A Shallow Marine Seismic Reflection Survey in Suisun Bay

Zhuping Liu, James W. Rector, Patrick Williams

ABSTRACT

23 shallow marine seismic reflection profiles were collected in Suisun Bay, CA, to help characterize the shallow faults associated with the earthquakes occurred in California during the past 40 years. We analyzed the noises in these shallow marine seismic reflection data, and applied a series of traditional seismic data processing techniques to improve the S/N ratio. Due to the low fold of the reflection data, we constructed analogue single-channel marine reflection profiles, sorted them to CMP domain and stacked the data, which proves to be an effective way in showing shallow structures.

INTRODUCTION

During the past 40 years, six major thrust and reverse earthquakes have occurred in California. All of these (except possibly the Loma Prieta earthquake) ruptured faults that were either unmapped or not mapped as active. Based on data from other projects, a large, active, blind thrust system within and extending north and south of Suisun Bay, in the Sacramento River Delta has been identified. However, the geometry, the level of the tectonic activities of the structures, and the possible hazard posed by the potential ruptures are not well known. In order to help to extend the knowledge of the style and processes of the structures, especially the evaluation of shallow faults, we did this shallow seismic reflection survey (23 lines totally) near Ryer Island in Suisun Bay in late May, 1998.

Recent equipment improvements and related research results on the data processing enable the routine high resolution study of active faults in the shallow marine environment. High resolution seismic survey can provide results that compare well with direct observation and trenching on land. High resolution data reveal clear expression of deformation coinciding with projections of mapped faults and with gravity data, and high resolution seismic data was used to characterize a fault connection between the Rodgers Creek and Pinole faults in eastern San Pablo Bay(Williams et al., 1995).

In the survey, we used a 48-channel hydrophone array and a Geometrics StrataView Exploration Seismograph as our recording system. The main frequency range of our Geopulse Source is 500~1500 Hertz. We used a GPS antenna and receiver system with sub-meter accuracy as our navigation system.

Challenges for acquisition and interpretation of the seismic reflection data from the shallow marine environment including the masking, attenuation, delay, and scattering of seismic energy by various kinds of environmental noise, entrained gas, and coarse lithologies. Interpretation can also be difficult where submerged objects, out-of-line obstructions, and seismic multiples complicate the seismic records. Entrained gas can produce bright reflectivity in otherwise unreflective horizons, and because of its very slow seismic velocity, delays the arrival of other reflected energy. Deconvolution, bandpass filtering, f-k filtering, NMO, DMO, stacking were applied to the data.

The low fold in this survey makes it difficult for the velocity analysis. Single-channel marine reflection profiling is a simple but highly effective method of seismic surveying at sea that finds wide use in a variety of offshore applications. It often provides good imaging of subsurfaced geology and permits estimates of reflector depth and geometry that are sufficiently accurate for many purposes. In this method, the outputs of the individual hydrophone elements are summed. Unfortunately, the record sections suffer from the presence of multiple reflections, especially multiples of the sea bed reflection, which may obliterate primary reflection events in the later parts of the records. Multiples are always a particular problem when surveying in very shallow water, since they then occur at a short time interval after the primary events. Because the aim of this survey is to help locate the defaults usually of large dip angles, this does not create a serious problem. Analogue single-channel reflection profiles are therefore constructed after apply NMO and DMO with estimated velocities. The data were also sorted to and stacked in CMP domain.

SURVEY LOCATION AND LOCAL GEOLOGY

Multifold seismic reflection data have been collected along 23 profiles at 4 locations near the Ryer Island, a small island between Grizzly Bay and Suisun Bay, California (Figure 1). Quaternary deformation in the western Sacramento-San Joaquin Delta region primarily is characterized by crustal shortening and the growth of young anticlines. Proprietary industry data and results from the recent BASIX experiment indicate that one or more generally east-west-trending anticlines are present within the western Delta region directly south of the Potrer Hills (R. Herriman, Chevron Geophysicist, personal communication, 1995). At present, these structures are not well understood, primarily because they are almost entirely beneath the water surface. Previous shallow high resolution seismic reflection data recently obtained for the BASIX experiment show that Ryer Island is the surface expression of a west-northwest-trending anticline.

