Physical seismic modeling of sand-filled channels

Don C. Lawton, Scott P. Cheadle, Eric V. Gallant and Malcolm B. Bertram

ABSTRACT

Acoustic seismic reflection data have been obtained over a physical model of a channel system typical of those found in the subsurface of southern Alberta. The model is constructed from steel and plexiglas with plaster modeling a low-velocity channel-sand fill. A zero-offset 3-D survey has been recorded over the model for use in 3-D acquisition design and migration tests for stratigraphic targets. One 2-D line of multichannel data has also been collected and an amplitude decrease with offset is observed in reflections from the top and base of the channel.

INTRODUCTION

A generic model of a sand-filled channel has been developed in the physical seismic modeling laboratory of the CREWES Project. The model is based on producing channel sandstones of the Glauconitic Member of the Mannville Formation, found in Lower Cretaceous sediments of southern Alberta. Acoustic and elastic scaled seismic surveys are being conducted over this model with 3 principal objectives:

a) to determine optimum acquisition and data processing parameters for 3-D seismic surveys over this type of target,
b) to test 2-pass 2-D versus full 3-D migration for subhorizontal stratigraphic targets, and
c) to study amplitude variation with source-receiver offset (AVO) in order to test numerical AVO modeling results in thinly bedded sequences.

Recently, 3-D seismic surveys have become popular for mapping subtle stratigraphic traps in southern Alberta (e.g. Hradsky and Griffin, 1984). However there have been few published studies relating to acquisition survey design for these targets. Some migration comparisons have been published from 3-D surveys over reefs (Peterson and Reynilsh: 1983), but few, if any, have addressed the case for mapping channels.

The study of variations in reflection amplitude with angle of incidence has been proposed by many workers as a means of extracting lithological information (Tatham, 1982: Ostrander, 1984: Ensley, 1984: Wren, 1984). Most AVO interpretation is performed using a model-based approach, usually from sonic logs. The models are raytraced and offset-dependent reflectivity is computed using the Zoeppritz equations and knowledge of the incident angle. Poisson's Ratio in the target zone is perturbed iteratively until the computed reflectivity function matches that observed in real data gathers.

Potential pitfalls in AVO analysis appear to have received only minor attention, particularly in thinly-bedded sequences (Jain, 1984; Lawton, 1989). Raytracing at non-normal incidence invokes an assumption of infinite bandwidth, and Snell's Law may be invalid for band-limited data and bed thicknesses of less than a wavelength. In southern Alberta, the thickness of Glauconitic sands rarely exceeds 30 m whereas the dominant wavelength of typical reflection data is rarely less than about 80 m. Hence there is a real need to critically assess numerical AVO modeling in this environment.

MODEL CONSTRUCTION

A channel model 0.6 m square was constructed out of plexiglas, plaster of Paris, and steel. The plaster constitutes the low-velocity fill in channels that were milled from a plexiglas layer 0.6 cm thick. A plan view of the model is shown in Figure 1 and it contains channels which vary in width, depth and shape and sinousity. Also included in the model are two simple overbank splay deposits.

The distance and time scale factors for the model are 1:5000, so the model represents a 3 km x 3 km area after scaling. Channel 1 has a uniform thickness of 31 m (scaled) whereas Channel 2 is primarily 15 m thick, with several 'scours' 31 m deep. Channel margins with the heavy outline in Figure 1 were bevelled at 45 degrees and the remaining margins were left as vertical 'cut-banks'. The stratigraphy of the model is shown in Table 1.

Table 1. Vertical section through channel 1 of model.

Layer	Compound	Thickness (actual, cm)	Thickness (scaled, m)	Vp (m/s)	Vs (m/s)
1	Plexiglas	5.08	254	2740	1385
2	Plaster	0.63	31	2150	1180
3	Plexiglas	0.95	48	2740	1385
4	Steel	1.59	80	5800	3300

The velocity of the plexiglas is lower than the actual velocity of Lower Mannville sediments, but the acoustic impedance contrast between the plaster and plexiglas is similar to that between the channel fill and the host sediments. Layer 4 (steel) was used to create a large acoustic impedance boundary a short distance below the channel, similar to Mississippian carbonates in southern Alberta. In this model, the base level of the thick channels was placed 48 m (scaled) above this high-velocity basal reflector, and 63 m (scaled) above for the thin channels. In the off-channel areas, the entire model above the steel was made up of plexiglas layers. The layers were bonded with an acoustically transparent epoxy resin. Considerable care was taken during the construction of the model to avoid entraining air bubbles in the bonds.

