Investigation of productivity enhancements for the Mini-SOSIE seismic system

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Introduction

For coal and CSG targets in the depth range 50-500m, Mini-SOSIE often provides imagery which is geophysically very competitive with more expensive surface sources such as Vibroseis. For very shallow depths (0-100m) Mini-SOSIE is often superior. Because of its portability and reduced impact, Mini-SOSIE has advantages in locations where access is difficult, or which are environmentally or politically sensitive. A trade-off with the conventional Mini-SOSIE system is that the record time is longer than for Vibroseis. Since the crew size is smaller, survey costs are not necessarily increased. Nevertheless, any reduction in Mini-SOSIE acquisition time would be advantageous, both economically and in terms of field exposure.

The time required to acquire a Mini-SOSIE survey is largely dependent on the number of impacts (rams) required, and the impact rate. These factors also influence the signal-to-noise ratio of the resulting data. Intuitively, more rams would be expected to improve signal-to-noise, as would a slower ram rate. In this investigation we have examined these influences, with the aim of increasing production speed but with little reduction in signal-to-noise ratio.

There are several concepts which, at least in theory, have potential for significantly improving Mini-SOSIE productivity. Those examined in this investigation include reducing the number of rams, increasing the ram rate, and using simultaneous acquisition.

Theory

To understand the limitations of these approaches it is important to have a basic understanding of the basic theory behind the Mini-SOSIE method. It employs an impulsive source (wacker/compactor) to acquire a large number of impacts in quick succession. The rate is high enough that events from successive records interfere with each other. If the impact sequence is random enough these can be separated using stacking or correlation methods.

A simplified form of the Mini-SOSIE process can be demonstrated using Z-transform concepts. The raw seismic trace (*T*) generated in the field is the convolution of the Mini-SOSIE impact sequence (*I*) with a single-impact record (*E*).

$$T(z) = I(z)\,E(z) \tag{1}$$

These records are long and difficult to interpret. They are analogous to uncorrelated Vibroseis data. To extract a meaningful seismic record (*S*) the trace is correlated with a recording of the impact sequence.

$$S(z) = T(z)\;I(z^{-1}) = I(z)\,E(z)\,I\,(z^{-1}) \tag{2}$$

This results in a trace that is equivalent to the autocorrelation of the impact sequence (R_{II}) convolved with the single-impact record.

$$S(z) = R_{II}(z)\,E(z) \tag{3}$$

If the impact sequence is random, the autocorrelation is approximately equal to a scalar (γ) which is related to the number of impacts.

$$S(z) = \gamma E(z) \tag{4}$$

That is, the correlation process boosts the signal by a factor of while suppressing the random noise. For a more in-depth analysis of these concepts, with the inclusion of various noise types, see Fletcher (2012).

Number of Rams

Perhaps the simplest consideration in this investigation relates to the choice of number of rams. Ram-counts of between 250 and 500 are typical in production Mini-SOSIE surveys. Equation 4 suggest that more rams should, in theory, produce a better record. Experience shows that this can be area dependent. In certain situations, there may be a clear optimum ram-count, beyond which little improvement is achieved. Indeed, in particular surface conditions where the competency of the surface changes over time, larger ram-counts can actually degrade the image.

Figure 1 compares a correlated Mini-SOSIE record generated with 250 rams, and a record generated with 100 rams. These are acquired under conditions of relatively low random noise. There is a small improvement in the signal-to-noise for the 250-ram record. However under these conditions the improvement may not justify the increased acquisition time and corresponding costs. Figure 2 shows a second example of reduced ram count, but under noisy conditions (a truck operating nearby). The signal-to-noise content of this record is very poor and indicates that reducing the number of rams is not a viable option in high-noise conditions.

Ram Rate

Another intuitive approach to improving productivity is to speed up the delivery of the rams, for example by using alternative hardware capable of more rapid delivery (e.g. rock breaker, jackhammer), or by using multiple wackers at the one source location.