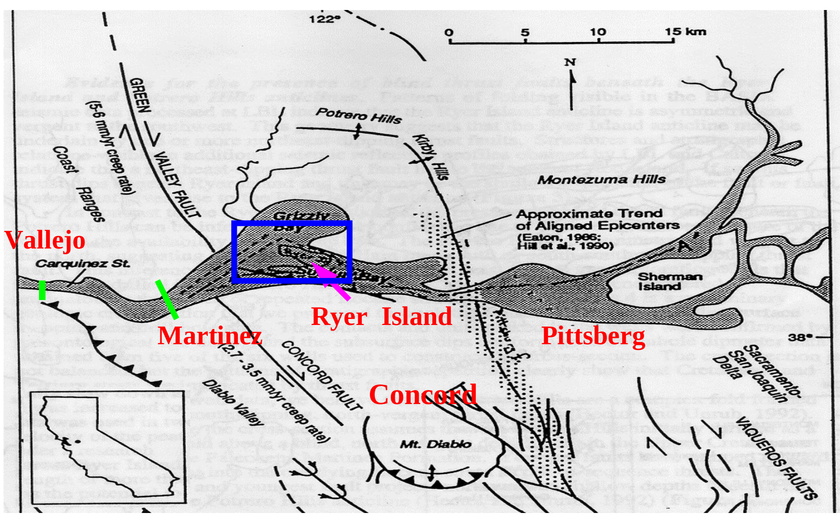


Figure 1. Location map of the survey area in Suisun Bay, CA.

FIELD PROCEDURES

The shallow marine seismic reflection data were recorded using a 18-bit A/D converter, 48-channel Geometrics StrataView Exploration Seismograph. The acquisition parameters are shown in Table 1. The information-carrying capacity of all seismic reflection data is directly proportional to reflection-frequency bandwidth, and high frequencies are also necessary to detect shallow reflections (Steeples, 1998). Large numbers of traces with source-receiver distances (<20m) are required to reliably image and determine stacking velocities of the shallowest features (Buker, 1998).

Table 1. Acquisition parameters in the survey**.**

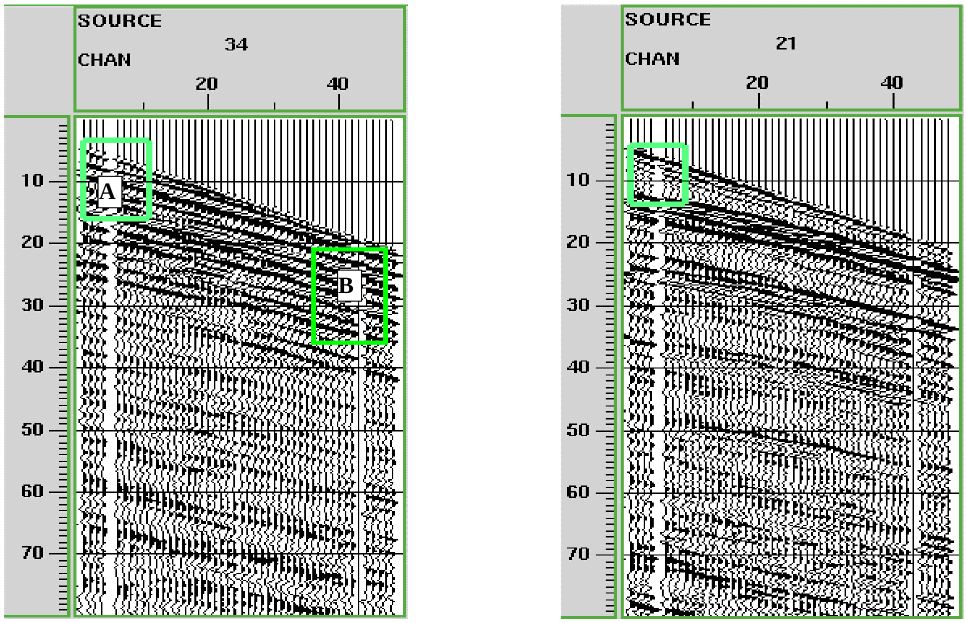
Parameters	Measurement
Source	GeoPulse(500~1500Hz)
Record length	256 ms
Sampling interval	0.25 ms
Shot spacing	3-4 m
Number of Channels	48
Minimum spacing	7 m
Maximum Spacing	30.5
Nominal fold	3-4
Length of profiles	1-2 km
Anti-alias filter	2000 Hz
Low cut filter	10 Hz

DATA ANALYSIS AND PROCESSING

In marine seismic surveys, especially shallow marine seismic surveys, various surface-related noises are superimposed on the shallow reflections. These noises mainly include direct waves, guided waves that travel horizontally within the water layer or in the layers beneath the water layer, refractions and water bottom multiples.