For acoustic experiments, the model is placed in the water-filled seismic modeling tank, and data are collected using small, spherical transducers (Cheadle, et. al., 1985). The depth of the channel horizon below the recording plane is adjusted by raising or lowering the model with respect to the transducers. For elastic modeling, additional plexiglas layers will be added to the top of the model.

ACOUSTIC MODELING

Initial experiments have been completed on the model. These were a zero-offset 3-D survey over the entire model, and a multichannel survey along one line. For these experiments, the top of the channel horizon was placed at a depth of 1100 m below the recording plane. The 3-D survey was undertaken over a square grid with a bin dimension of 0.4 cm x 0.4 cm (20 m x 20 m), resulting in 25,600 traces (160 lines x 160 shotpoints per line). These data will be migrated on the IBM processing facility using Western Geophysical software, and various migration schemes will be tested. The data volume will be loaded onto the LANDMARK workstation before and after migration so that the effectiveness of migration can be assessed with time slices through the channel horizon.

One line of multichannel data has also been collected along Line 65 of the model (Figure 1). The line contained 40 records, each record consisting of 120 traces, with a near offset of 100 m, a far offset of 1280 m and a group interval of 20 m, yielding 15 - fold subsurface coverage. An example of a shot gather from the dataset is shown in Figure 2; this record was taken with the shotpoint located between channels 1 and 2 and the channel events are clearly visible in the data. The leading and trailing halves of the spread were recorded simultaneously using two different receiver transducers and the reverberations following the first reflection (top of plexiglas) show that the impulse responses of the transducers are not exactly equal. The raw data were scaled, CMP-gathered and corrected for NMO using stacking velocities calculated from the velocity data in Table 1. Examples of gathers from off-channel and over the thick part of channel 2 are shown in Figure 3. The on-channel gather shows clear events from the top and base of the channel and mode-converted energy is also contained in the data. The channel events show an amplitude decrease with offset and this will be subject to detailed study and comparison with numerical results using the same velocity structure.

The move-out corrected gathers were stacked, and a comparison between the 15-fold section and the single-fold section from the 3-D zero-offset is shown in Figure 4. Both sections show similar reflection character across the channels, but the multifold section has a higher signal to noise ratio, resulting from stacking out the reverbatory tail of the reflection wavelet.

DISCUSSION

The channel model constructed is providing useful acoustic seismic data for assessing 3-D seismic survey design over statigraphic targets, and for testing migration techniques. Amplitude variations with source-receivers offsets are evident and these can be compared with numerical methods. A full multi-offset 3-D survey is currently being planned.

Acoustic modeling will be followed by elastic modeling, particularly multicomponent surveys using P and SH source transducers. Of particular interest will be to assess whether P-SV data can successfully delineate the channels and provide information about the elastic properties of the channel fill.

REFERENCES

Cheadle, S. P., Bertram, M. B., and Lawton, D. C., 1985, Development of a physical seismic modeling system, University of Calgary: Geological Survey of Canada Paper 85-1A, 499-504.

Ensley, R. A., 1984, Comparison of P- and S-wave seismic data: A new method for detecting gas reservoirs: Geophysics, 49, 1420-1431.

Hradsky, M., and Griffin, M., 1984, Sandstone body geometry, reservoir quality and hydrocarbon trapping mechanism in Lower Cretaceous Mannville Group, Taber/Turin area, southern Alberta: CSPG Memoir 9, 401-411.

Jain, S., 1987, Amplitude-vs-offset analysis: a review with reference to application in western Canada: Journal of the Canadian Society of Exploration Geophysicists, 23, 27-36.

