Casmalia Landfill Reflection Walkaway Survey

NORCAL Geophysical Consultants, Inc. conducted a seismic reflection walkaway survey at Casmalia Resources Superfund Site on July 27, 2004. The survey was designed to evaluate the feasibility of using the seismic reflection technique to image the bottom of a hillside drainage that had been filled with a variety of refuse. The pre-fill steep sided, gully drained to the south. Approximate 150 ft of fill material including rows of stacked barrels, settling pond sludge, and compacted fill material currently fills the drainage. Two walkaway test lines were acquired at nearly right angles, one parallel and one perpendicular to the strike of the drainage (Figure 1). The objective was to determine if seismic reflection techniques could map the original floor of the drainage with enough resolution to detect areas where contaminants might pool.

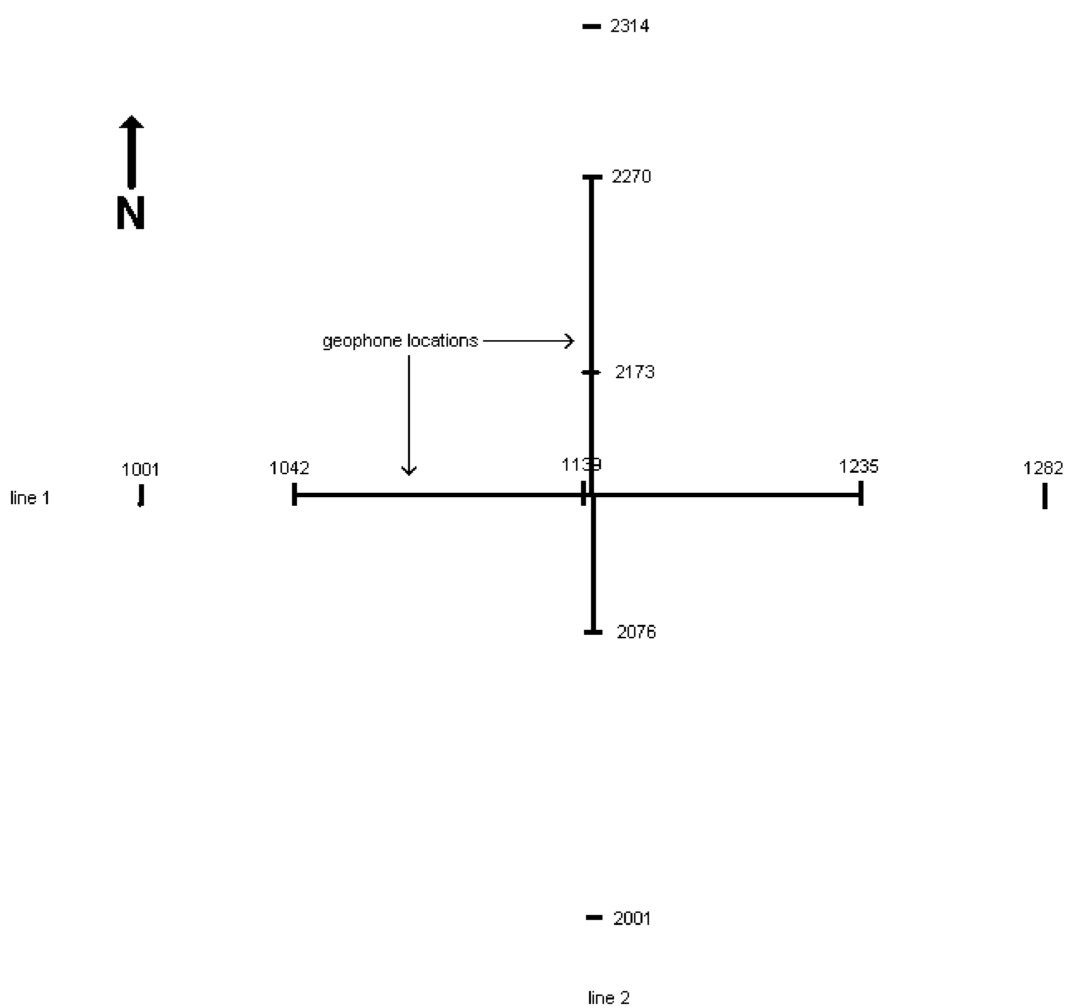


Figure 1. Generalized site map showing the relative locations of shot points and receiver (geophone) lines. Geophones were distributed at 5 ft intervals. Shots were placed immediately off-end of each line and at surface locations that were accessible and would provide useful data.

The seismic acquisition equipment included an ATV mounted accelerated weight drop, single Geospace 40-Hz geophones, and a 96-channel Geometrics Geode recording system. The weight drop was used to record multiple shots at each station. Geophones were placed after loose soil and vegetation were scraped away. Receiver stations were separated by 5 ft. Each one-second shot record was recorded with ¼ msec sampling rate.

At each shot location (station) we performed tests to determine the number of shots necessary for optimum source operation. The tests consisted of three individually recorded shots, followed by a set of three shots that were vertically stacked in the seismograph. This comparison provided the data needed to determine the number of shots optimum for each shot station and the utility (if any) for not vertically stacking in the seismograph. Based on these tests, we conclude that, for future surveys, the first shot at each station should be used to seat the striker plate only and should not recorded (Figure 2). If the first impact is recorded it should be discarded.

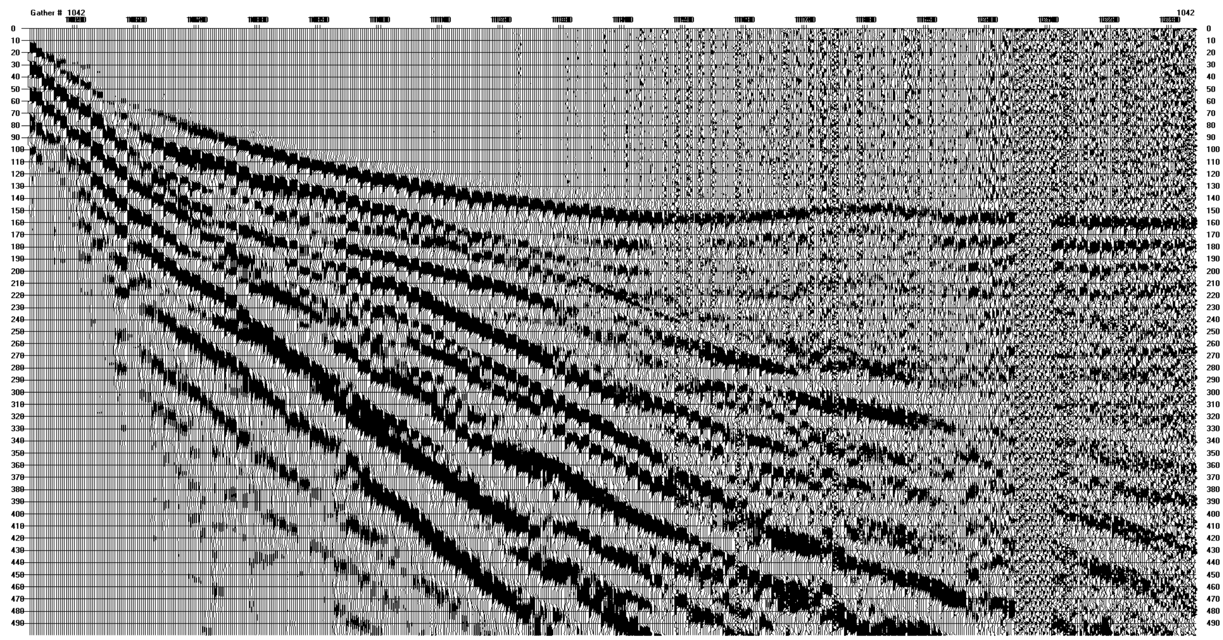


Figure 2. Shot gather with three impacts from each shot recorded and displayed coincidently. Traces within this gather are grouped according to common receiver, therefore all traces recorded by a specific receiver while the source was occupying this station are displayed sequentially from first shot at this station to last shot at this station. The saw tooth appearance of the first arrivals is indicative of source wavelet or timing irregularities. In this case, this first shot this location is abnormal (in comparison to other shots from that location). This abnormality is related to changes in the source wavelet before compared to after the striker plate is seated into the ground.

The spectral characteristics of the data dictate the maximum resolution potential. In this context, the resolution includes both vertical and horizontal, as well as thin bed resolution and problems associated with separating contributions from overlapping narrow bandwidth wavelets. The useable reflection frequencies obtained using the weight drop source ranged from around 50 Hz to just over 125 Hz. These spectral characteristics are consistent with our expectations for weight drop sources (Figure 3). A large percentage of the seismic energy propagates as surface waves.