Guided waves

Guided waves are trapped within a water layer and travel in the horizontal direction. They are dispersive, especially for shallow water depths; i.e., each frequency component travels at a different speed, which is called horizontal phase velocity (Yilmaz, 1987). Guided waves are an important source of coherent noise in our survey and are mainly confined to the supercritical region of propagation, where no transmission occurs into the substratum. Actually, sometimes the first arrives are followed by such a dominant series of guided waves that there are not obvious reflections on the raw shot gathers (as shown in Figure 2a). Guided waves exhibit characteristics that depend on water depth and on the geometry and material properties of the substrata. They manifest themselves with a complex interfering wave pattern at shallow water, then gradually separate into simple water-bottom multiples at increasing water depths, as shown in Figure 2, which are 2 common-shot gathers from our Line # 11.

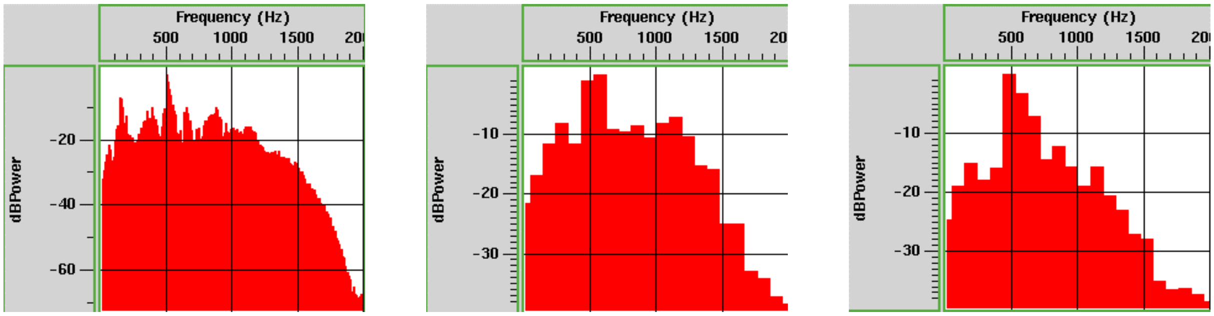


(a) (b)

Figure 2. Sample shot gathers from Survey Line #11. The vertical axis is time in milliseconds. The water depth is about 1.4 meters (a) and 8.3 meters (b).

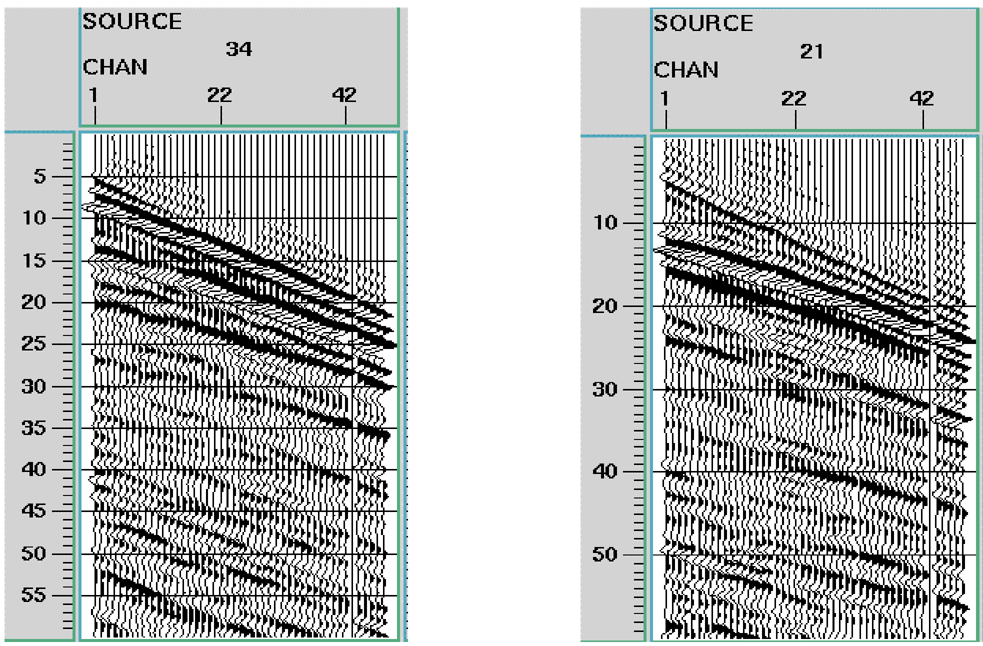
In Figure 2, GW are guided waves, WB are water-bottom reflections and M1, M2 are the water-bottom multiples. Figure 3 are the spectra of the specified regions in the gathers in Figure 2. Energy reflected from layers near the surface should have a frequency content close to that of the direct wave and the early refracted arrivals on the field files (Steeples and Miller, 1998). When compared Figure 3 (b) and (c), however, we can see that there are more lower-frequency components in (c), which implies that besides shallow reflections zone A contains noises of lower frequency (guided waves).

