accomplished using 2D poststack Kirchhoff depth migration although the presence of these multiples and multi-mode events presented complications for migration. The study suggests that pure-mode and converted-wave multiples can be significant recorded events in the presence of high velocity rocks with a wedge-like geometry.

The Wedge Models

Widess (1973) provides a foundation for understanding how the amplitude of reflection events changes as the thickness of a bed decreases. We furthered this study by recording and analyzing 2D seismic data recorded over simple wedge models in the physical modelling laboratory at the University of Calgary. The wedges were made of Plexiglas resting on a PVC slab and immersed in water, as shown in Figure 1. The scaling factor used for distance in the model was 1:2500, so that the approximately 40 cm long by 20 cm deep model represented 1000 m in horizontal distance and 500 m in depth. In this discussion the laboratory scale dimensions of the physical model will be referred to as "scaled", while the represented field dimensions will be called "full scale". The velocities and densities of the materials in the model were not scaled. Four different wedge dips were modeled, the so-called 5, 10, 15, and 20 degree wedges. Numerical and physical modeling data were compared, along with graphical ray tracing results, to identify the travel times and modes of observed events. These models are analogues of high velocity wedges of carbonate rocks in thrust faults in the Rocky Mountain Foothills, and permafrost or basalt encountered in Canadian frontier basins.

A 2D zero-offset survey was conducted over each of the four wedge models, each with 400 traces at a trace spacing of 2.5 m (full scale). The source and receiver consisted of spherical piezoelectric transducers in water emitting frequencies in the range of 100 to 600 kHz (scaled). Since the velocities in the model were unscaled and the distance scaling was 1:2500, the time scaling used was necessarily 1:2500 as well. Data was recorded at a sample rate of 0.125 ms (full scale), giving a maximum recording time of 0.512 s (full scale). The data for the 20 degree wedge are displayed in Figure 2.

Finite-Difference Models

A primary objective of the study was to identify the events visible on the physical model data. In order to achieve this, numerical models were created and used, along with graphical ray tracing, to find the travel times and modes of the different events. The numerical modeling method used was a 2D acoustic finite-difference algorithm, implemented in Matlab as part of the *finitedif* toolbox created by the Consortium for Research in Elastic Wave Exploration Seismology (CREWES) at the University of Calgary (Youzwishen and Margrave, 1999). Exploding reflector models were created using the known wedge model geometries and velocities. An exploding reflector model is one in which sources are placed along each reflector in the model and are initiated at time zero, allowing waves to propagate to the surface at a velocity equal to half the physical velocities. The exploding reflector model approach was chosen for this study because exploding reflector models are good approximations for zero-offset sections; i.e. equivalent to the surveys recorded over the physical models. The exploding reflector model for the 20 degree wedge is shown in Figure 3.

The exploding reflector modeling did simulate multiples but, because the finite-difference algorithm used was acoustic, the models did not include mode conversions. However, modifying the wedge velocity to be equal to the shear velocity of Plexiglas allowed for the simulation of reflection events that involved conversion to shear waves in the wedge.

Event Identification

Examination of the exploding reflector models, combined with graphical ray tracing, allowed for the identification of events visible on the physical model data. These included primary reflections, as well as multiples and diffractions. During the ray tracing it was found that there is a maximum number of pure mode wedge multiples possible for a given wedge dip. For pure P-wave events, of the form P[PP]nP, the number of multiples is given by $n*D < 90°$, where n is the number of reflection points in the wedge and D is the dip of the wedge. This means that for the 20 degree wedge there are a maximum of four pure P wave events from the angled base of the wedge. For events that convert to shear waves in the wedge, of the form P[SS]nP, the same relationship holds, but there is an additional constraint related to the critical angle at the upper surface of the wedge. The relationship is $\sin(n*D) < (1380\text{m/s})/(1480\text{m/s})$. This means that for the 20 degree wedge there are three events of this type possible. The travel times for the P[PP]nP and P[SS]nP events were found to be predictable using a single analytical expression, given by

$$T = \left(\frac{v_P d_W}{v_W \sqrt{v_P{}^2 - v_W{}^2 \sin^2(nD)}} \right) + \frac{\sin(nD)}{v_P} \left(x - \frac{d_W v_W \sin(nD)}{\sqrt{v_P{}^2 - v_W{}^2 \sin^2(nD)}} \right)$$

where *vP* and *vW* are the velocities of Plexiglas and water (*vP* can be the P-wave or S-wave velocity), *dW* is the depth of the water above the wedge, and *x* is the distance of the source-receiver pair from the tip of the wedge.