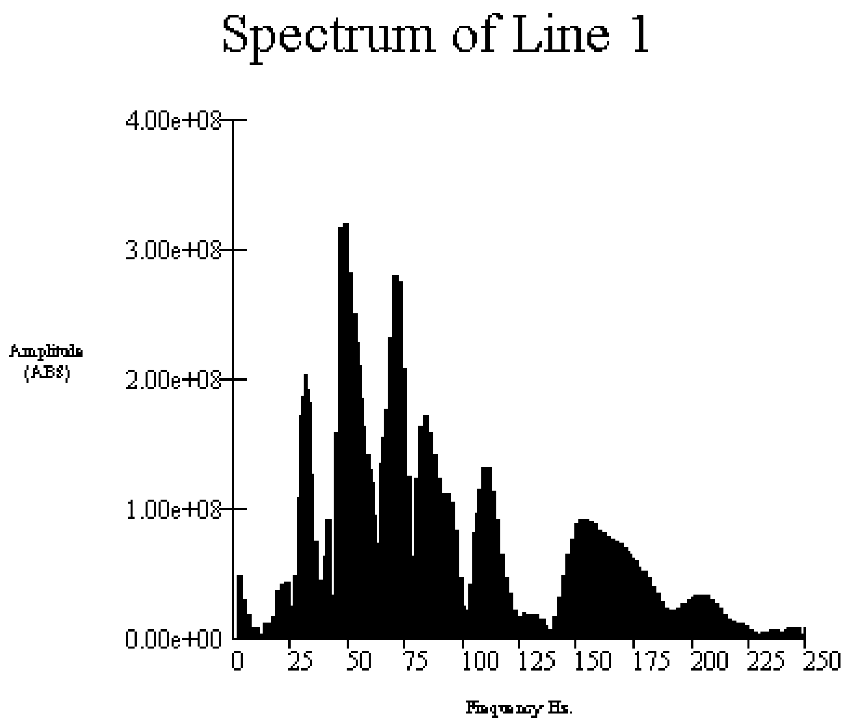


Figure 3. Whole record spectrum from weight drop near the first shot station on Line 1. The useable reflection frequencies range from about 50 to just over 125 Hz. The majority of the energy between about 150 Hz and 250 Hz represent air-coupled waves.

We produced Psuedo 192-channel shot gathers, with apparent trace separation of 2.5 ft, by shifting and combining two 96-channel shot gathers recorded from a fixed spread with shot locations that were separated by 2.5 ft. With this technique, it is possible to enhance event coherency and improve discrimination of any spatial aliasing. This apparent reduction in receiver spacing and subsequent increase in the number of recording channels is made possible by assigning the same source station to two shots locations (even though they are physically separated by 2.5 ft) and assigning geophones stations staggered by 2.5 ft (even though the geophones are physically in the same location for both shots) on one shot relative to the other. This technique allows geophones separated at 5-ft intervals to emulate receives separated at 2.5-ft intervals, while doubling the number of recording channels from 96 to 192. It is important to note that this method of increasing the apparent number of recording channels and decreasing the apparent receiver spacing is only affective when little or no source static is observed. Surface impact sources respond best to this method.

The receiver spread deployed along Line 1 extended from approximately the western edge of the buried drainage wall, across the landfill, and ended just beyond what appears to be the eastern edge of the buried drainage wall. The longest offset station on the west end was at Station 1001 (see Figure 1). Shot gathers from across this site possess pronounced ground roll, guided waves, and first arrivals on the raw shot record (Figure 4-14 (a)). After filtering with a digital bandpass filter (30-60-125-180) the body wave energy becomes more pronounced with a marked decrease in the apparent relative amplitude of the surface wave (Figure 4-14 (b)). Application of spectral balancing (band limited spiking deconvolution) using the same bandwidth as the digital filter (30-60-125-180) decreases the higher frequency non-source generated background noise, but boosts the relative amplitude of body waves to surface waves (Figure 4-

14 (c)). We applied Fk filtering (this is basically a slope or velocity filter) to remove as much of the ground roll as possible (figure 4-14 (d)). A second fk filter was applied to the data, after the ground roll specific fk filter, in an attempt to suppress as much of the higher velocity guided waves and refractions as possible (figure 4-5, 7-11, 13-14 (e)). Finally, the spectral balanced data were fk filtered with both slopes (ground roll and guided waves) in an attempt to remove as much non-reflection energy as possible (Figure 4-5, 7-9 (f)). The following data sets have all been processed in this fashion. Figure captions should be referenced for exact operations performed on each data set.

Line 1

The orientation of Line 1 makes reflections returning from the drainage walls the most likely events that would be observed from a reflection perspective. These near-vertical incidence reflections would arrive near the middle of the spread. Considering the material the source wavelet would have to travel through both down and back up, clean interpretable arrivals are unlikely. While reflections traveling to and from the opposite wall of the drainage will arrive at the longer offset traces and have a much higher than actual apparent velocity.

Looking carefully at the processed shot gathers it is possible to interpret what appear to be flat or slightly reverse dipping events beneath the first arrivals and guided waves and before the ground roll and air coupled waves. These arrivals are not consistent with any surface wave energy and do not mimic the earliest arriving events, making it unlikely they are related to refracted energy. This observation makes reflections the most likely interpretation of these events. However, considering the extremely low velocity of the fill material, it is not possible to estimate the normal move-out (NMO) velocity of these events. It would also be impossible to stack these events, if they were acquired using standard 2-D or 3-D methods. With the extreme dips of this nature, the exact placement of the reflecting point cannot be made.

Our examination of the shot gathers at shorter offset distances suggests the existence of relatively flat arrivals that might be emerging from beneath the ground roll or guided waves after fk filtering. Extreme caution is called for when interpreting events in this area of the shot gather after slope filtering. It is highly likely that aliasing has occurred, and the events are simply a processing artifact. Flat events that appear at greater two-way travel times on shot records that have had spectral balancing and fk filtering applied, are quite likely an artifact of over processing. Shot Station 1001 is probably outside the portion of the drainage that has been back-filled with refuse. Therefore, it is unlikely that shot-gathers recorded from this location would contain near-offset reflections.

Seismic energy generated at Station 1042, which is likely located above the west drainage wall, has a less complicated travel path to reach reflecting points at the base of the fill than at Station 1001. It is possible to interpret relatively flat events at two-way travel times of approximately 250 msec, that have no clear correlation to the slopes of earlier arrivals. These events possess the negative slope which, from a reflection perspective, would be expected if they were returning from reflectors with extreme dip (reflector getting shallower at greater distances from the source). This dip angle would be consistent with the buried wall on the east side of the drainage. Artifacts of the extreme processing are evident on fk-filtered data. These events must not be ignored during processing, lest they be inadvertently stacked coherently and interpreted as reflections on CMP sections.

A slight offset in the refracted arrivals occurs at about Station 1190. This anomaly can not be related to surface features. Therefore, it is either related to topography of the refractor, or to changes in material velocity beneath Stations 1160 to 1190. Careful study suggests that there might be diffractions originating from this feature indicative of point source scatter. Characterizing the geologic phenomena producing this diffracted energy is not possible with the current data set.

Little in the way of useful reflection information can be extracted from the shot gathers recorded at Station 1139 (Figure 6). However, the processing has enhanced a couple of events that occur just before the surface wave, and just after the air-coupled wave, that have a geometry that is not inconsistent with reflected energy. However, with these shot-gathers alone, it is not possible to rule out the possibility that these events are either guided waves or sub-cross over refractions.

Shot-gathers recorded at Station 1235 on the east side of the fill possess characteristics similar to those recorded at Station 1042 on the west side (Figure 7 & 8). The near-offset source location data have the same first arrival static beneath Station 1190 that were observed from the west end. One notable aspect of these data is the more pronounced linear events at longer offsets. Events at travel times greater than 200 ms cannot be reasonably explained by any wave propagation path other than reflections. These events could easily be artifacts of the slope filtering, except that there are subtle indications that they are present on raw (a) and filtered (b) data sets.

At the close offset eastern stations we compared sledgehammer (Station 1235) and weight drop (Station 1236) energy sources, as shown on Figures 7 and 8 respectively. The partitioning of energy is approximately equivalent and the apparent reflection wavelet characteristics are also very similar for both sources. However, the predominant difference is clearly the total recorded power produced by the weight drop. Therefore, from an operational and data quality perspective, the weight drop is the better non-invasive source for this site.

The dip of reflections observed on these shot gathers is also negative relative to the source location as was seen on shots from the western side. This observation is consistent with the steep sided drainage concept. As the source is moved over the eastern drainage wall, the dip of the west drainage wall is such that a reflection returning from that wall would have an NMO curve with an apparent negative curve. From a geometric perspective these deep events (>200) msec are consistent with the geologic model we are currently working with.

One troubling factor is the time-depth of the possible reflection events. The data indicate possible reflection events at two-way travel times of 200-msec and 300-mse. Given the estimated 150-ft depth to the drainage floor, the average velocity would have to be around 1500 ft/sec if the 200 msec event was to be correlated to the drainage floor, and around 1000 ft/sec if the 300 msec event was from the drainage floor. These velocities are very low for 150 ft of native earth material, but not outside the realm of possibilities for fill material. The concerting aspect is that with such low velocities the attenuation would likely be so great that, when combined with the inevitable scatter from the debris in the pit, we would not expect reflections to possess such coherency and signal strength.

Longer offsets gathers on the east side still seem to possess reasonably good events within the optimum window for this site which is below the guided waves and first arrivals and above the air-coupled waves and ground roll (Figure 9). Again, the apparent slope of events within this window appear to be reversed.

Line 2

Line 2 was acquired parallel to the axis of the drainage. Therefore the geometry of the drainage walls relative the 2-D sensitivity of these gathers is dramatically different than on Line 1. This difference is immediately evident in the first arrivals. The apparent velocity of the first arrivals is quite different than that observed on the Line 1 data.

