Analysis of Moere Vest OBNs as Continuous Data

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ABSTRACT

The Moere Vest Ocean Bottom Node Survey was acquired for the purpose of exploration with controlled seismic source. However, the nodes recorded continuously. This paper will explore the use of the ambient seismic field for the purpose of creating low frequency virtual sources by seismic interferometry. I find that this OBN dataset contains abundant energy at microseism frequencies that yield virtual seismic sources by cross-correlations. The cross-correlation gathers contain dispersive interface waves and events with a hyperbolic move out.

INTRODUCTION

Ocean Bottom Nodes (OBNs) are placed on the seafloor and record continuously for the duration of the deployment. A vessel carrying a seismic source will sail over the nodes and shoot a seismic survey. The data is downloaded after the nodes are retrieved. The continuous recordings are typically cut into shorter records starting at the timestamp of each shot.

However, here we study the data as continuous recordings because the nodes recordings contain a wealth of seismic energy besides the controlled source shooting. Energy in the frequency range from 0.1 to 2.0 Hz is referred to as microseisms (Longuet-Higgins, 1950). The aim of this paper is to show that these data contains sufficient microseism energy to be of interest for seismic interferometry.

Seismic interferometry is a technique that aims to create virtual seismic sources by cross-correlations of ambient seismic energy (Aki, 1957; Claerbout, 1968; Lobkis and Weaver, 2001; Weaver and Lobkis, 2002; Wapenaar, 2003, 2004; Wapenaar and Fokkema, 2006). Under certain requirements on the characteristics of the ambient seismic field, a cross-correlation of recordings made at two stations results in a signal that is proportional to the Green's function of wave propagation between those two stations.

First, I briefly survey all the energy recorded by computing a spectragram that shows how the spectrum of the recordings vary as a function of time. Second, I perform cross-correlations of the microseism energy recorded in the hydrophones of all 179 stations.

MOERE VEST OBN RECORDINGS AS CONTINUOUS DATA

This dataset is comprised of 179 ocean bottom stations in a linear array spanning almost 70 km, see Alves (2014). However, the seismic shooting extended beyond the array to record long offsets. Figure 1 contains a map with the location of the Moere Vest OBN survey in the Norwegian Sea and a bathymetry map of the Moere Vest area with the station locations. The station spacing of the center part of the line with 141 stations is 250 m. An additional 5 stations on either side of the line with spacing 5000 m provide for recordings at long offsets, each end had an extra station. At the center of the line there were 26 stations in a microspread with spacing as short as 2 m.