Either a combination of deconvolution, bandpass filtering and f-k filtering or simple spectral balancing is the most effective means of enhancing the amplitude and visibility of reflected signals relative to the guided waves (Buker, 1998). We processed the shot gathers shown in Figure 2 with deconvolution, bandpass filtering and f-k filtering and show the processed gathers in Figure 4.



(a) (b) (c)

Figure 3. (a) Spectrum for the whole shot gather shown in Figure 2 (a); (b) Spectrum for region A in Figure 2(a); (c) Spectrum for region B in Figure 2 (a).



(a) (b)

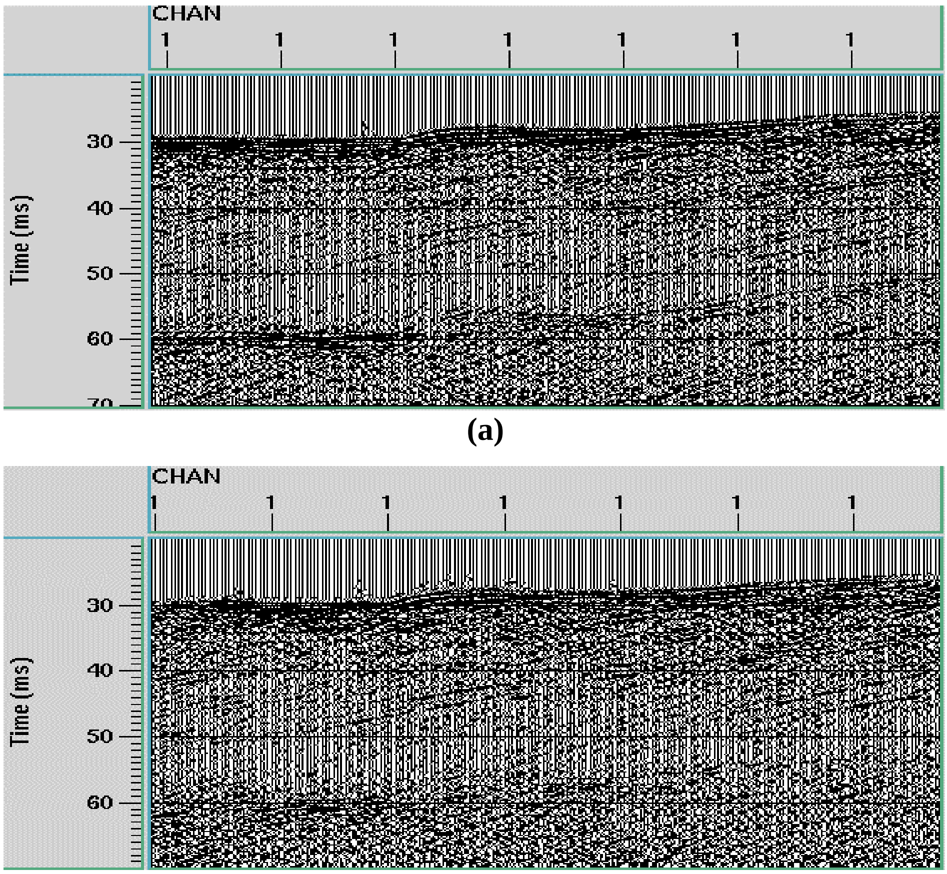
Figure 4. (a) Raw shot gathers shown in Figure 3(a) after bandpass filtering and ensemble deconvolution. (b) Raw shot gathers shown in Figure 3(b) after bandpass filtering and ensemble deconvolution. As in Figure 2, the vertical axis is time in milliseconds.

Multiples

The processing procedure shown in Table 3 is proved to be an effective way to remove multiples of relatively long periods (Figure 5). Strong water-bottom multiples in 50-60 ms (Figure 5(a)) were removed as shown in Figure 5(b). This method, however, only works well to long-period water-bottom multiples, and it removes useful subsurface reflections that have the same dip as the water-bottom multiple reflections. For instance, it does not work when the water bottom and underground layers are horizontal. As for short-period water-bottom multiples, the procedures to remove guided wave can also be used to suppress them.