If there were no limitations on wackers and recording equipment, it is, in theory, possible to increase ram-rates without data degradation. Unfortunately, real-world limitations mean that more rapid delivery results in the impact sequence becoming less random (assumption of Equation 4). This results in ghosts in the correlated record, and is referred to as correlation noise.

Figure 3 shows the signal-to-correlation-noise ratio for a number of different impact sequences all having 300 rams. This demonstrates that as recording time is reduced (i.e. ram-rate is increased) the signal / noise ratio falls.

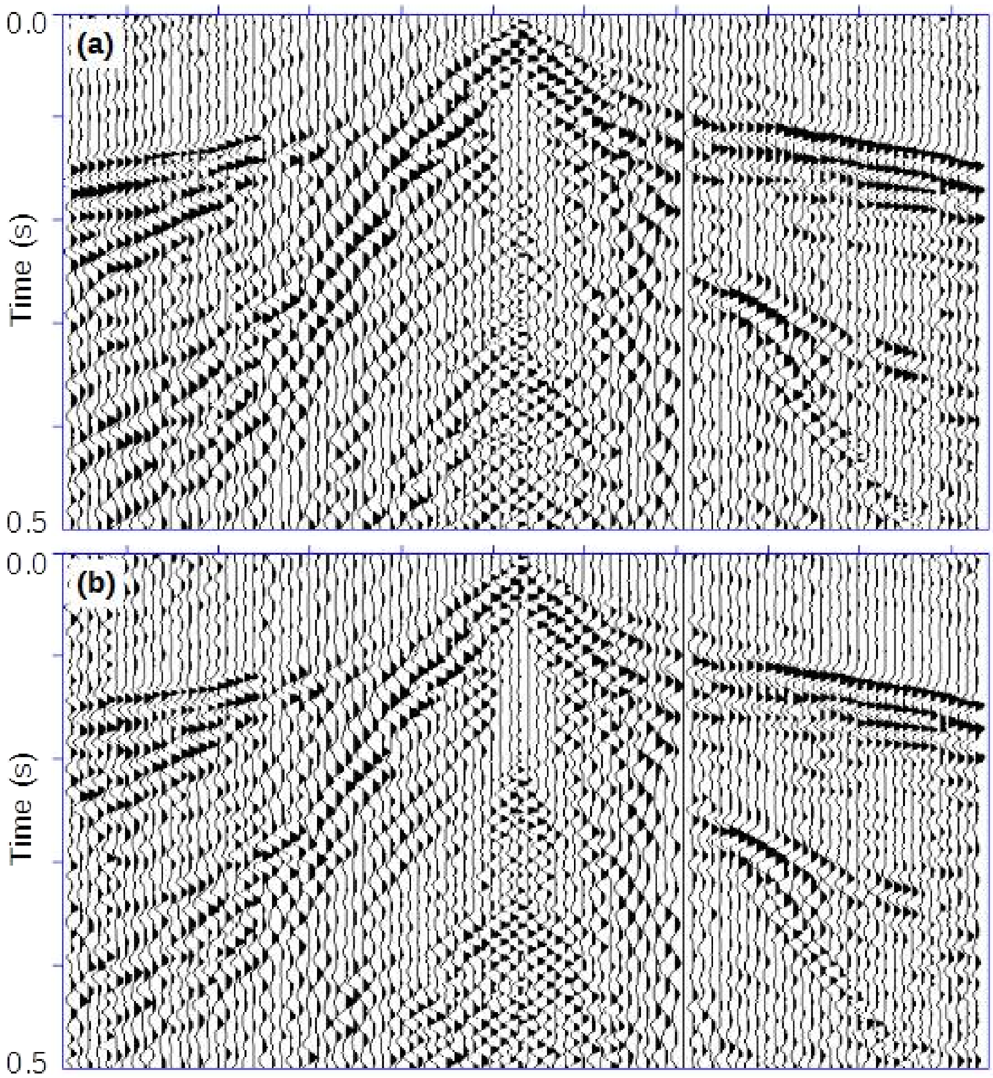

Figure 1: Comparison of a shallow Mini-SOSIE record acquired with (a) typical ram count (250) and (b) with reduced ram count (100). In this case, the larger ram count provides only a small improvement in quality.