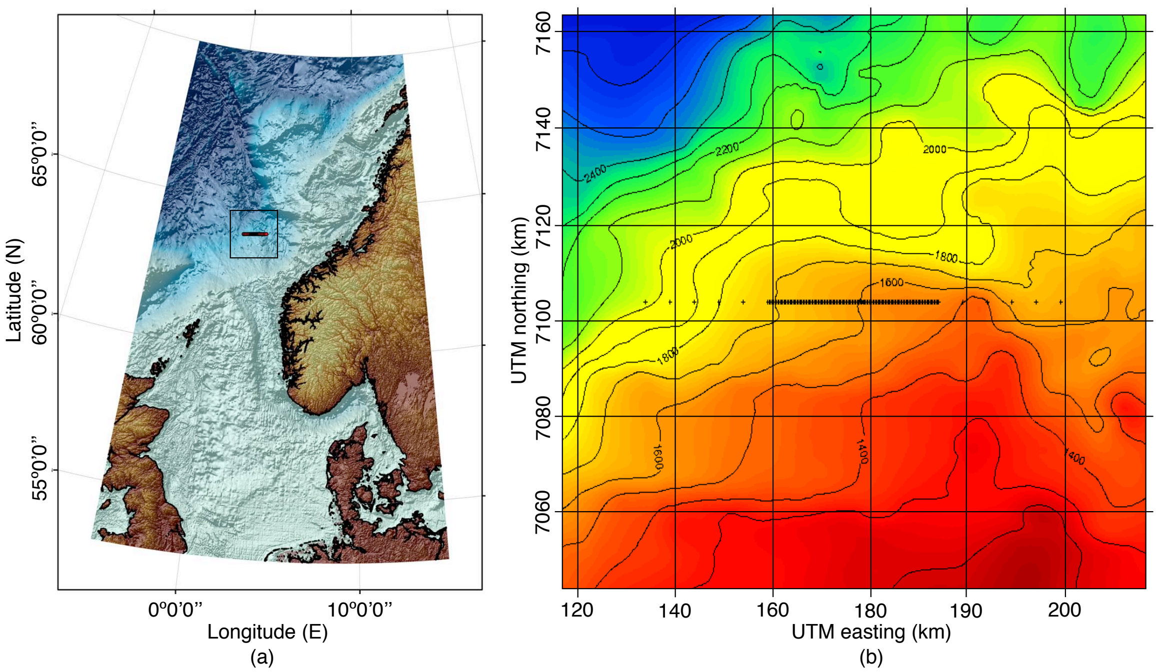

Figure 1: a) Map showing the location of the Moere Vest OBN survey. b) Bathymetry map of the Moere Vest area showing the stations in black crosses. Contour lines are drawn at 100 m interval. [**NR**]

The stations are not deployed simultaneously. The stations are turned on aboard the vessel and an unmanned Remotely Operated underwater Vehicle (ROV) flies a few stations at a time to the seabed for deployment. Figure 2 shows the deployment times for each node. The node numbering is from west to east. Although the recording from one node ended prematurely, all stations were recording simultaneously for a duration of about 7 days.

I investigate the frequency content of the recordings by computing a spectragram for three stations; the first station to be deployed; last station to be deployed; and a station from the microspread. The frequency spectrum of the hydrophone record-

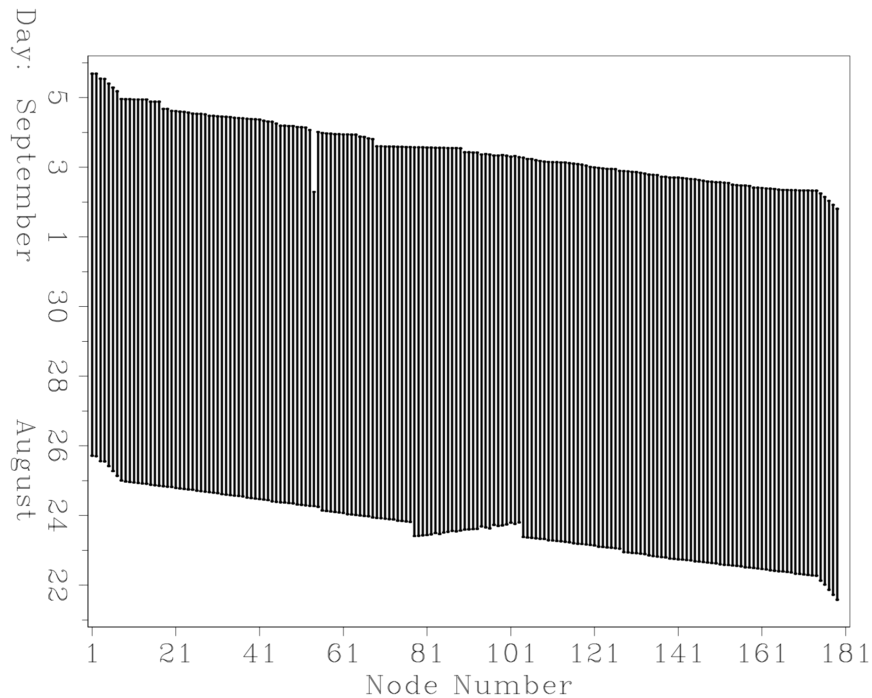

Figure 2: Deployment times of each node. All stations were recording simultaneously for a duration of about 7 days. [**ER**]

ings is computed in non-overlapping 2-minute long windows, and each spectrum is displayed side by side to show how the spectrum varies as a function of time (Figures 3a-c).