At the far offset off the south end of the line (Station 2001), the separation between the guided waves and first arrivals at early times, and the air coupled wave and surface at later times, is quite small (Figure 10). This makes the optimum reflection window quite small. No events are evident on these gathers that could be considered reflections. Fk processing clearly has the potential, if not strongly harnessed, to produce artifacts that will stack coherently on CMP sections.

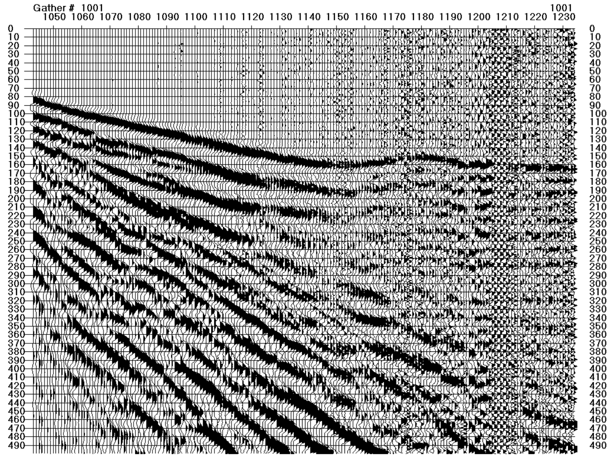
Problems with a narrow optimum window are exacerbated on closer offset data sets (Figure 11). Very little opportunity exists on these data sets for reflection energy to be present at amplitudes at or above the noise level. However, it is interesting to note that there is a high amplitude, extremely low velocity event with a zero offset time of around 100-msec. This event has some of the characteristics of wide-angle reflections beneath Stations 2120 to 2180. However, two things must be kept in mind, first wide angle reflections do not make representative reflection events on CMP stacked sections and second, they have characteristics that are very similar to refractions which can be easily mistaken as wide angle reflections.

The split-spread geometry data obtained at Station 2173 has less useable information than the split spread geometry data acquired at Station 1139 on Line 1 (Figure 12). Nothing useful can be extracted from these gathers.

The data acquired at the north end of Line 2 provides a seismic picture of the subsurface similar to that obtained at the south end of the line. Here too, the near-offset data do not possess distinctive sub-wide angle reflections (Figure 13). However, the event identified on near offset gathers from the south end of the line is present in the north end data as well. This apparent wide-angle reflection is most obvious on filtered data (b). If it were a real reflection and not a refraction of some sort, it would likely be from a very shallow depth, maybe 50 ft, and represent a very pronounced acoustic impedance contrast that is consistent across this site. The fact that this event was not observed on Line 1 could be due to the extreme geometry of the drainage beneath that line. It would not be advisable to attempt to interpret geology from this wide-angle event once processed and stacked on a CMP section. Wide-angle events do not possess the same characteristics of near vertical events and, therefore, many of the assumptions necessary to processes seismic reflection data are not valid.

The far-offset data acquired at Stations 2001 and 2314 on Line 2 exhibit pronounced artifacts on the fk filtered data. As a result, no confidently interpretable reflections are evident in these data sets (Figure 14).

Station 1001



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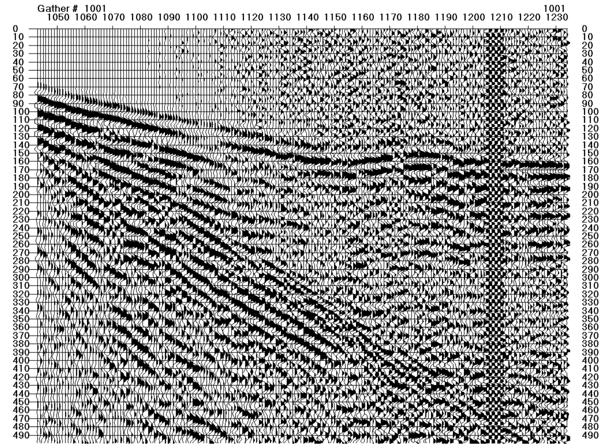
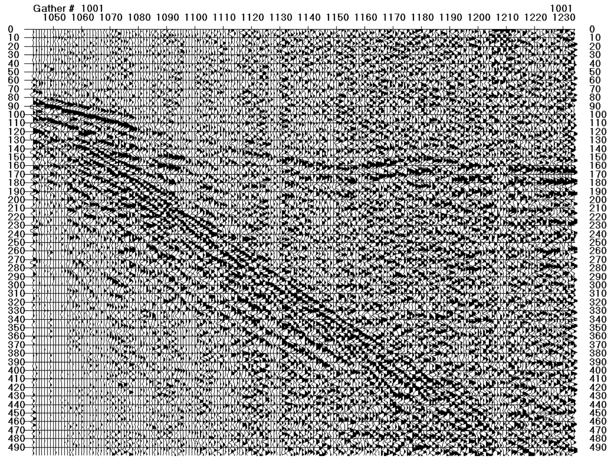
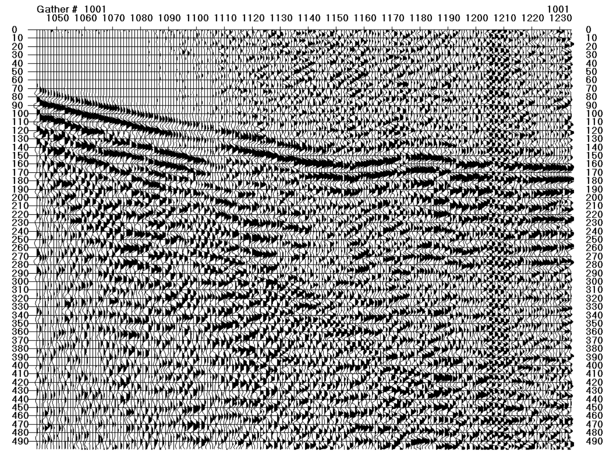


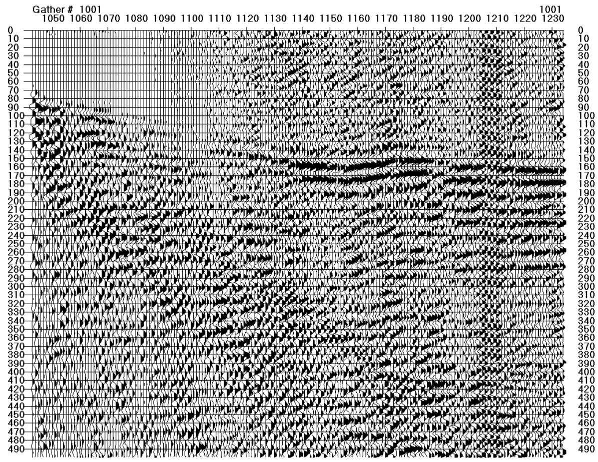
(b) filtered



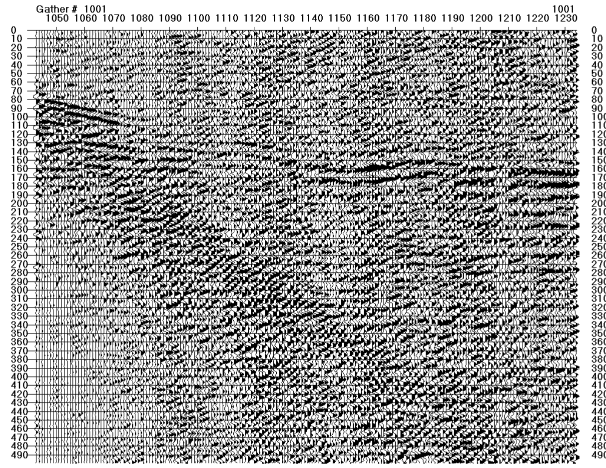
(c) spectral balanced



(d) fk groundroll



(e) fk guided waves

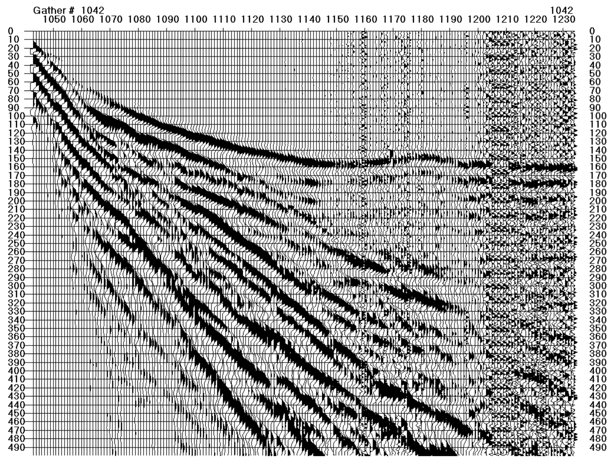


(f) SB fk combo

Figure 4. Shot Station 1001. (a) raw data, (b) digital filter (30-60-125-180), (c) spectral balancing across the same frequency parameters as the digital filter, (d) fk filtering focusing on

the ground roll arrivals, (e) an additional fk filter targeting the guided wave energy, and (f) a combination guided wave and ground roll filter of the spectral balanced data.