Migration

The physical model data was migrated using a post-stack Kirchhoff depth migration algorithm. Migrations were performed on all four wedge models using the exact P-wave velocity model. The result for the 20 degree wedge is shown in Figure 4. The migration successfully collapsed the diffraction from the tip of the wedge and removed the pull-up on the PVC slab under the Plexiglas. The top and base of the Plexiglas and PVC were moved to their correct depths. The first P-wave reflection from the angled part of the wedge was migrated to the correct angled position. The wedge multiples are still visible after migration, interfering with the clarity of the image. In a subsequent migration the PSSP reflection from the angled part of the wedge was moved to its correct migrated position by changing the velocity assigned to the wedge in the migration velocity model to equal the S-wave velocity of Plexiglas.

References Cited

Widess, M.B., 1973, How thin is a thin bed?: Geophysics, v. 38, p. 1176-1180.

Youzwishen, C.F., and G.F. Margrave, 1999, Finite difference modeling of acoustic waves in Matlab: CREWES Research Report, 11, Ch. 6.

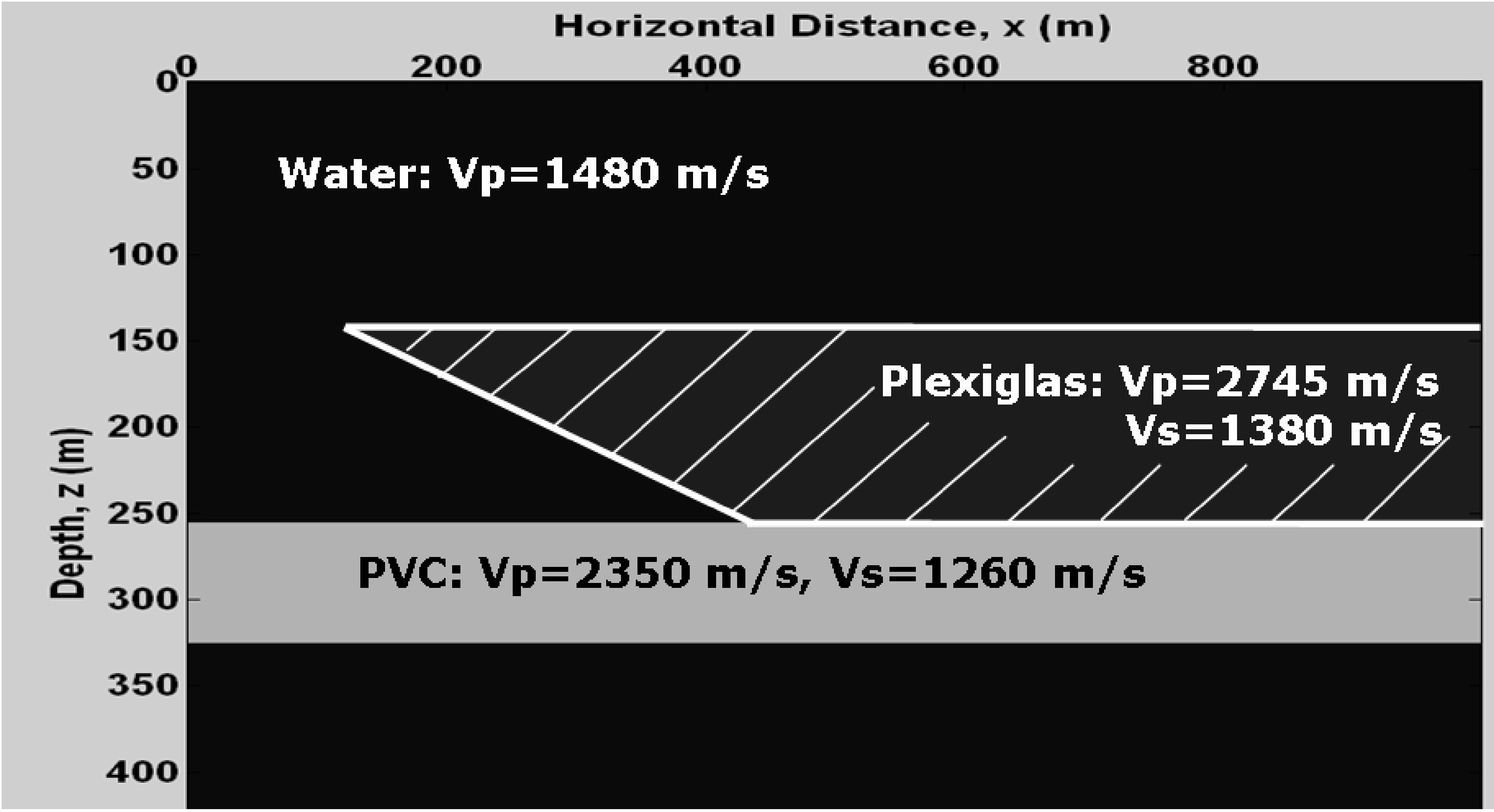

Figure 1. Wedge model used in physical modeling experiment.

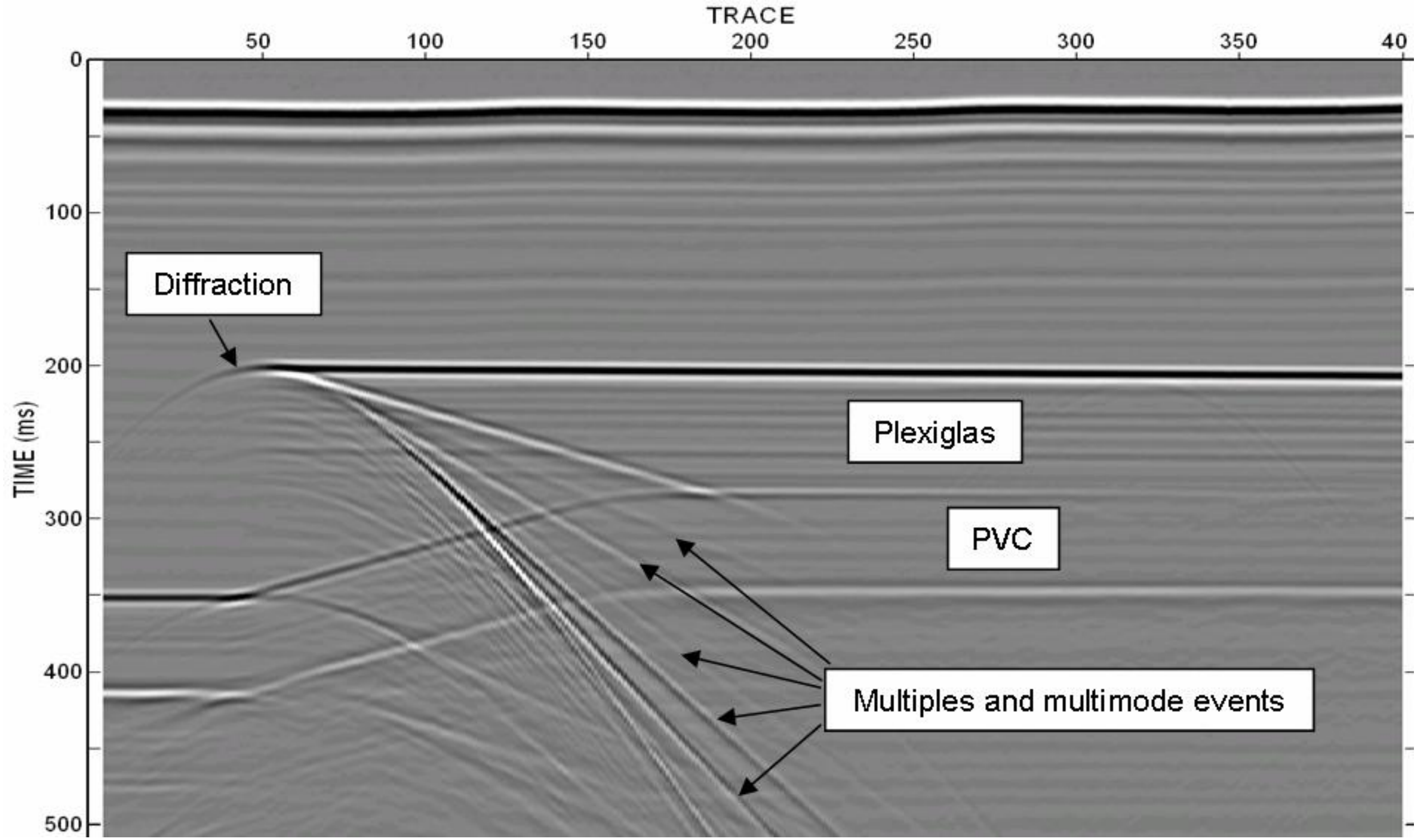

Figure 2. Physical model data for the 20 degree wedge. Trace spacing is 2.5 m (full scale).

