Side-scanning Seismic: Analysis and a physical modeling study

Robert R. Stewart and Giovanni Marchisio

ABSTRACT

A processing procedure is presented here to use off-line energy (sideswipe), recorded on three-component (3-C) receivers, to create seismic sections. The processing procedure should include a polarization filter designed to enhance arrivals from particular off-line distances or angles. Filtered events from off-line distances can then be NMO-corrected, stacked, and migrated using full three-dimensional geometry. The procedure can be used to construct off-line sections. These methods are tested using ultrasonic, 3-C physical modeling data. The physical modeling data simulate lines offset from a buried reef. A migrated off-line section shows the reef.

INTRODUCTION

One problem which may be encountered in conventional 2-D (single line) surveying in regions of significant structure is that of sideswipe. That is, energy may be recorded on the seismic line which is not from geology directly below the line (Tucker and Yorston, 1973; French, 1974; Brown, 1988; Larner et al., 1983; Hospers, 1985). As Tucker (1982) says, "And sideswipe there will always be when lines are shot at other than more-or-less right angles to dip or structural trends." The dynamics of these off-line events are such that after data processing, they can often be found on the final section as coherent events. These misplaced events may be erroneously interpreted as true anomalies vertically below the line.

To understand the sideswipe problem and its potential use in imaging, let's consider a simple geometry for an off-line point scatterer half way between the source and receiver. From Figure 1, the approximate total traveltime t of the event will be:

$$t^2 = t_0^2 + \frac{4y^2}{V_{rms}^2(t_0)} + \frac{h^2}{V_{rms}^2(t_0)} + \frac{\Delta x^2}{V_{rms}^2(t_0)} \tag{1}$$

where

t_0 is the zero-offset, two-way traveltime,

y is the off-line offset of the scatterer,

h is the source-receiver offset,

$V_{rms}(t_0)$ is the RMS velocity at time t_0.

$\Delta x/2$ is the scatterer offset from the source-receiver mid-point.

From equation (1), we can see that off-line events will have a hyperbolic shape similar to that of in-line events: thus the coherency with respect to NMO and migration. However, as the off-line events will arrive later than in-line events from the same depth, but with the same curvature (velocity), it may be possible to attenuate them using careful velocity filtering. This would be similar to multiple rejection.

If the line had been recorded with three-component (3-C) geophones, then we might have another option to attenuate off-line events. Off-line events will arrive at the 3-C geophone with some energy recorded on the y (transverse) channel (Ebrom et al., 1989; Stewart and Marchisio, 1991). This energy may be very small if there is a significant low-velocity near surface or if the off-line distance is small and the anomaly deep. Whenever, transverse-channel energy is detected though, we could suppress its associated vertical channel energy. This would lead to vertical-channel recordings less contaminated with events from off the line.

On the other hand, the recording of off-line energy in the acoustic case has been used to great advantage in oceanography (Clay and Medwin, 1977; Johnson and Helferty, 1990; Gardner et al., 1991). Side-scanning sonar uses a high-frequency acoustic beam directed perpendicularly to the direction of travel. Each sonar burst or ping insonifies a strip of the water-bottom's topography or near surface. The backscattered sound, as a function of time, can be reconstructed into a picture of the water-bottom surface (and possibly lithofacies) laterally away from the boat's path.

In this paper, for the solid earth case, we are interested in exploring the idea that sideswipe might be used to construct lateral seismic images. If this is possible there could be great benefit in providing some 3-D geologic information from less expensive 2-D surveys. Particularly relevant geologic areas may include

i) Those of complex structure (where seismic waves are scattered from many directions) and
ii) flat strata regions containing anomalies, such as reefs, where scattering might be strong from a localized area.

To test some of these ideas we have conducted several ultrasonic 3-D surveys over and beside a simulated reef. A basic processing flow is outlined to image the reef from data not directly above it.

PHYSICAL MODELING

The scaled model under consideration is shown in Figure 2. All scaled values are calculated by multiplying the actual numbers by 5000. The model consists of a reef shaped aluminum disk buried in several layers of Plexiglass. The 2-D survey includes lines shot directly above the axis of the reef and parallel lines at off-line distances of 500 and 750 m. A vertical source and 3-C receivers were used in all cases with a constant source-receiver offset of 250 m. and a shot point separation of 50 m.