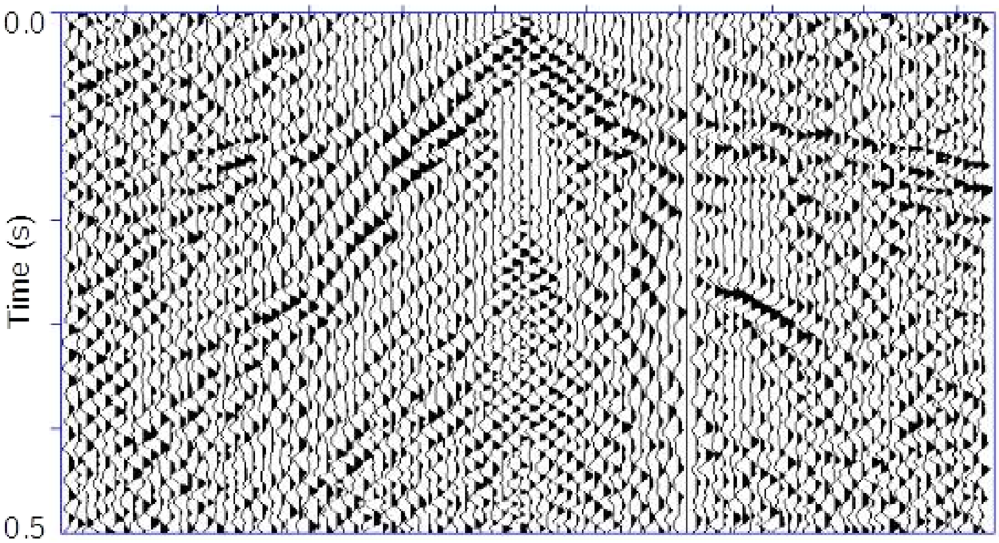

Figure 2: A reduced ram count (150) in the presence of strong noise sources may result in significantly reduced signal-to-noise ratio. Effectiveness of reduced ram counts need to be assessed based on the site noise conditions.

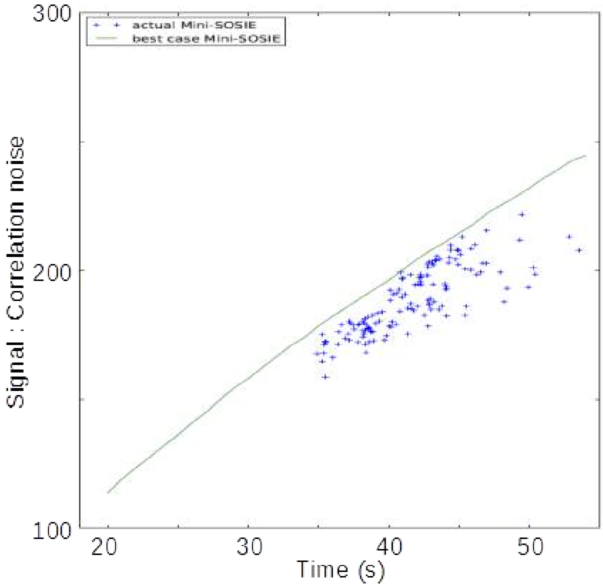

Figure 3: Examination of relationship between signal, correlation noise, and recording time for typical system limitations (0.5ms sample rate, max impact rate approximately 10Hz, 300 rams). Green line indicates the best possible theoretical result, blue dots are based on actual impact sequences from field recordings. As acquisition time is reduced (i.e. ram rate increased), signal/noise ratio reduces. From Fletcher (2012).