Station 1042



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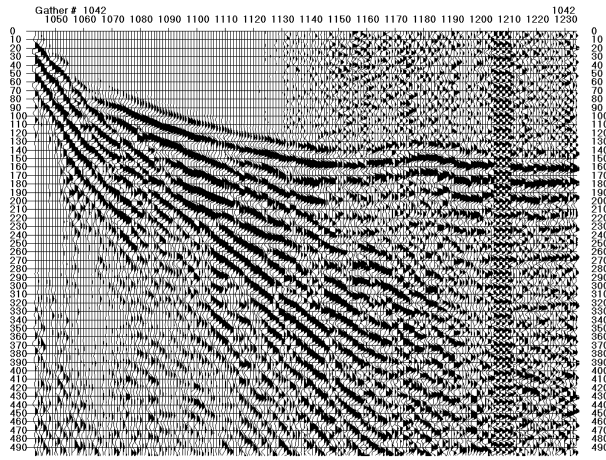
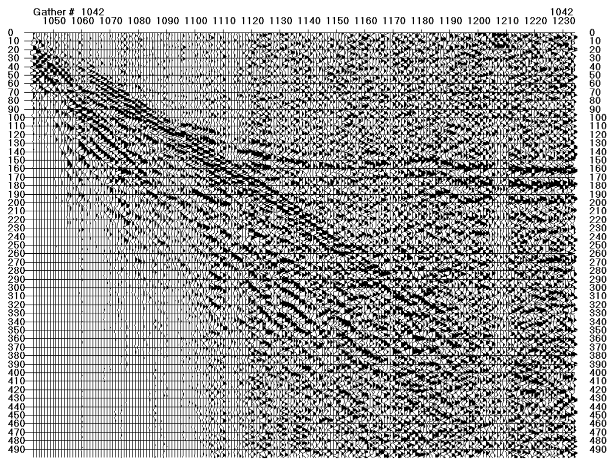
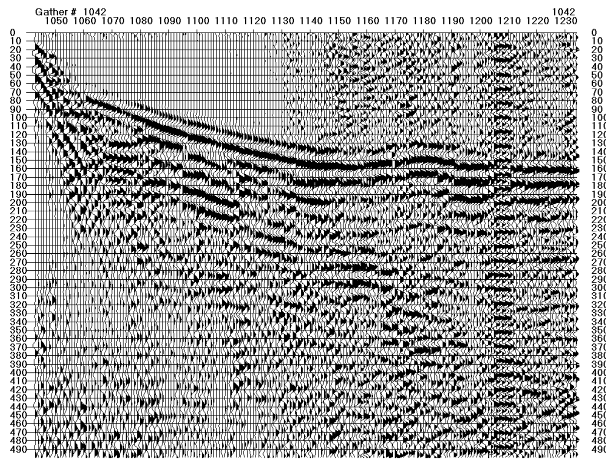


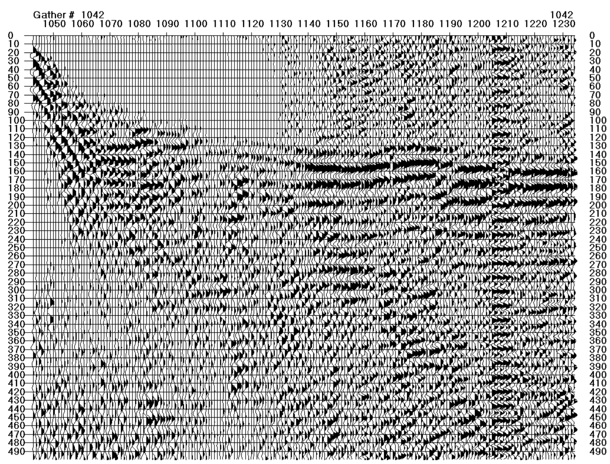
(b) filtered



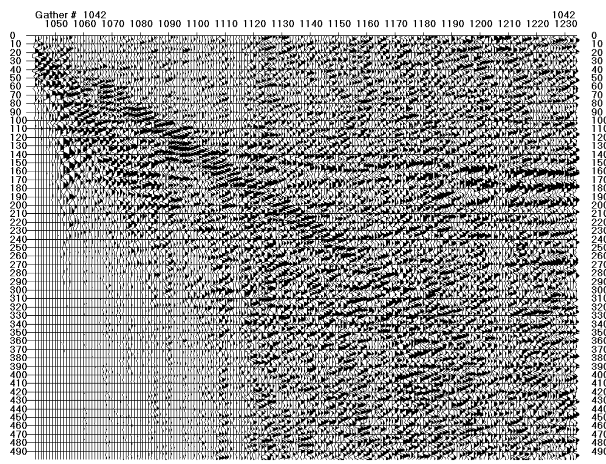
(c) spectral balanced



(d) fk filtered ground roll



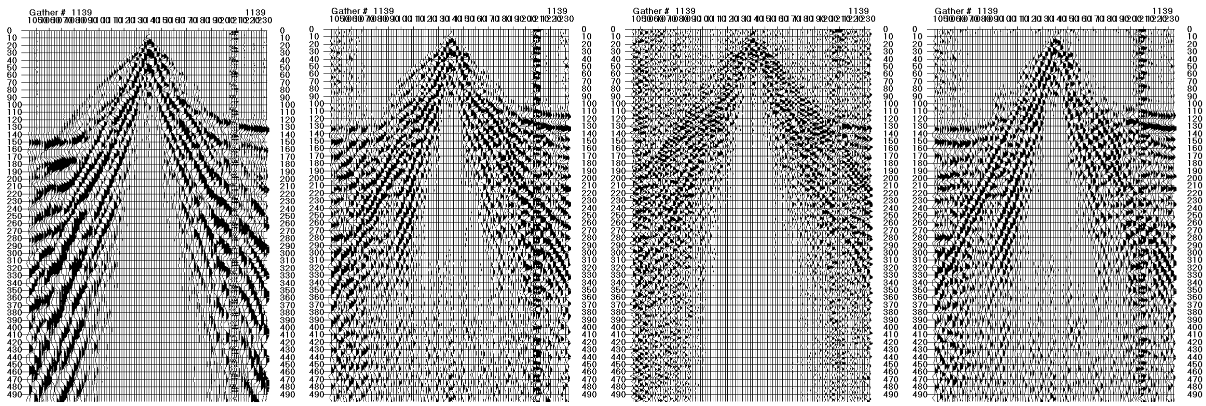
(e) fk filtered guided wave



(f) SB fk guided and ground roll

Figure 5 Shot Station 1042. (a) raw data, (b) digital filter (30-60-125-180), (c) spectral balancing across the same frequency parameters as the digital filter, (d) fk filtering focusing on the ground roll arrivals, (e) an additional fk filter targeting the guided wave energy, and (f) a combination guided wave and ground roll filter of the spectral balanced data.

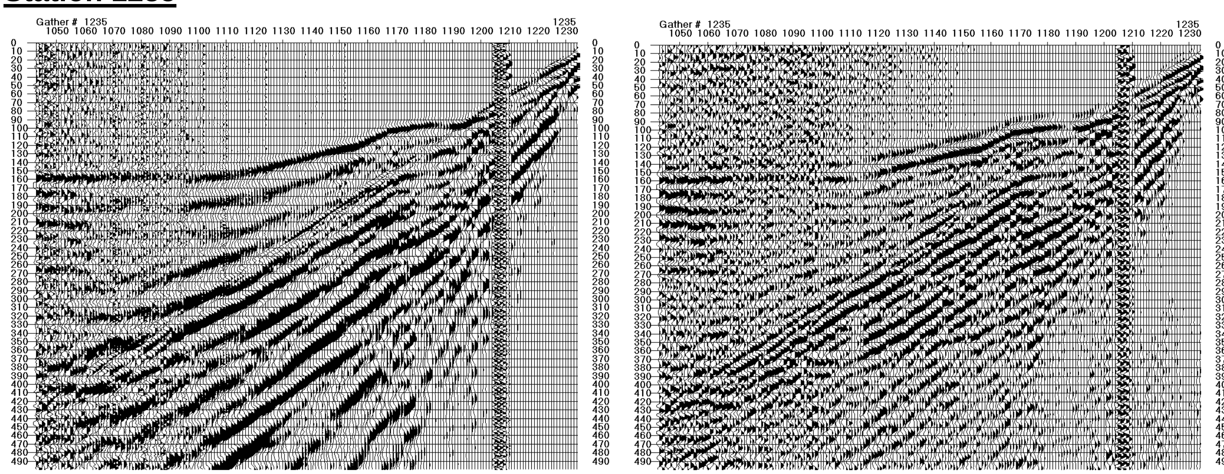
Station 1139



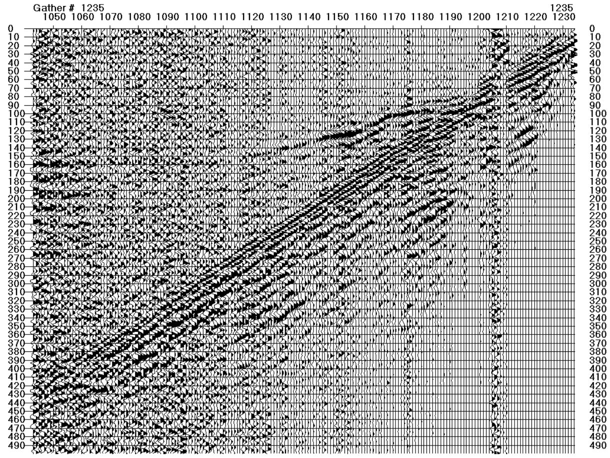
(a) raw (b) filtered (c) spectral balanced (d) fk guided and GR

Figure 6 Shot Station 1139. (a) raw data, (b) digital filter (30-60-125-180), (c) spectral balancing across the same frequency parameters as the digital filter, and (d) fk filter targeting the guided wave energy and ground roll.