The 500 m. off-line section is plotted in Figure 3. In this case, a vertical source and transverse receiver are recorded. The off-line energy is apparent as a hyperbolic-like events with apices at 0.7s, 1.1s and 1.4 s., which correspond respectively to pure-P, converted P-to-S and pure-S arrivals. The nearly flat events are reflections from interfaces located directly below the line. In this paper we will only show the results of processing the pure-P events.

PROCESSING PROCEDURE

The conventional vertical source-vertical receiver section acquired on the reef axis is displayed in Figure 3. An f-k migration of this section is plotted in Figure 4. The reefs flat top is nicely imaged, as would be expected. Next we consider the vertical source-transverse receiver line offset 500m from the reef apex (Figure 5). A polarization filter could be applied at this point to separate the off-line scattered energy from the flat in-line reflections. In this preliminary case, no filter was used. Also we used the known y offset to process the section to normal-incidence, zero-offset time. We remove NMO (Δt) in equation (1) by subtracting

$$(\Delta t)^2 = \frac{4y^2}{V_{rms}^2(t_o)} + \frac{h^2}{V_{rms}^2(t_o)} \,. \qquad (2)$$

We can next migrate the section in Figure 5 in the x direction using the P-wave velocity of Plexiglass. Figure 6 shows the migrated section. The curvature of the migrated event at 0.65 sec. in Figure 6 reflects the fact that the y offset used and much of the reflected energy intersects the 3-D reef on its side. The over migrated events do not correspond to pure-P events. This migrated section corresponds to a vertical slice at y = 450m.

CONCLUSIONS

A procedure has been outlined here to take single-line, 3-C data and from them reconstruct an off-line section. This procedure makes use of the 3-D Dix equation, and geometry off-line scatterers and 3-C receivers. Generally, to process the data a polarization filter in specific off-line directions would be applied, then the data would be stacked and migrated in the in-line direction to make off-line sections.

ACKNOWLEDGEMENTS

REFERENCES

Brown, A.R., 1988, Interpretation of three-dimensional seismic data: Am. Assoc. Pet. Geol., AAPG Memoir 42.

Clay, C. S. and Medwin, H., 1977, Acoustical oceanography: Principles and applications: J. Wiley and Sons.

Ebrom, D. A., Tatham, R. H., Sekharan, K. K., McDonald, J. A., and Gardner, G.H.F., 1989, Nine-component data collection over a reflection dome: A physical modeling study: Presented at the 59th Ann. Internat. Mtg. Soc. Expl. Geophys.

French, W. S., 1974, Two-dimensional and three-dimensional migration of model-experiment reflection profiles; Geophysics, 39, 265-277.

Gardner, J. V., Field, M. E., Lee, H., Edwards, B. E., Masson, D. G., Kenyon, N., and Kidd, R. B., 1991, Ground-truthing 6.5 kHz side scan sonographs: what are we really imaging?: J. Geophys. Res., 96, B4, 5955-5974

Hospers, J., 1985, Sideswipe reflections and other external and internal reflections from salt plugs in the Norwegian-Danish basin: Geophys. Prosp., 33, 52-71.

Johnson H. P. and Helferty, M., 1990, The Geological interpretation of side-scan sonar: Rev. Geophys., 28-357-380.

Larner, K., Chambers, R., Yang, M., Lynn, W., and Wai, W., 1983, Coherent noise in marine seismic data: Geophysics, 48, 854-886

Stewart, R. R. and Marchisio, G., 1991, Side-scanning seismic: Analysis and a physical modeling study: Presented at the 1991 Ann. Nat. Can. Soc. Expl. Geophys. Mtg., Calgary.

Tucker, P. M., 1982, Pitfalls revisited: Soc. Expl. Geophys.