While correlation noise is undesirable, its nature is usually well known, and relates to the known impact sequence. As a result it maybe possible to build a digital filter that can minimise the correlation noise (e.g. Strong, 2004; Fletcher 2012; Fletcher et al, 2013). Figure 4 shows an example from a poorly randomised record. A significant portion of the correlation noise has been removed using digital filters in Figure 4b. This theoretical concept is still under practical development, but shows significant promise.

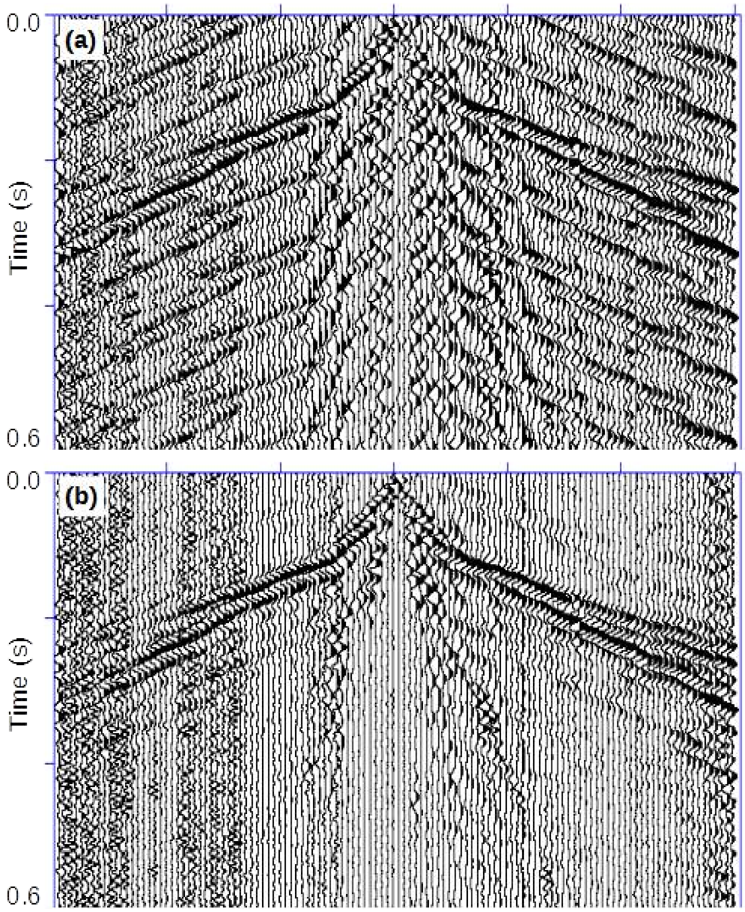

Figure 4: Removal of correlation noise via digital filtering. (a) Mini-SOSIE record generated from an impact sequence having poor randomness. (b) If the impact sequence is well known much of the correlation noise can be removed using digital filters.

Simultaneous Acquisition

In Vibroseis acquisition it is possible to record at multiple source locations simultaneously, and then separate the individual datasets during processing (e.g. Garotta, 1983; Martinez, 1987). This can be achieved by using orthogonal reference sweeps, which are separately correlated with the dataset to extract the image associated with each source.

In the Mini-SOSIE technique the impact sequence is analogous to the Vibroseis reference sweep. If multiple impact sequences are random then they are approximately orthogonal. Figure 5a simulates the simultaneous acquisition of single impacts from two different source points. The raw record shows severe interference between the two impacts. However, using many impacts and an approach similar to Vibroseis simultaneous recording, the individual records can be separated (Figures 5b and 5c). Some correlation noise remains in these figures, particularly on the far offsets. However, the nature of the cross contamination makes it amenable to removal during subsequent CMP processing.