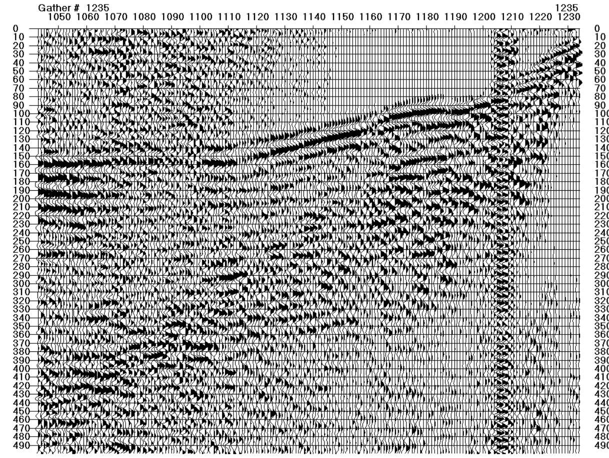
Station 1235



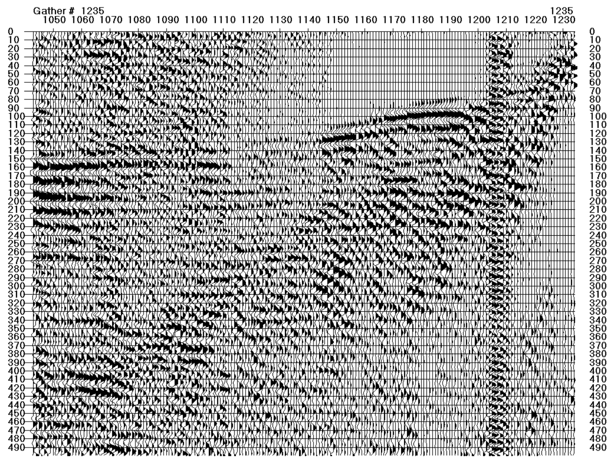
(a) raw (b) filtered



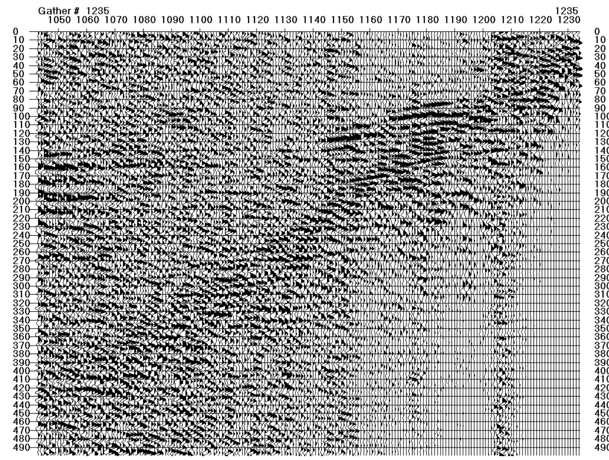
(c) spectral balanced



(d) fk ground roll



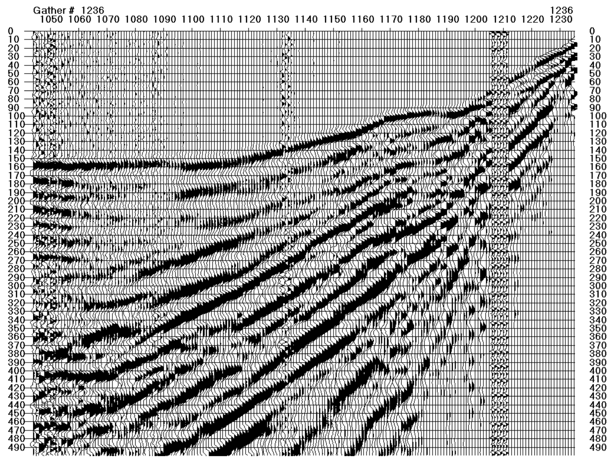
(e) fk guided and GR



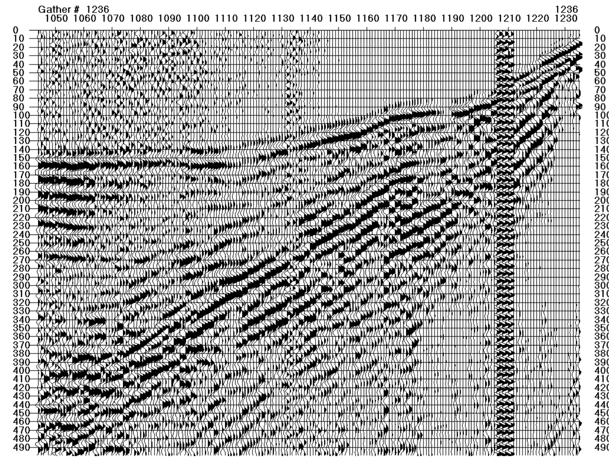
(f) fk SB guided and GR

Figure 7. Shot Station 1235. (a) raw data, (b) digital filter (30-60-125-180), (c) spectral balancing across the same frequency parameters as the digital filter, (d) fk filtering focusing on the ground roll arrivals, (e) an additional fk filter targeting the guided wave energy, and (f) a combination guided wave and ground roll filter of the spectral balanced data.