Lawton, D. C., 1989, Effects of thin bed tuning on AVO analysis: Abstract, Annual meeting of the CSEG, Calgary, 1989.
Ostrander, W. J., 1984, Plane-wave reflection coefficients for gas sands at non-normal angles of incidence: Geophysics, 49, 344-352.
Peterson, F. M., and Reynish, W. C., 1983, 3D seismic - a cost-effective approach: Journal of the Canadian Society of Exploration Geophysicists, 19, 7-15.
Tatham, R. T., 1982, Vp/Vs and lithology: Geophysics, 47, 336-344.
Wren, A. E., 1984, Seismic techniques in Cardium exploration: Journal of the Canadian Society of Exploration Geophysicists, 20, 55-59.

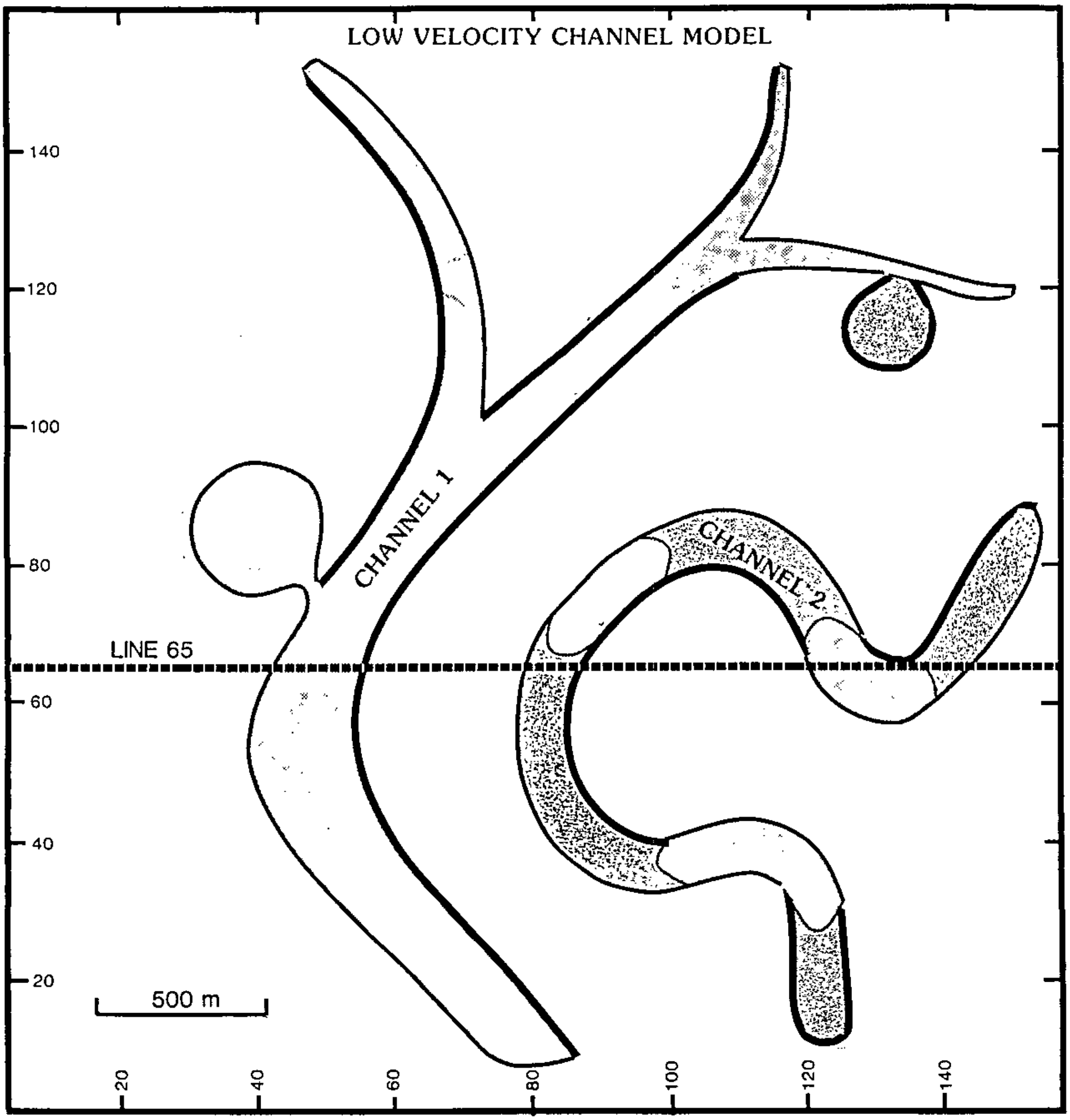

FIG. 1. Plan view of the channel model. The dot pattern shows thick channels and the stipple pattern shows thin channels.