Tucker, P. M. and Yorston, H. J., 1973, Pitfalls in seismic interpretation: Soc. Expl. Geophys., Monograph Series, No. 2.
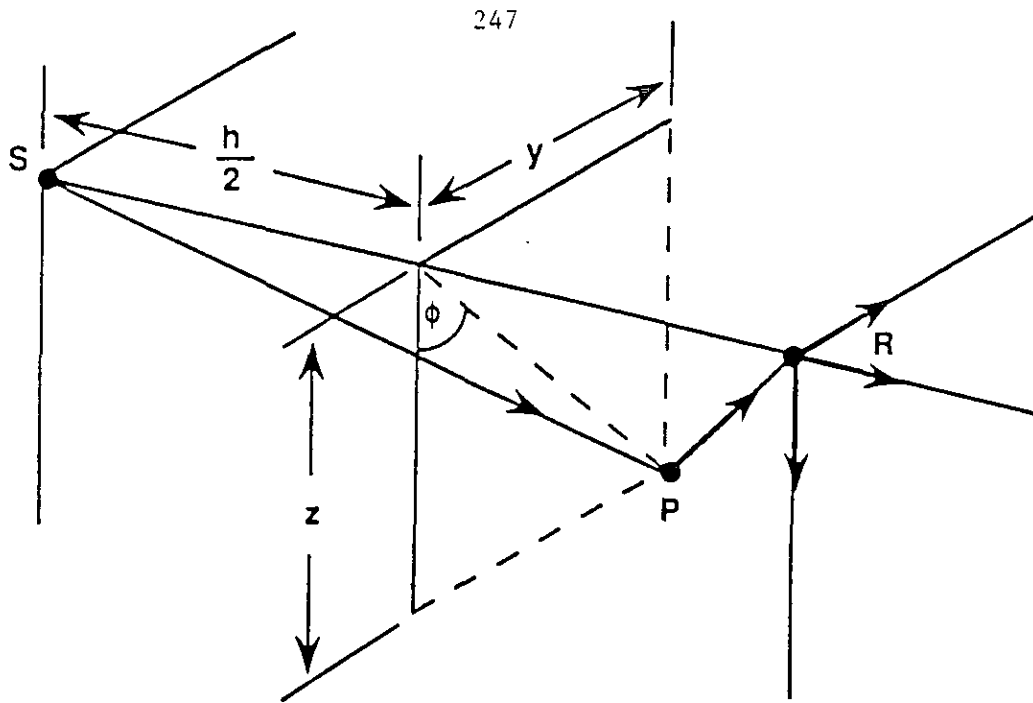
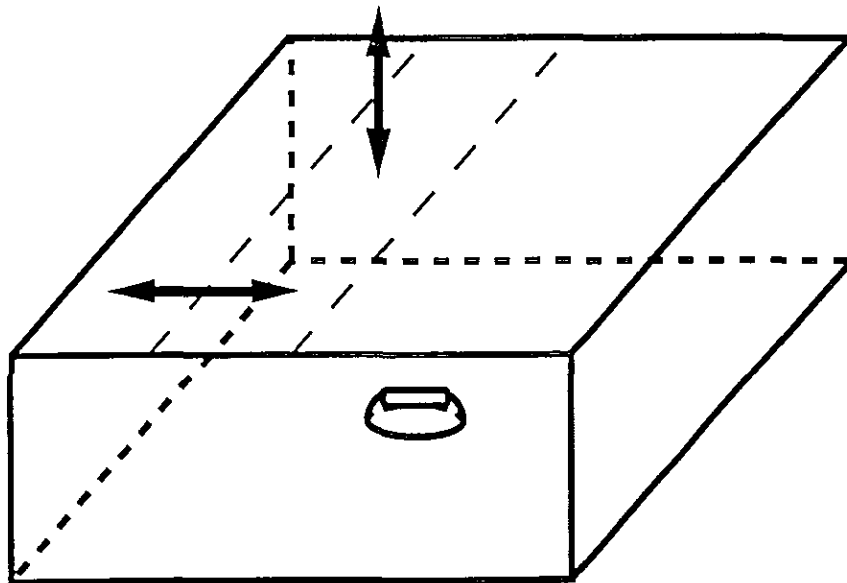Figure 1. Off-line scatter geometry.