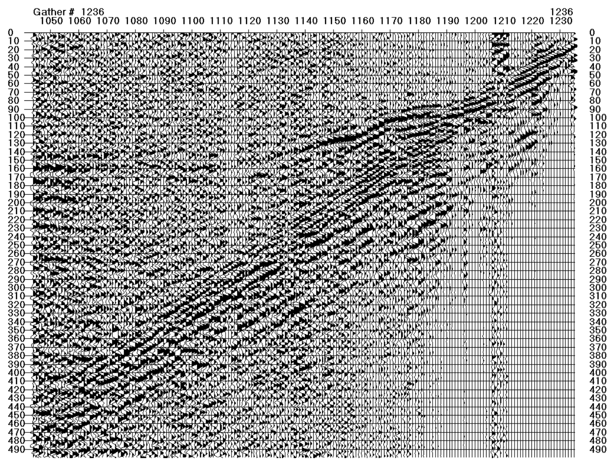
Station 1236



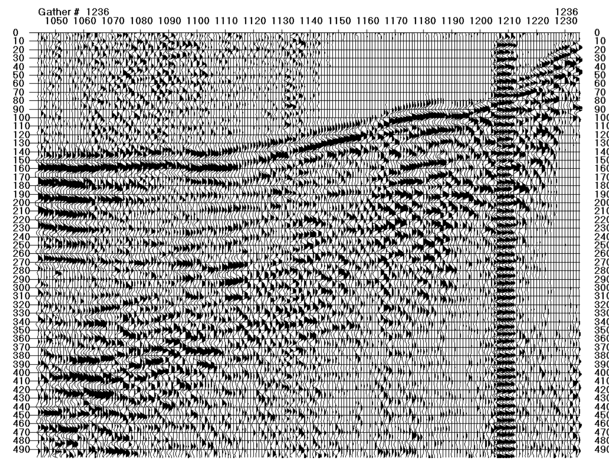
(a) raw



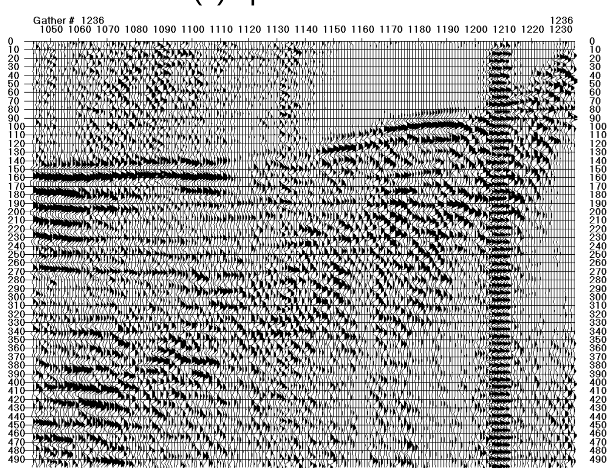
(b) filtered



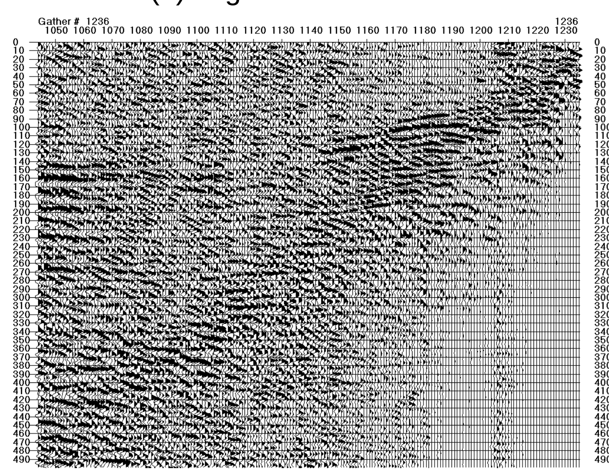
(c) spectral balanced



(d) fk ground roll



(e) fk guided and GR

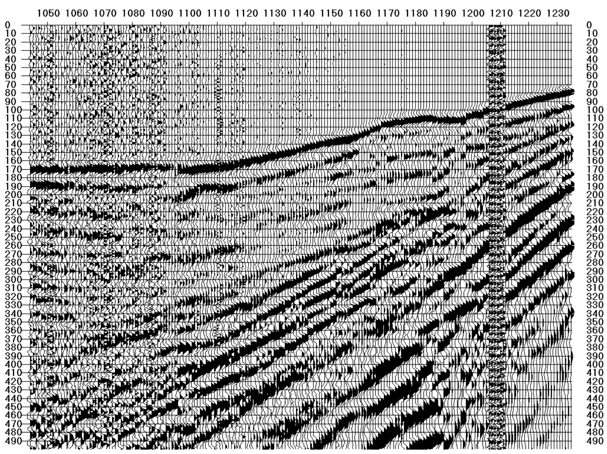


(f) fk SB guided and GR

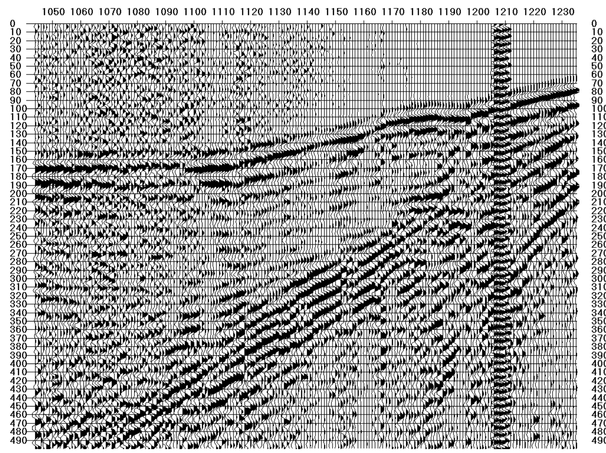
Figure 8. Shot Station 1236. (a) raw data, (b) digital filter (30-60-125-180), (c) spectral balancing across the same frequency parameters as the digital filter, (d) fk filtering focusing on

the ground roll arrivals, (e) an additional fk filter targeting the guided wave energy, and (f) a combination guided wave and ground roll filter of the spectral balanced data.

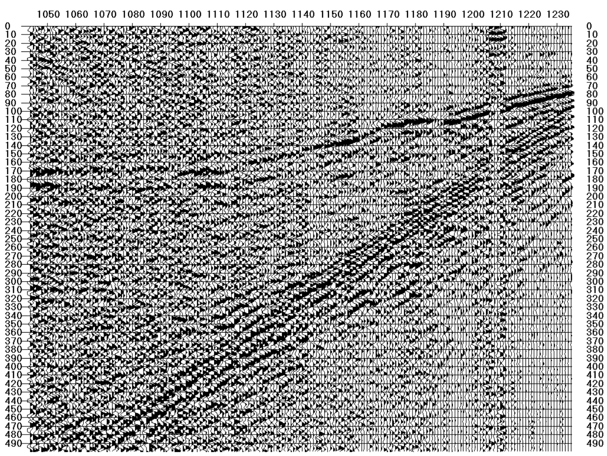
Station 1282



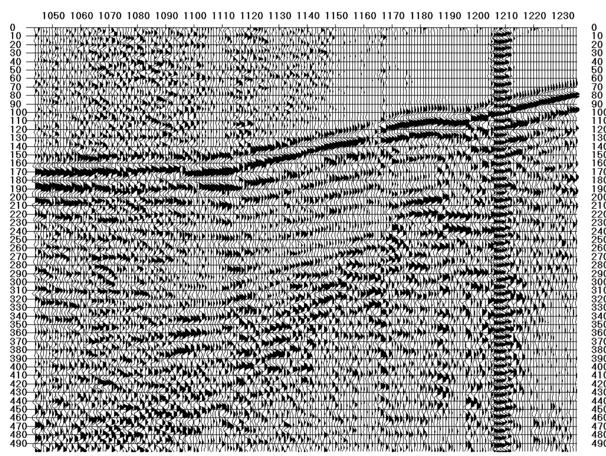
(a) raw



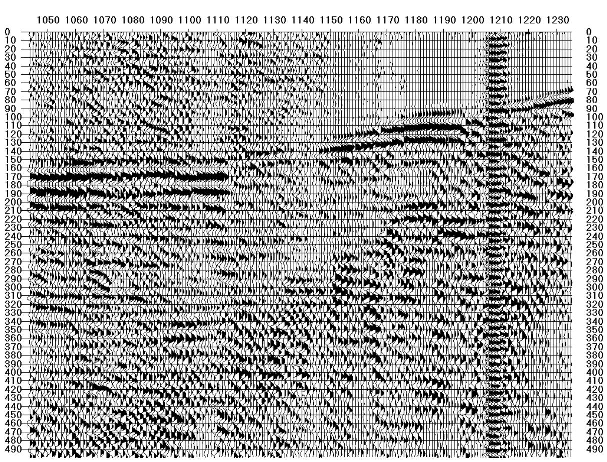
(b) filtered



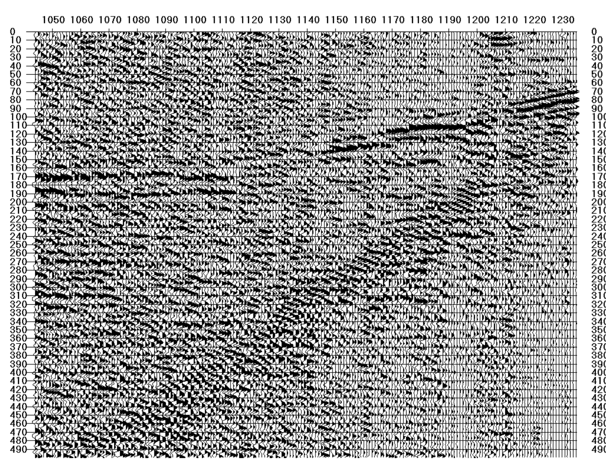
(c) spectral balanced



(d) fk ground roll



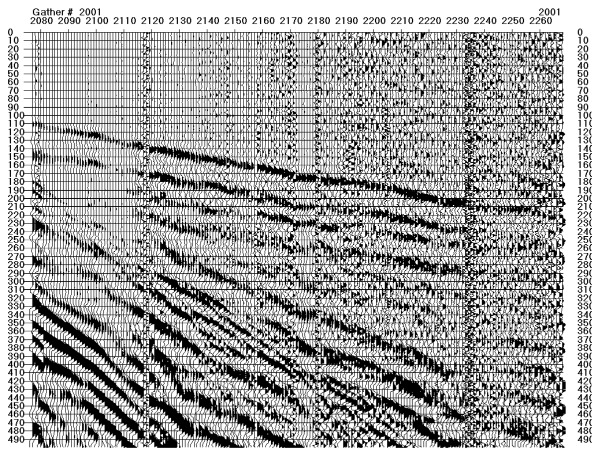
(e) fk guided and GR



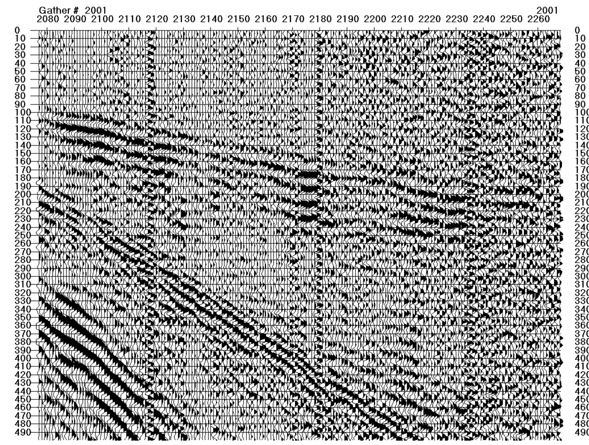
(f) fk SB guided and GR

Figure 9. Shot Station 1282. (a) raw data, (b) digital filter (30-60-125-180), (c) spectral balancing across the same frequency parameters as the digital filter, (d) fk filtering focusing on the ground roll arrivals, (e) an additional fk filter targeting the guided wave energy, and (f) a combination guided wave and ground roll filter of the spectral balanced data.