The low frequencies of the Moere Vest OBN recording (between 0.1 and 2.0 Hz) contain energy that is continuously present. This energy is referred to as microseism noise and is weather generated. Generally, we expect two energy bands in this regime (the single- and double-frequency microseism peaks). We observe these two energy bands during August 23^{rd} to 24^{th}. However for the majority of the recordings we observe only one broad energy band. It remains to be investigated whether we can distinguish a single and double microseism peak, or if the energy at the upper and lower ends of the microseism frequency range is composed of waves from different propagation regimes or wave types.

At the higher frequencies of the Moere Vest OBN recording (above 2 Hz), we observe several controlled source seismic surveys. These are most easily identified by observing that shooting happens in episodes. During August 26^{th} to 28^{th} a few long shot lines were recorded for the whole line. Later, between August 31^{st} to September 2^{nd} six shorter shot lines were recorded along the microspread.

In order to cross-correlate the recordings made at different nodes, they need to be synchronized in time. The best approach is to add zeros before and after each recording to ensure that each trace is equally long. The first 2 hours and last 2 hours

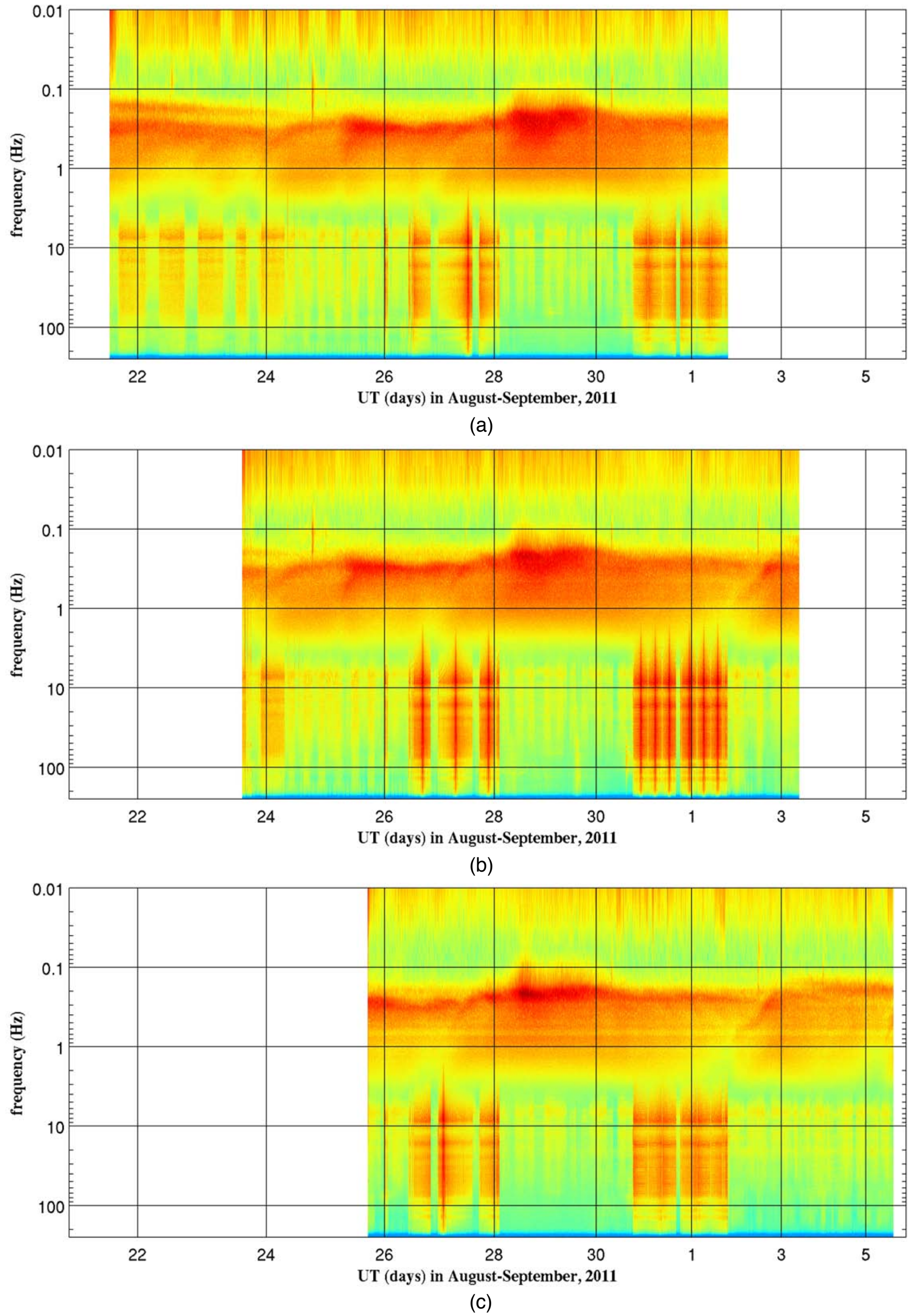

Figure 3: Spectragrams showing how the frequency content of the hydrophone recordings vary as a function of time. a) The first station to be deployed, b) a station from the microspread, c) the last station to be deployed. [**ER**]

of each recording are discarded, because the nodes were not yet positioned on the sea floor. With a Hann window we taper an additional 2 hours at the beginning and end of the recordings. Figure 4 contains a gather of all hydrophone recordings bandpass filtered between 0.5 and 1.5 Hz, with zeros added before and after each trace, to align them in time.

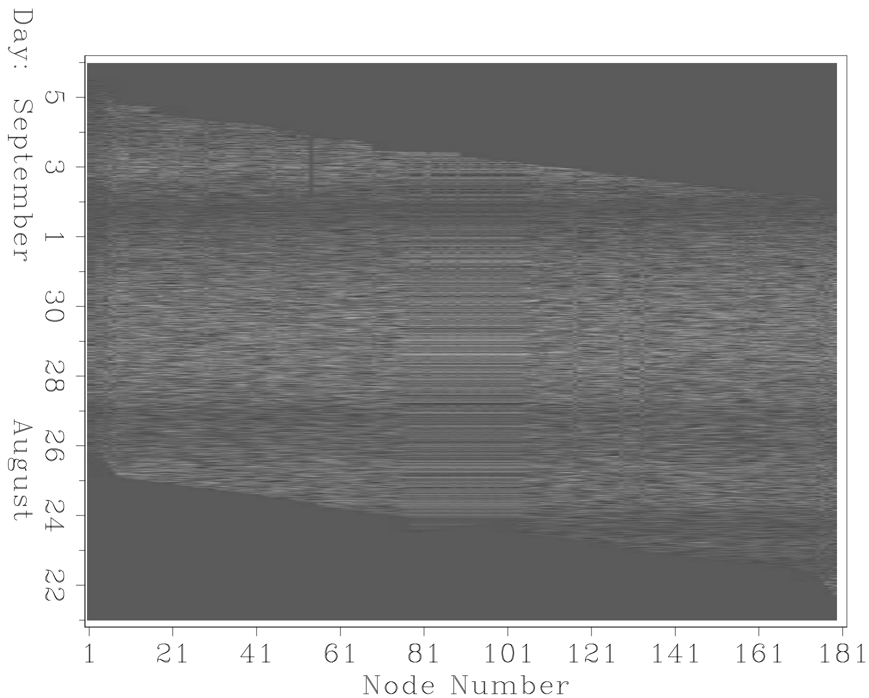

Figure 4: A gather of all the recordings synchronized with their deployment times. The gather is bandpass filtered for microseism energy between 0.5 and 1.5 Hz. The microspread in the middle shows clock drift: the nodes were better synchronized in August and less in September. [**ER**]