500 m

Figure 2. Schematic diagram of the scaled reef model.
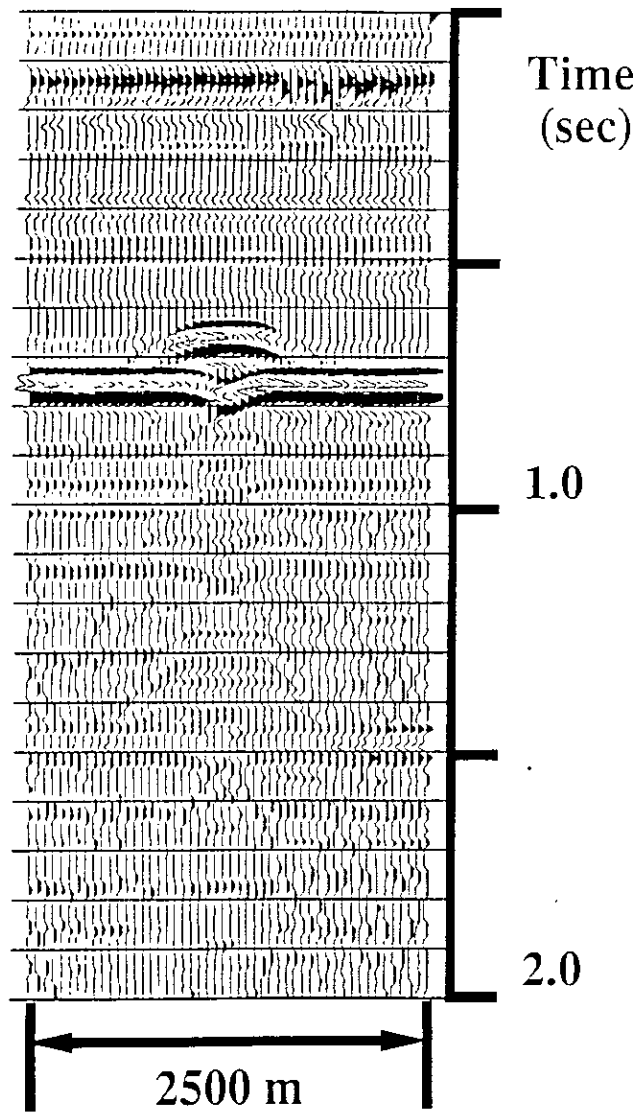
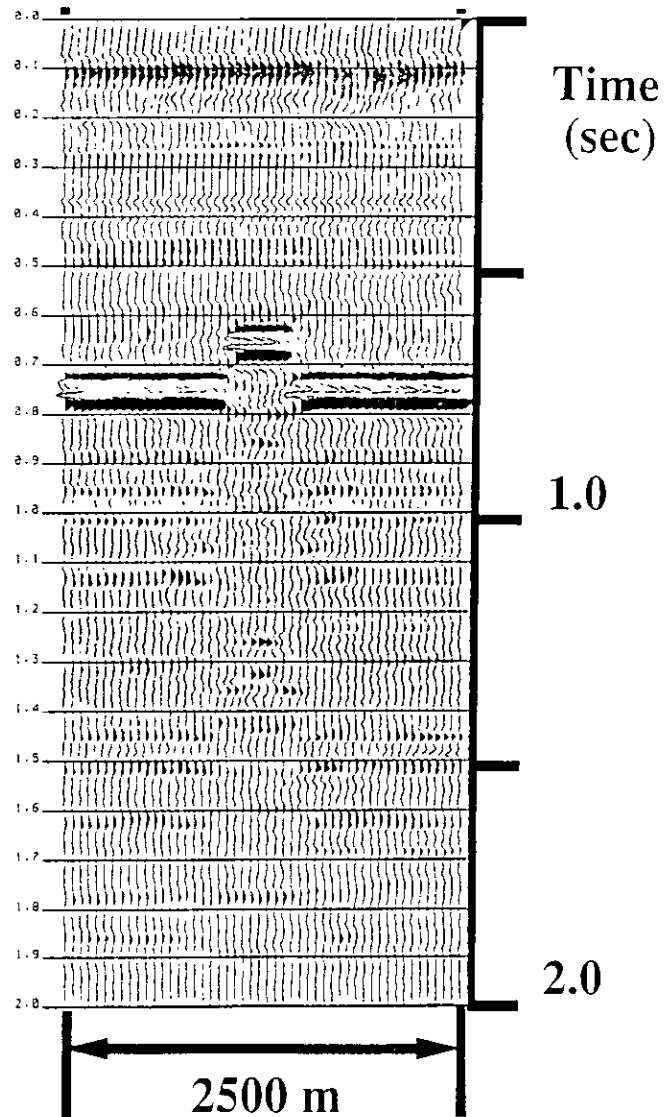Figure 3. Raw vertical source-vertical receiver section, from on top of the reef.