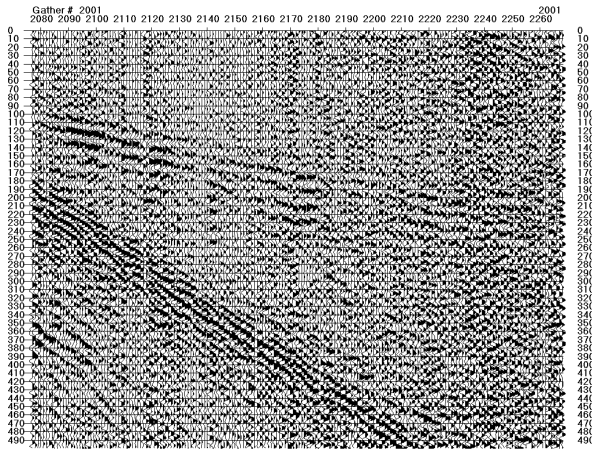
Station 2001



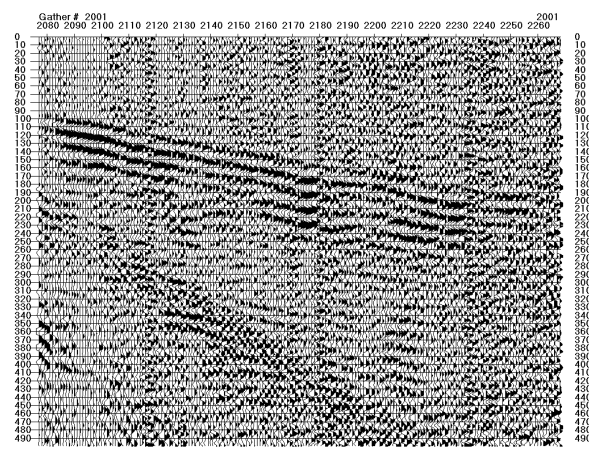
(a) raw



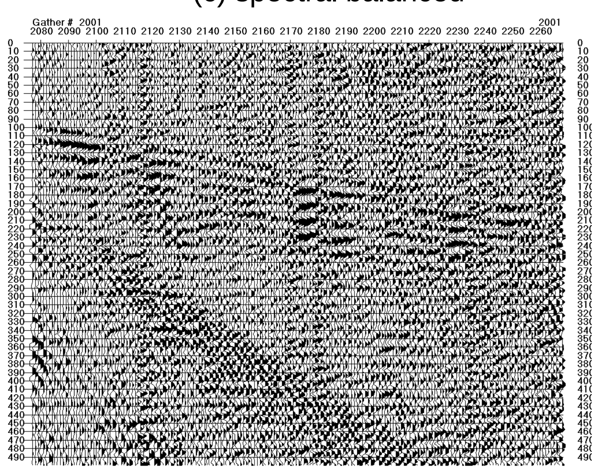
(b) filtered



(c) spectral balanced



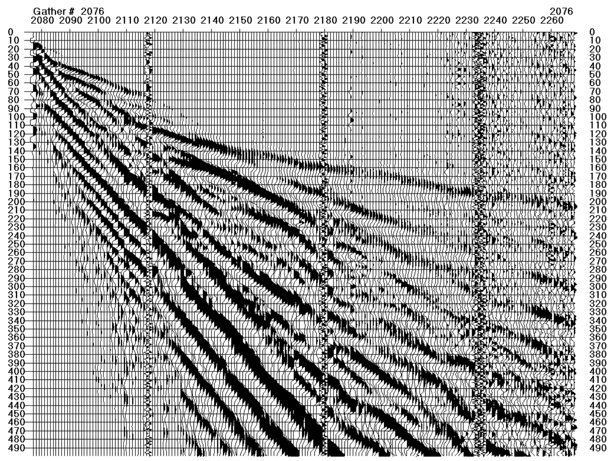
(d) fk ground roll



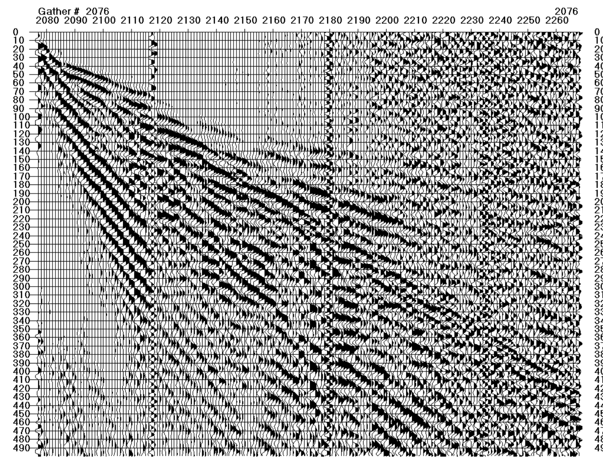
(e) fk guided and GR

Figure 10. Shot Station 2001. (a) raw data, (b) digital filter (30-60-125-180), (c) spectral balancing across the same frequency parameters as the digital filter, (d) fk filtering focusing on the ground roll arrivals, (e) an additional fk filter targeting the guided wave energy, and (f) a combination guided wave and ground roll filter of the spectral balanced data.

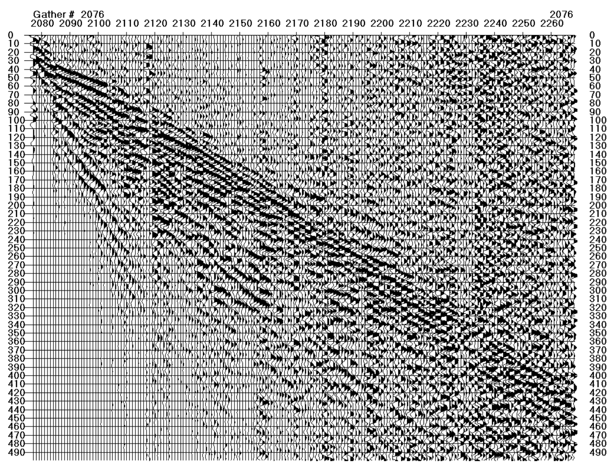
Station 2076



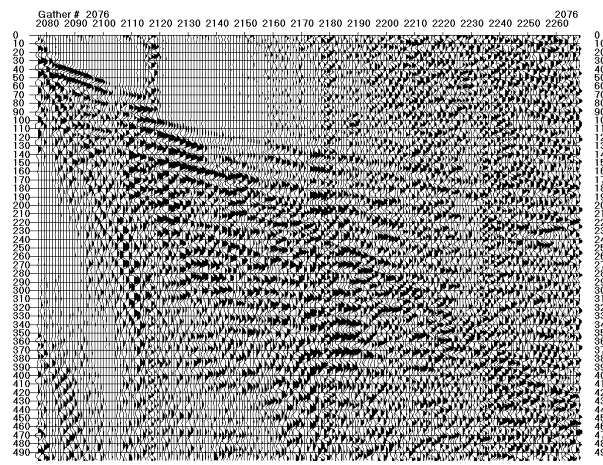
(a) raw



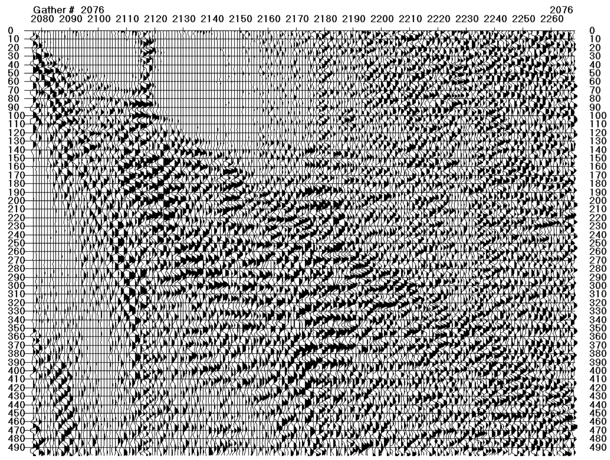
(b) filtered



(c) spectral balanced



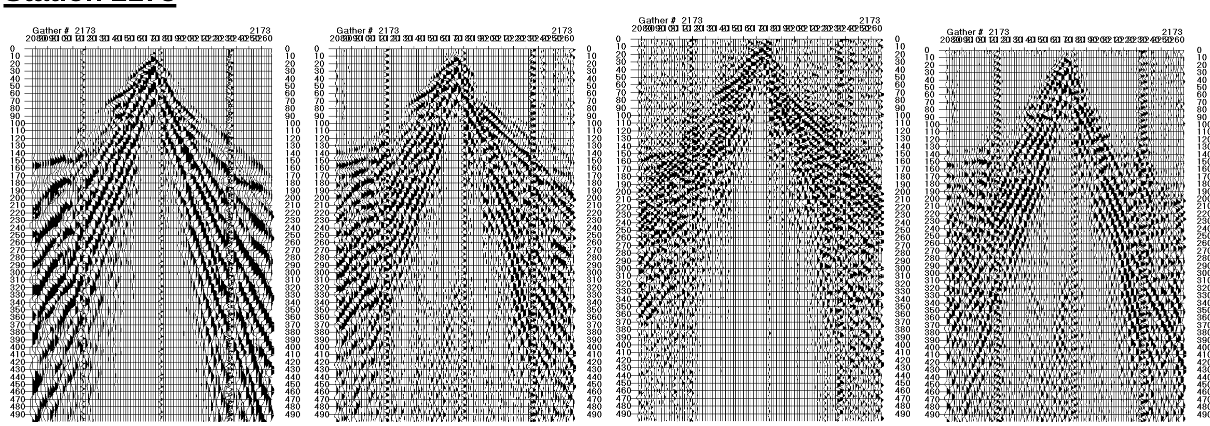
(d) fk ground roll



(e) fk guided and GR

Figure 11. Shot Station 2076. (a) raw data, (b) digital filter (30-60-125-180), (c) spectral balancing across the same frequency parameters as the digital filter, (d) fk filtering focusing on the ground roll arrivals, (e) an additional fk filter targeting the guided wave energy, and (f) a combination guided wave and ground roll filter of the spectral balanced data.