Table 3. An effective flow to remove multiples.

Water bottom picking
Header statics (align water-bottom multiples)
Event Alignment
Apply fractional statics
Trace mixing
Remove header statics



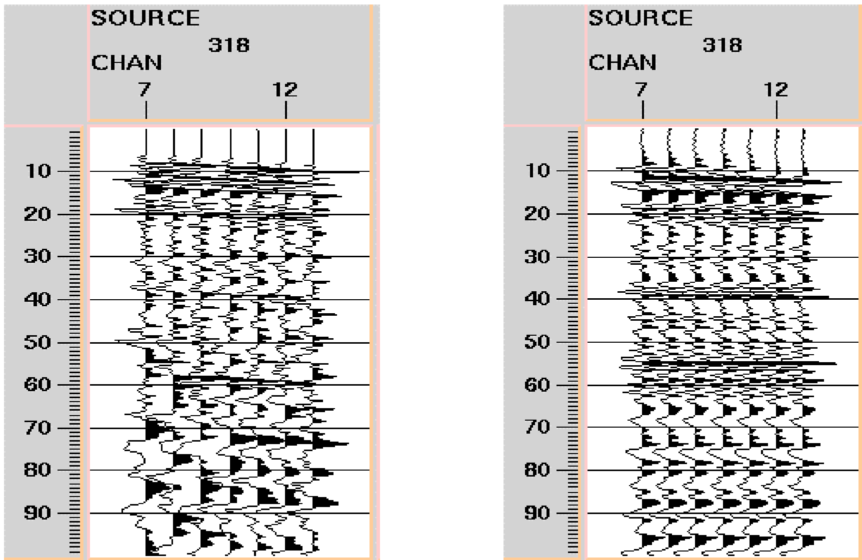
(a)

(b)

Figure 5. Common-offset profile before (a) and after (b) removing water-bottom multiples. These data was collected in Suisun Bay in January, 1998.

Low fold

In this survey, the seismograph stores the data on the hard disk in that instrument. The data were stored internally in SEG-2 format and each file has an identical file name and shot time, which can be used to incorporate with the navigation data. Even though the pulser can trigger the source at any interval from as small as 0.01 s to infinity, the seismograph can only store the 48-channel data in 3~4s. While the speed of the boat being about 15 miles per hour and hydrophone spacing being 0.5 m, the nominal fold of our survey is only 3-4. Analogue single-channel marine reflection profiling is an alternative solution to this low-fold problem. First, NMO and DMO were applied to the data in common-shot domain with estimated velocities (1470-1600 m/sec). Second, every six traces of the data in common-shot domain were stacked to construct analogue single-channel profiles. Third, the data were sorted to CMP domain and stacked again. Before stacking the traces in common-shot domain, ensemble deconvolution, band-pass filtering, f-k filtering were also applied to the traces. Figure 6 shows that deconvolution, band-pass filtering, f-k filtering, NMO and DMO before common-shot stacking improve the data.



(a) (b)

Figure 6. Seven traces from a common-shot gather before (a) and after (b) deconvolution, bandpass filtering, f-k filtering, NMO and DMO

Processing procedure and some results

The main goal in processing reflection seismic data is to enhance primary reflections by suppressing unwanted energy in the form of coherent and random ambient noise. Data were processed (summarized in Table 2) on a workstation with Landmark's ProMAX seismic processing package.

Table 2. Processing procedure

Processing Step
Data conversion & editing
Ensemble Decon (predictive decon)
Bandpass filtering
f-k filtering
NMO
Ensemble DMO in T-X domain
Band pass filtering
Ensemble stacking (every 6 traces in common-shot domain)
Trace mixing
CMP stacking
Multiple removal

An analogue single-channel reflection profile is shown in Figure 7. And Figure 8 is a CDP stacked section before and after multiple removal.

REFERENCES

Buker F., Green A., and Horstmeyer H., 1998, Shallow seismic reflection study of a glaciated valley: Geophysics, 63, 1395-1407.

Steeples D., and Miller R., 1998, Avoiding pitfalls in shallow seismic reflection surveys: Geophysics, 63, 1213-1224.

Williams, P.L.,R. Anima, J. McCarthy, T. V. McEvilly, T. Nakata, M. Okamura, and K. Shimazaki, Geophysical detection of fault activity, geometry, and recurrence behavior: Rodgers Creek and Pinole Faults, California, (Submitted to JGR, 4/95)

Yilmaz, O., 1987, Seismic data processing: Soc. Expl. Geophys.