The nodes in the center of the gather in Figure 4 all appear similar. These nodes are part of the microspread. Those nodes are so close together that the waveforms should appear very similar between nearby nodes. While at early times the arrivals in the microspread appear aligned, at a later times certain recordings in the microspread become misaligned with their neighboring recordings. This indicates that the internal clocks of the nodes do not stay synchronized, a phenomena referred to as clock drift. Hatchell and Mehta (2010) used seismic interferometry to estimate clock drifts and positioning errors.

CROSS-CORRELATIONS OF MICROSEISM NOISE

Seismic interferometry is a theory that describes how interstation Green's functions can be retrieved from ambient seismic recordings by a cross-correlation. The hydrophone recordings from all stations were aligned in time and padded with zeros (see previous section). For the limited purposed of this paper I ignore the clock drift. However, a more in-depth study using seismic interferometry on these data has to include a correction of the data for the clock drift prior to cross-correlations.

I elect the trace from one station as a master trace and cross-correlate the aligned and zero padded data for all 179 traces with this master trace. This effectively retrieves a gather as if there was a source at the master station. I repeat this procedure for 12 stations along the line. All cross-correlation gathers are shown in Figure 5.

The correlation gathers generally show more energy at negative correlation lags for stations on the east side of the master station and at positive correlation lags for stations on the west side of the master station. This indicates that the dominant direction of wave propagation in the ambient field was towards the west (away from the shallower waters and Norwegian coast line). Figure 6 contains a regularized offset gather of all the gathers from Figure 5.

Studying Figures 5 and 6, it is apparent that they contain dispersive interface waves traveling with a group velocity of about 1333 m/s. But there is also energy arriving with an apparent hyperbolic move out as a function of offset. These events intersect with the time-axis in the first 10 seconds. These hyporbolas are already visible in the cross-correlation gathers of individual virtual seismic sources in Figure 5.

CONCLUSIONS

This paper revealed that during the Moere Vest OBN survey there is abundant energy in the microseism frequency range 0.1 to 2.0 Hz. From cross correlations we find that the microseism energy is propagating predominantly westward. In the cross-correlation gathers we find dispersive interface waves with a group velocity of about 1333 m/s. But more interestingly we find events with an apparent hyperbolic move out. A more extensive analysis should reveal what kind of waves they are and where they originate from.