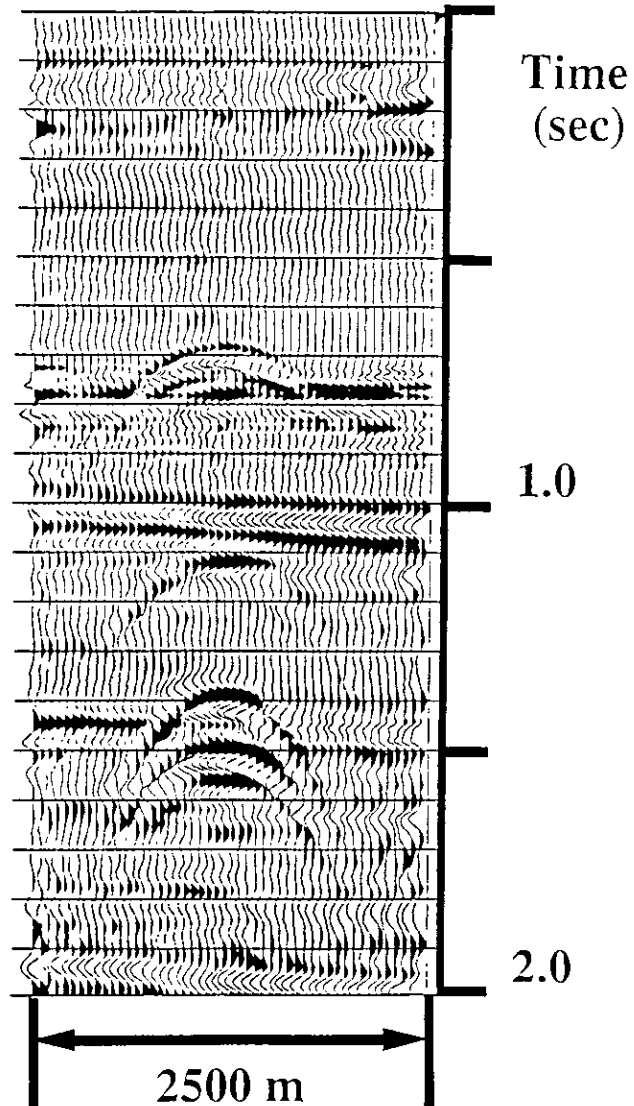Figure 4. P-wave migration of the section in Figure 3.

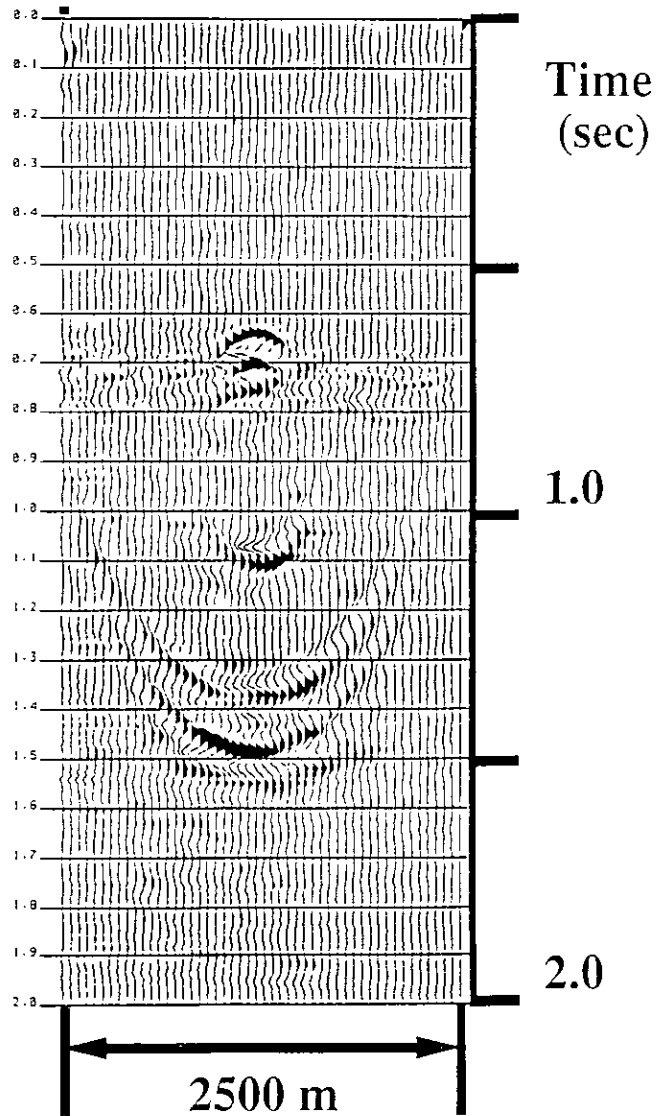Figure 5. Raw vertical source-transverse receiver section, offset 500 m from the reef top.

Figure 6. P-wave migration of the section in Figure 5.