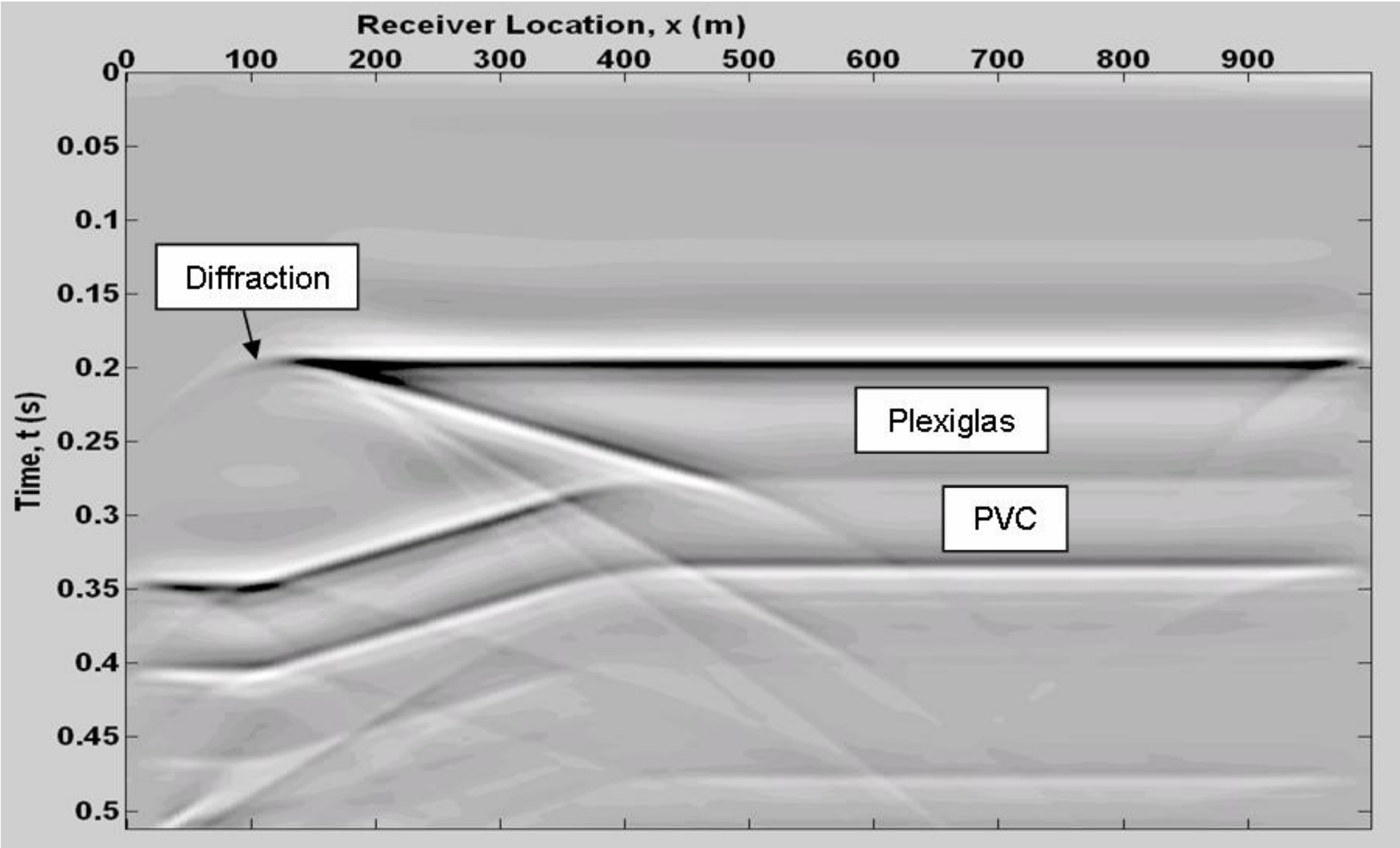

Figure 3. Exploding reflector model for the 20 degree wedge.