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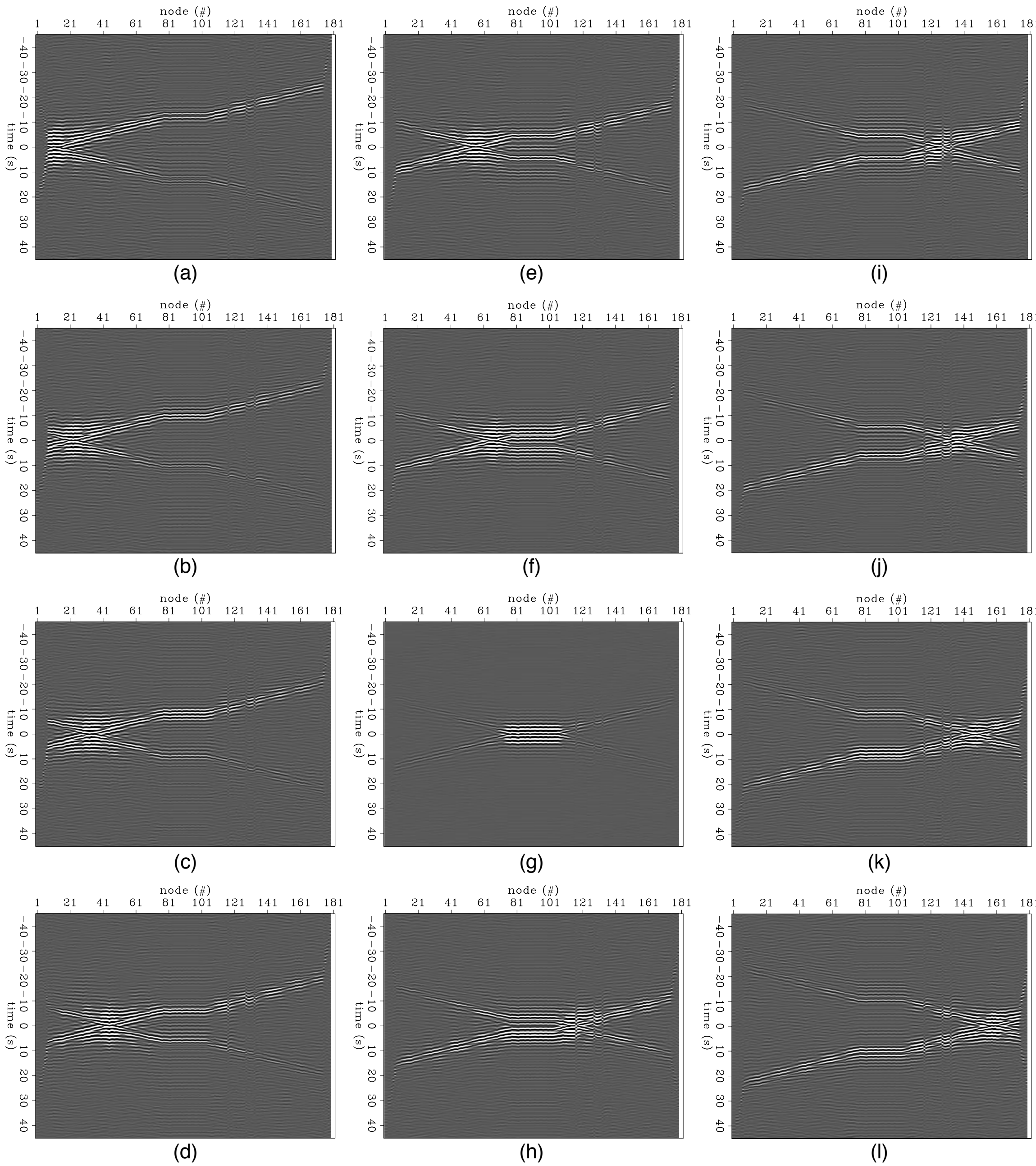

Figure 5: Cross-correlation gathers,sorted from west to east, of the data recorded between different nodes. a-l) Each contains a gather for which a different master station is turned into a virtual seismic source. [**ER**]