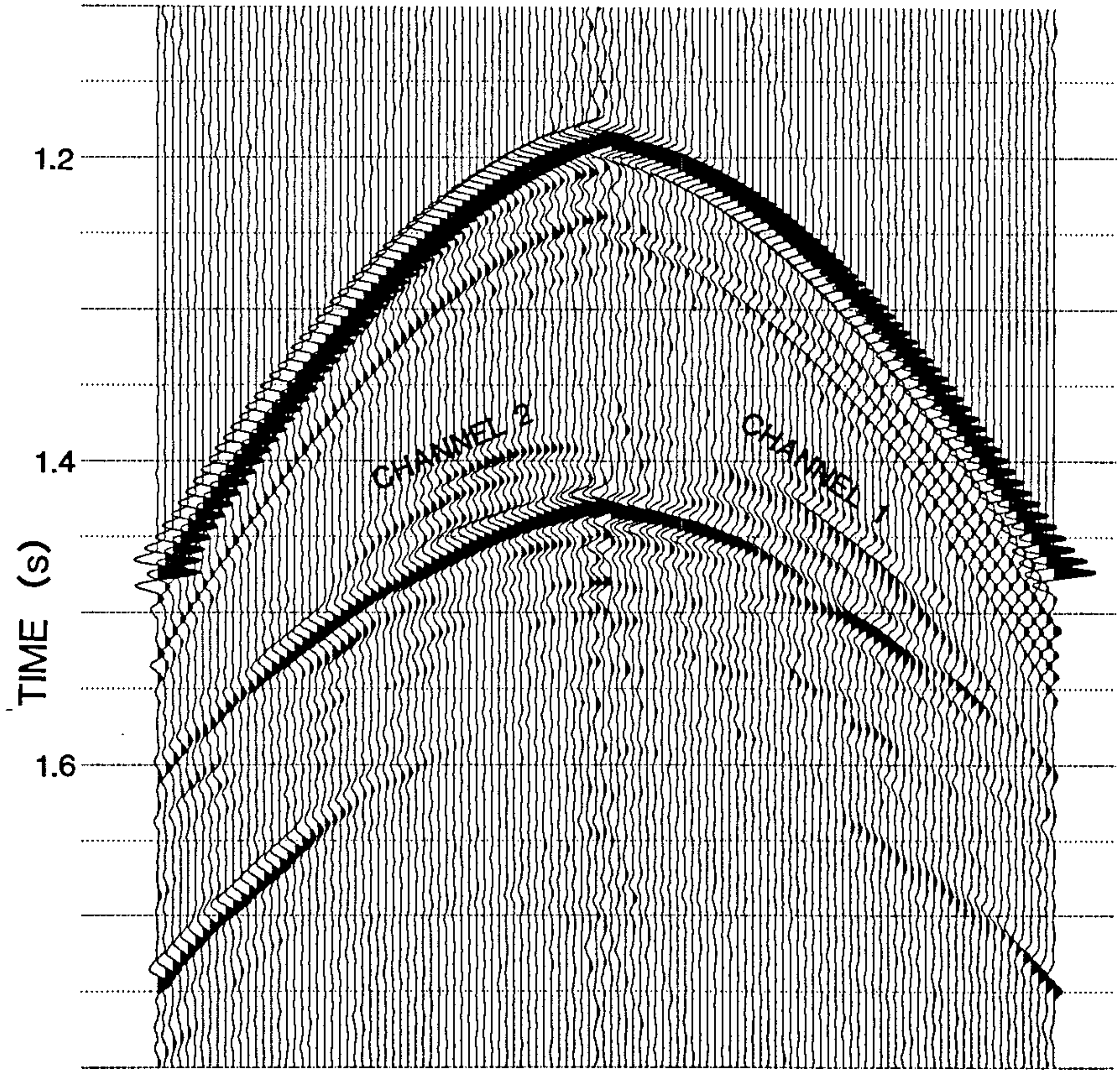

FIG. 2. Example of a shot gather from line 65, showing channel events.