Figure 6 (top) shows two real shot records, at adjacent shot points and correlated via the normal mini-SOSIE method. The uncorrelated records were also stacked to approximate a simultaneous recording at these two shot points. This was then correlated against individual impact sequences, to extract the individual records (Figure 6 bottom). There is a small reduction in the signal-to-noise ratio in the simultaneous recordings. Generally, however, this experiment suggests that individual records can be extracted from real-world simultaneous Mini-SOSIE recordings.

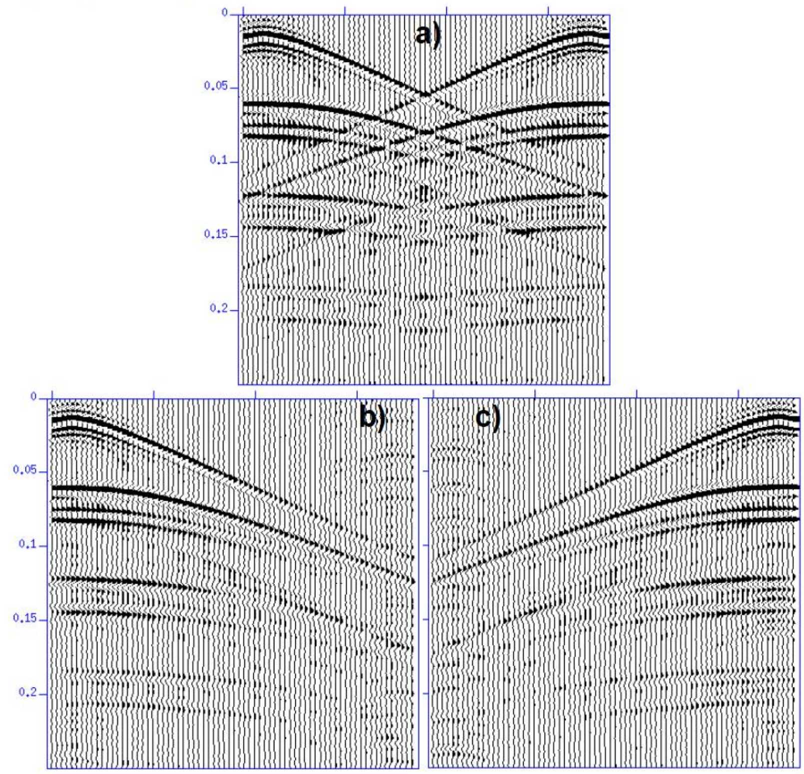

Figure 5: Model example of simultaneous Mini-SOSIE acquisition. (a) two impacts acquired at different locations at the same time interfere . (b) and (c) records obtained by correlation of a combined Mini-SOSIE record from two sources with individual impact sequences. There is some cross contamination on far offsets.

If two sources are close together the relative signal (primary source)-to-correlation-noise(secondary source) should be quite high as demonstrated in Figure 6. However, if the sources are far apart the amplitude of the correlation noise (and source generated noise) associated with the second source may be large, compared to the far-offset signal from the primary source.

Figure 7 illustrates this for two sources that are separated by a greater distance. Clearly, the strong source-generated noise and groundroll events from the secondary source are swamping the desired signal from the primary source. These tests indicate that a leap-frog acquisition method might provide the best implementation of the simultaneous-source Mini-SOSIE concept.

Conclusion

High levels of randomness are generally important for any Mini-SOSIE technique. If this can be achieved, there is potential for significant productivity enhancement, via methods such as high ram-rate devices, multiple rammers, and simultaneous source-point acquisition. In situations where it is more difficult to maintain randomness, digital filtering has strong potential for recovery of records contaminated by correlation noise.

This investigation has shown that while each of these methods has capability for enhanced productivity, we would expect some reduction in data quality at the shot record stage. Additional field tests are required to investigate whether any such negative effects are still apparent following full CMP processing.