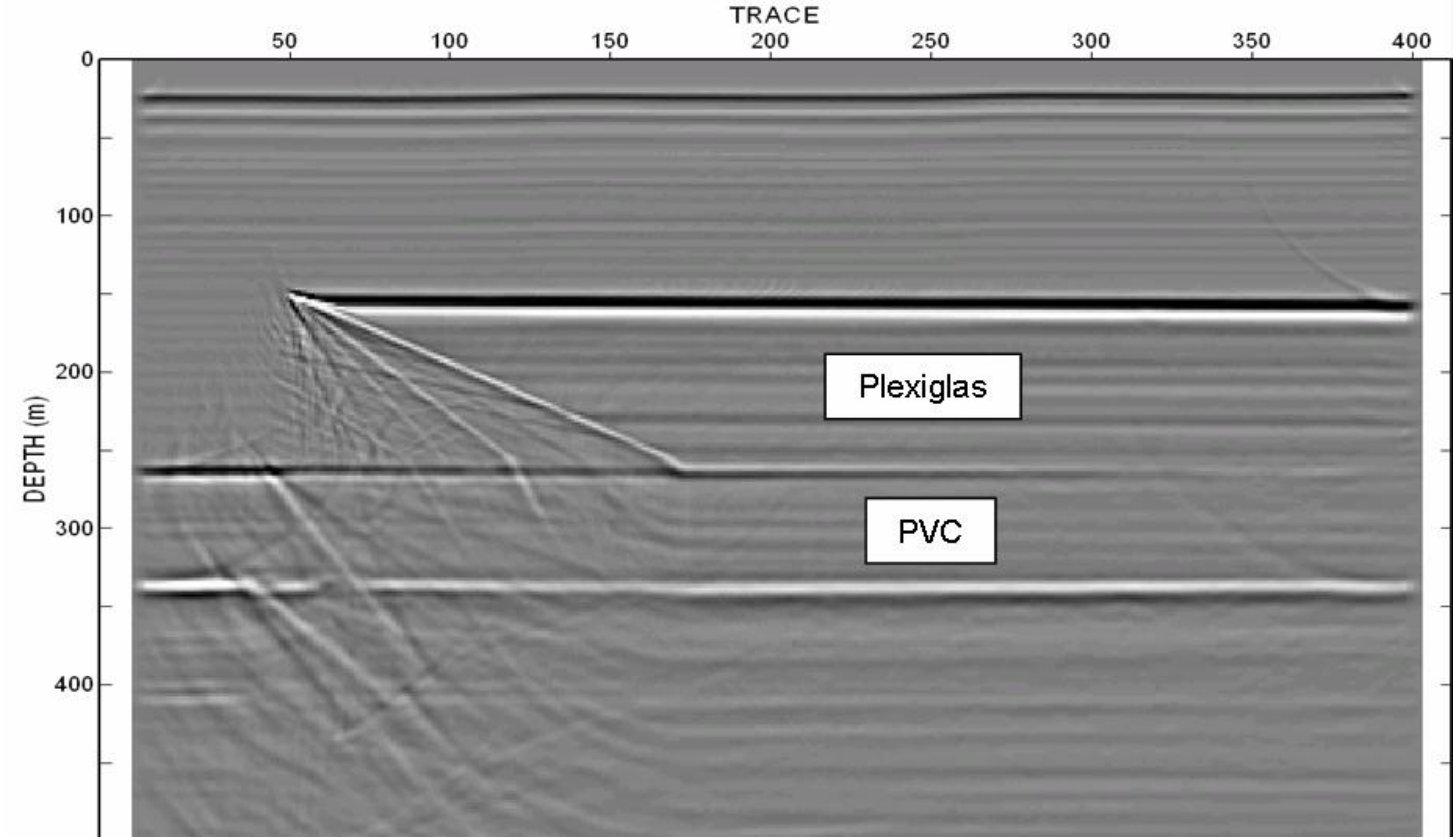

Figure 4. Kirchhoff depth migration of physical model data for the 20 degree wedge.