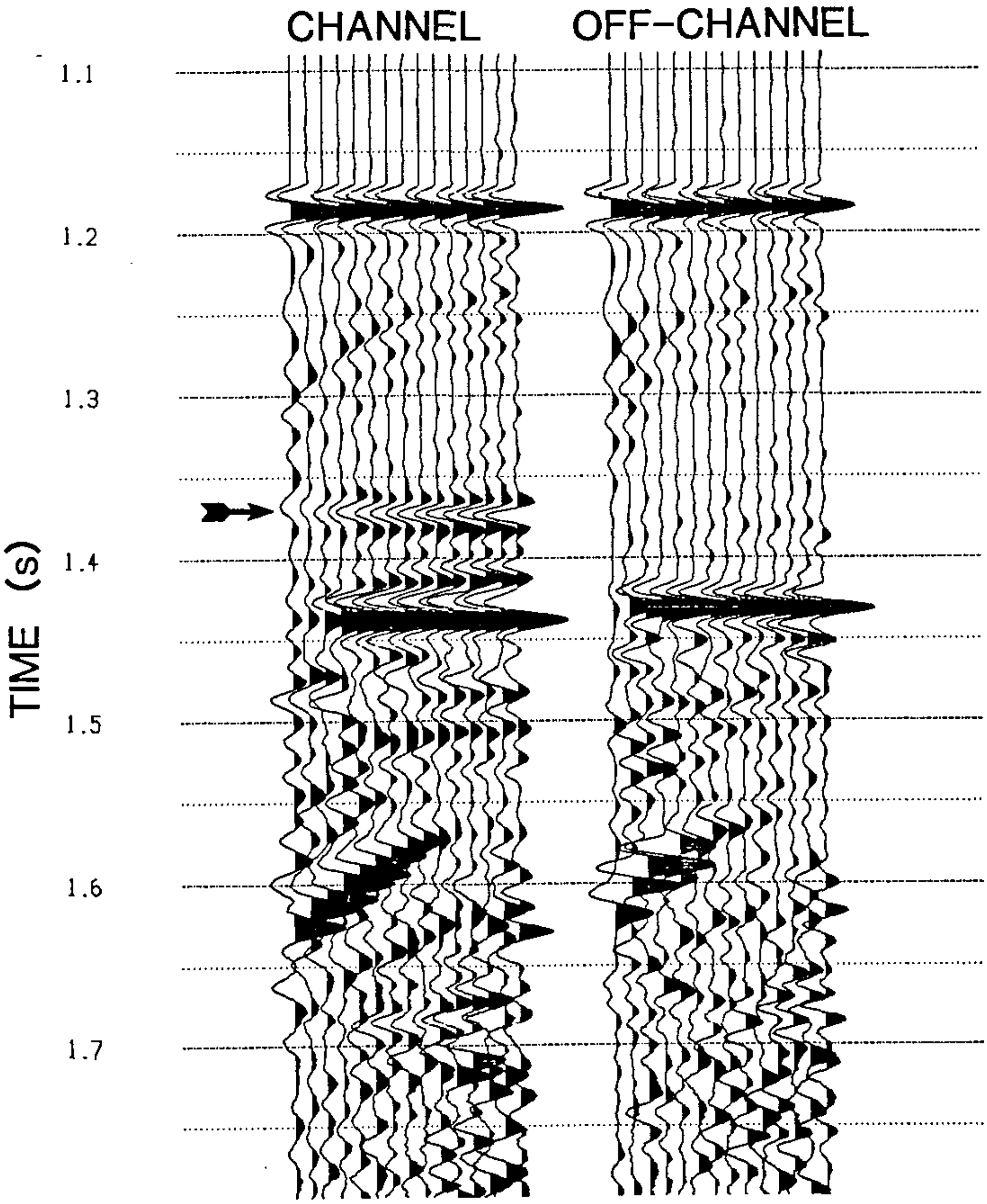

FIG. 3. NMO-corrected CDP gathers from on-channel and off-channel locations. The arrow marks the top of channel reflection. Note the significant amplitude of mode-converted energy at about 1.6 seconds.