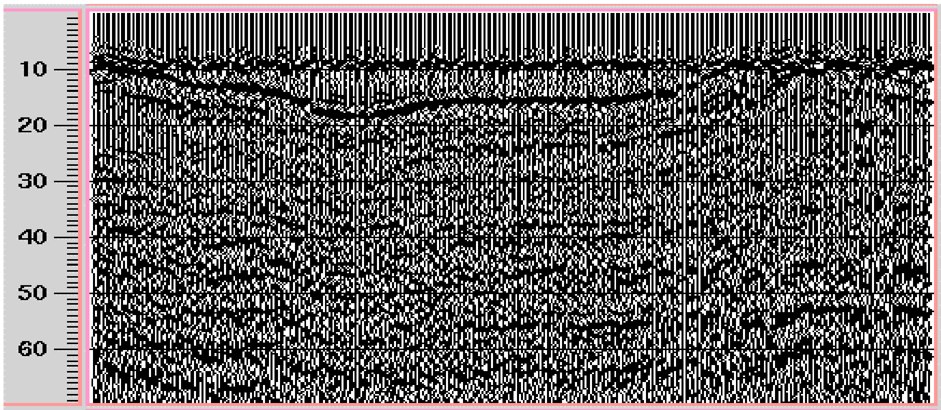
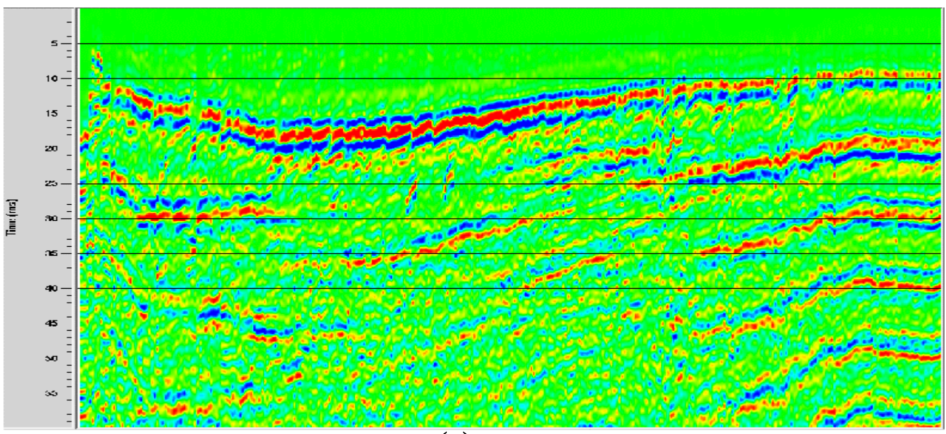
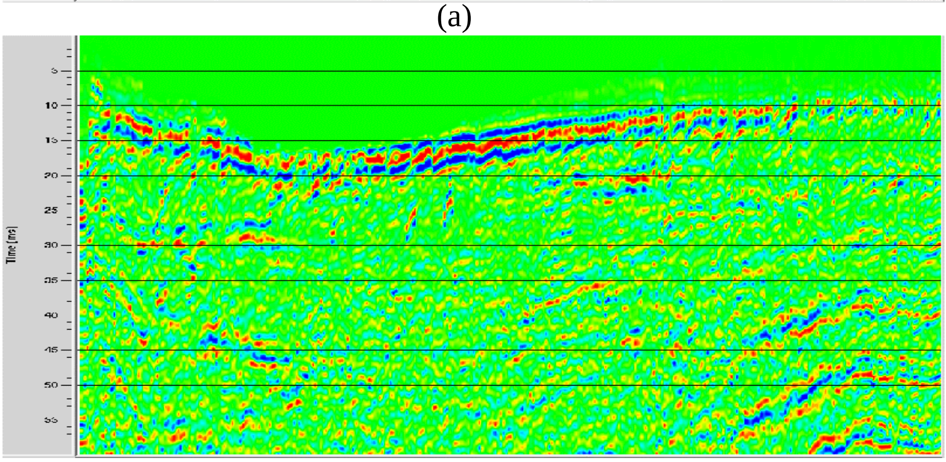


Figure 7. An analogue single-channel marine reflection profile (from Line #11).



(a)



(b)

Figure 8. A CDP stacked profile before (a) and after (b) multiple removal (from Line #9).