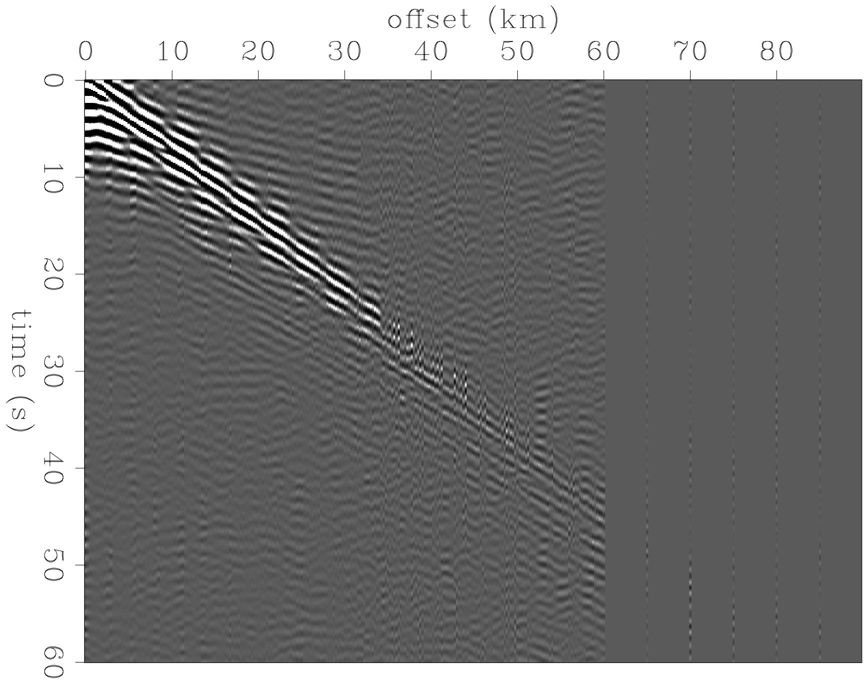

Figure 6: Offset sorted gather of all cross-correlations of Figure 5. [**ER**]

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APPENDIX: MICROSEISM ENERGY VERSUS CONTROLLED-SOURCE SEISMIC ENERGY

In this appendix I show the dominance of the microseism energy in the low frequencies of the recordings. I perform a series of bandpass filters on a common receiver gather of the hydrophone recordings and the vertical component geophone recordings (Figures A-1 and A-2). The bandpass is implemented in the frequency domain with Hann window with a flat center.

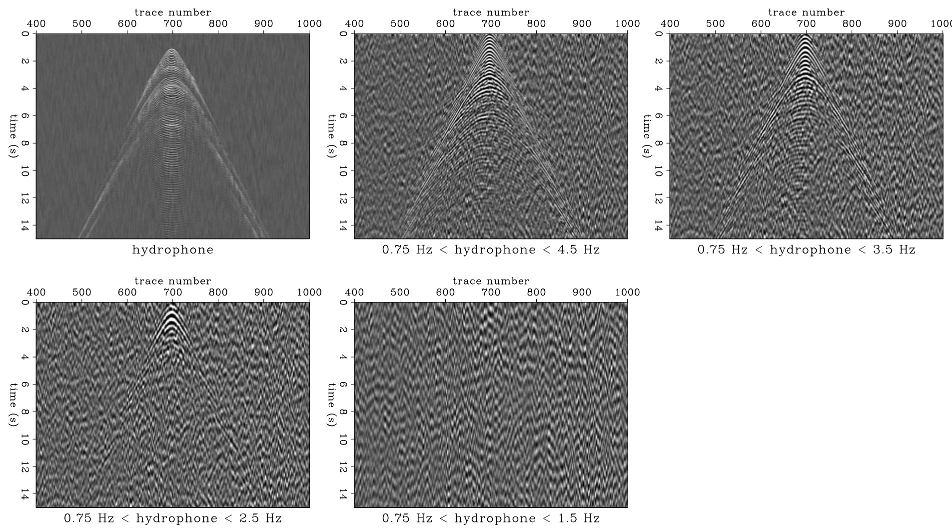

Figure A-1: Hydrophone common receiver gather: the original (upper left) and a series of bandpass filtered gathers showing the low frequency content. [**ER**]