References

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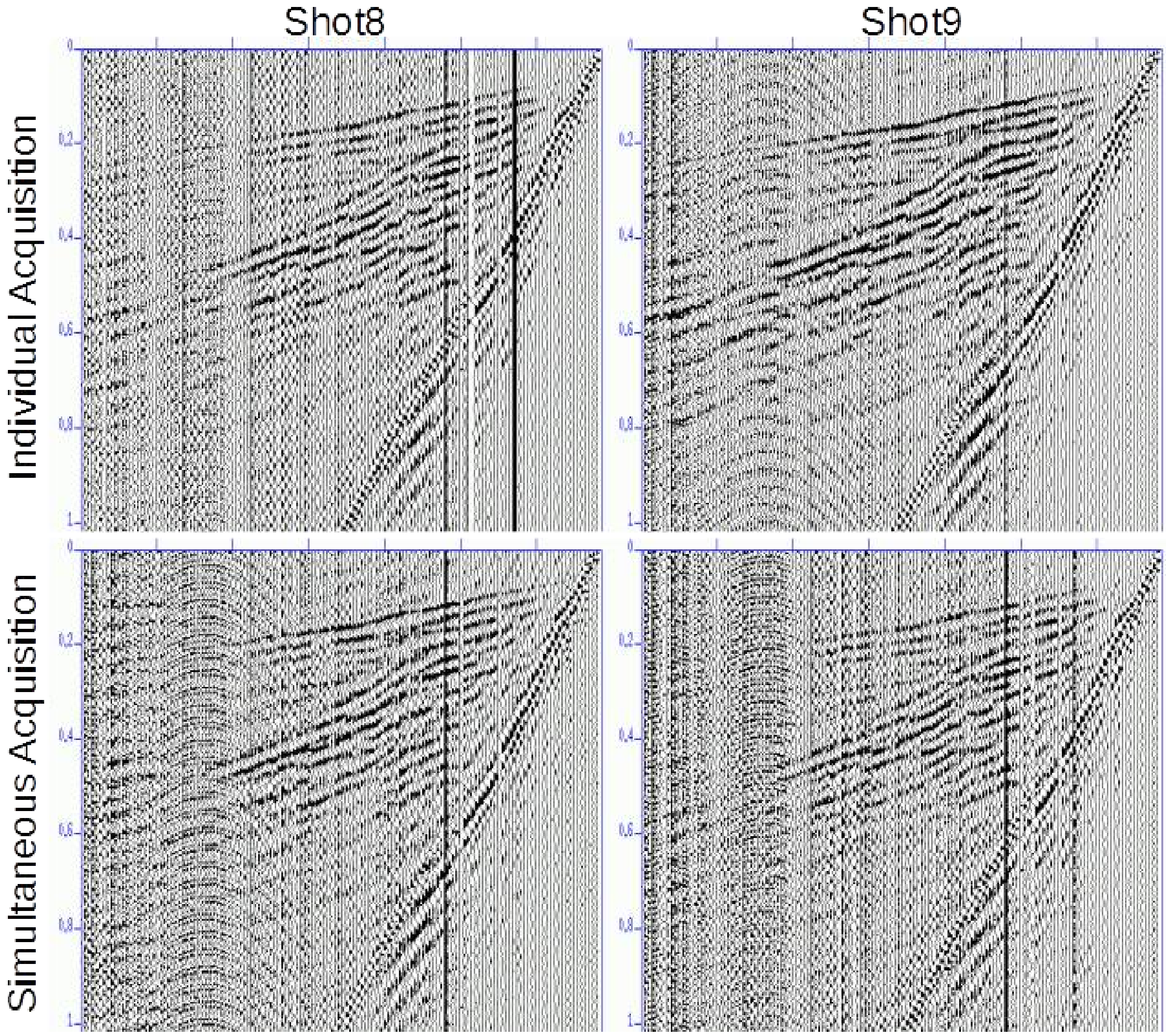

Figure 6: Comparison of individual and simultaneous acquisition for adjacent shot points.