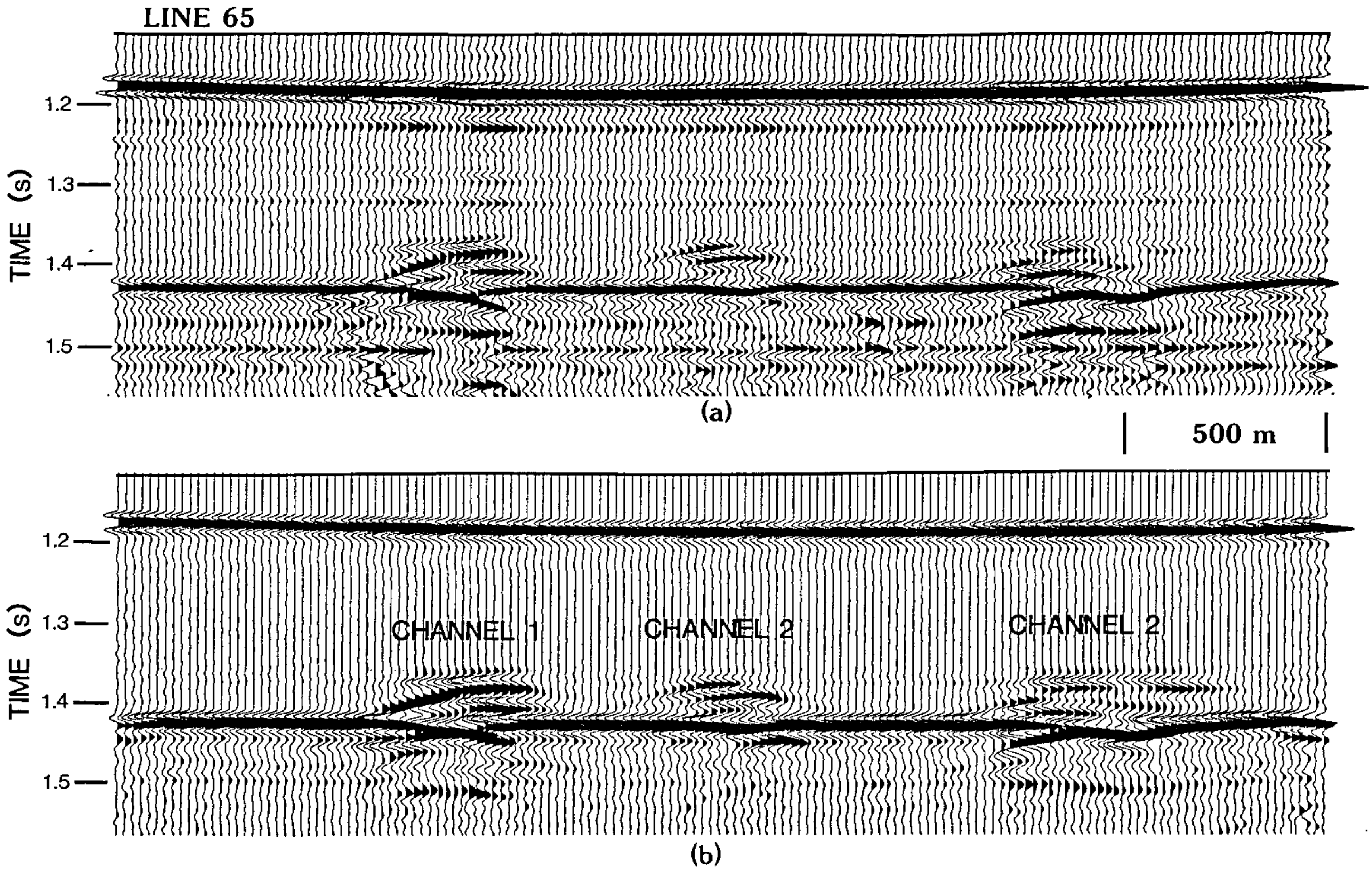

FIG. 4. Comparison between unmigrated (a) single-fold and (b) 15-fold seismic sections from Line 65 of the channel model.