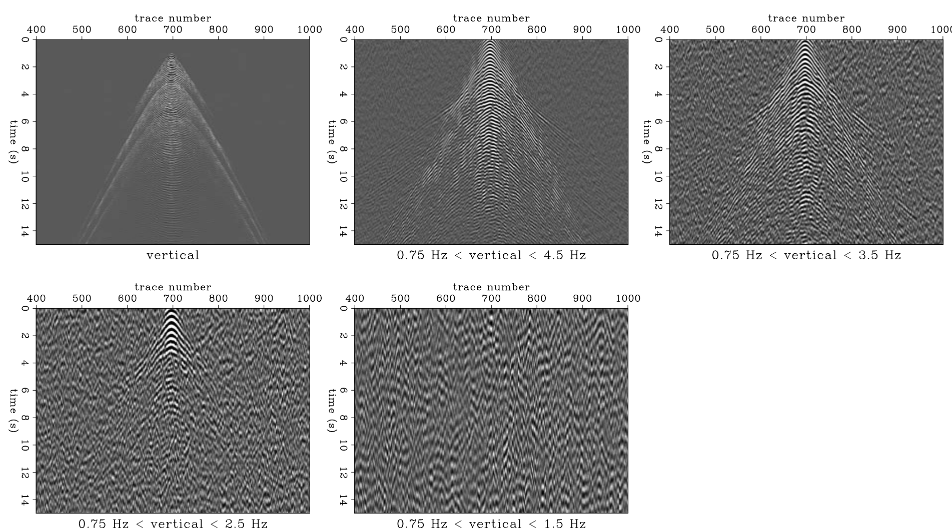

Figure A-2: Vertical geophone common receiver gather: the original (upper left) and a series of bandpass filtered gathers showing the low frequency content. [**ER**]

Below 5 Hz there is little source energy left. However, the remaining low-frequency seismic source energy may contain reflections and refractions of the dominant and high-contrast geological formations in the subsurface. From the spectragrams in Figure 3 we see that the energy of the controlled source shooting and the energy of the microseism noise overlap in the frequency range 1 to 2 Hz. With two bandpass filters (flat center with Hann window sides) tied at respectively 0.75-1.0-1.25-1.75 Hz and 1.75-2.0-2.25-2.75 Hz, we can see that 1.75 is a good upper limit for a bandpass filter to separate the frequency ranges in which the microseism noise or the controlled source seismic energy is dominant (Figure A-3).

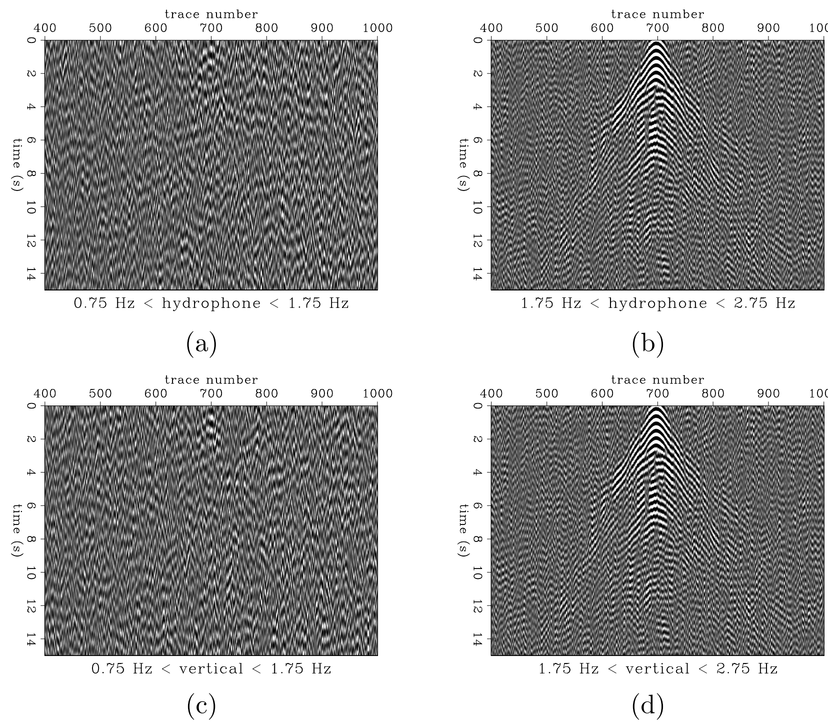

Figure A-3: a-b) Hydrophone common receiver gather filtered below and above 1.75 Hz respectively. c-d) Vertical component geophone common receiver gather filtered below and above 1.75 Hz respectively. [**ER**]