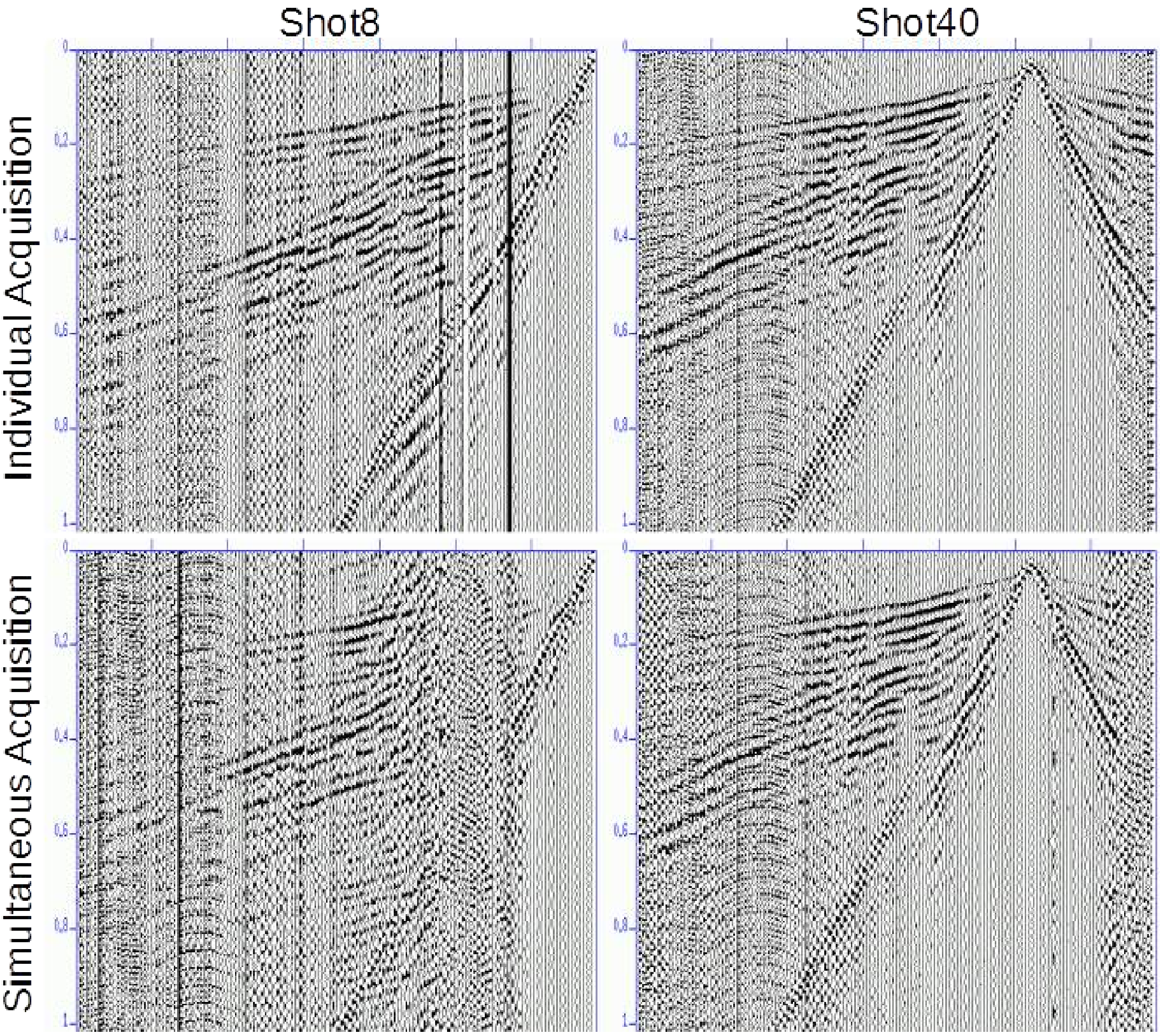

Figure 7: Comparison of individual and simultaneous acquisition for separated shot points.