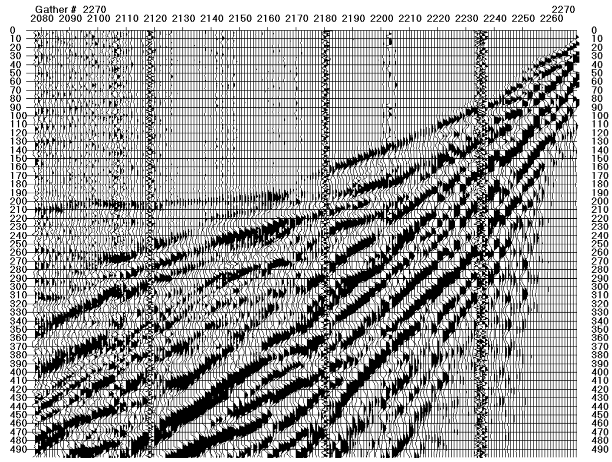
Station 2173



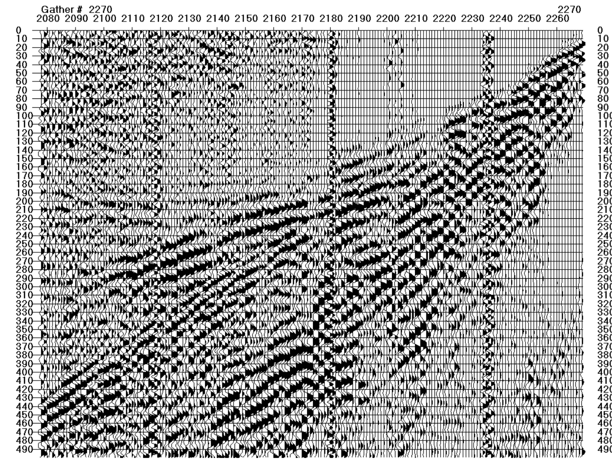
a) raw (b) filtered (c) spectral balanced (d) fk guided and GR

Figure 12 Shot Station 2173. (a) raw data, (b) digital filter (30-60-125-180), (c) spectral balancing across the same frequency parameters as the digital filter, and (d) fk filter targeting the guided wave energy and ground roll.

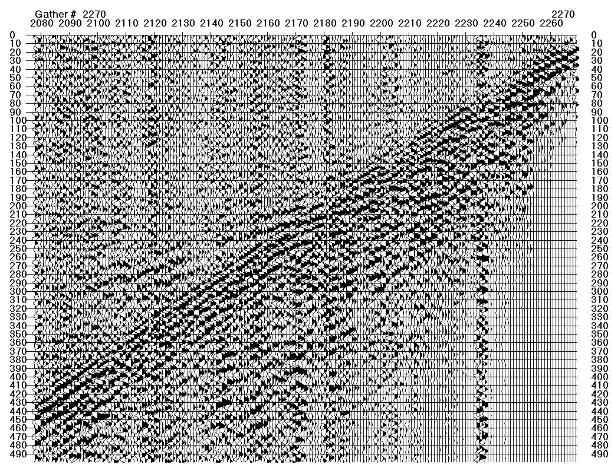
Station 2270



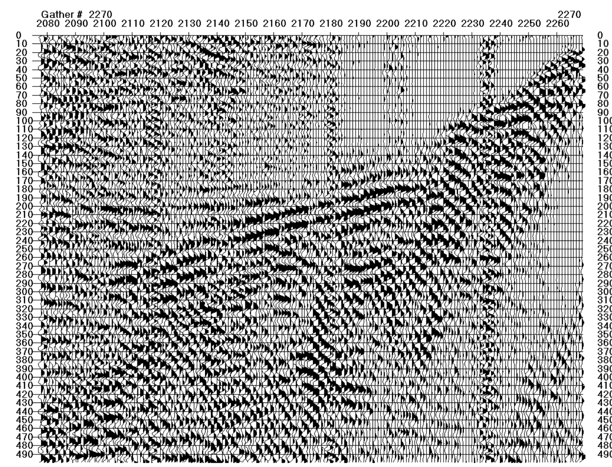
(a) raw



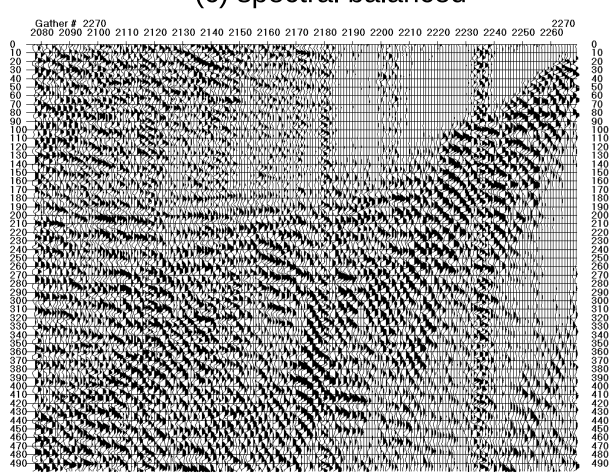
(b) filtered



(c) spectral balanced



(d) fk ground roll

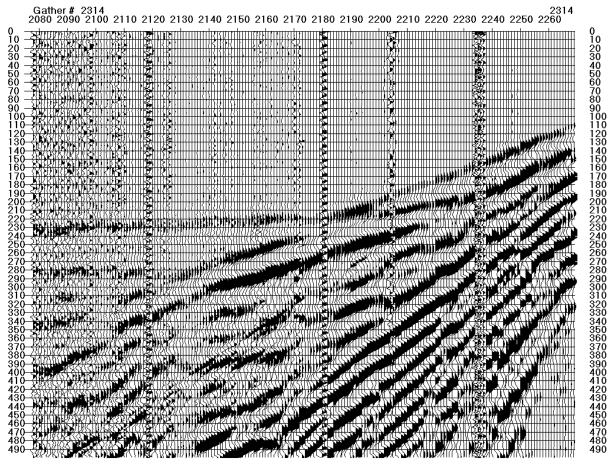


(e) fk guided and GR

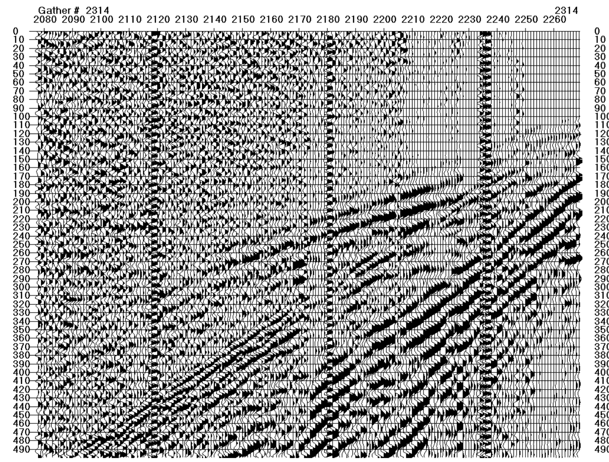
Figure 13 Shot Station 2270. (a) raw data, (b) digital filter (30-60-125-180), (c) spectral balancing across the same frequency parameters as the digital filter, (d) fk filtering focusing on

the ground roll arrivals, (e) an additional fk filter targeting the guided wave energy, and (f) a combination guided wave and ground roll filter of the spectral balanced data.

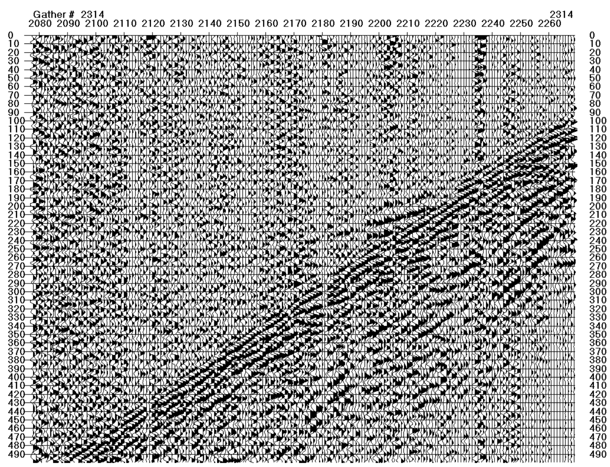
Station 2314



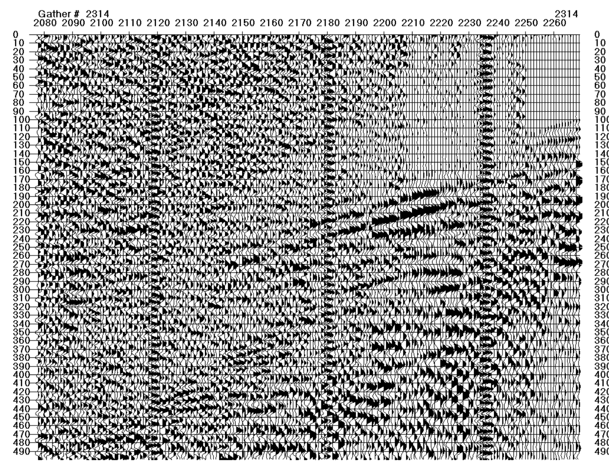
(a) raw



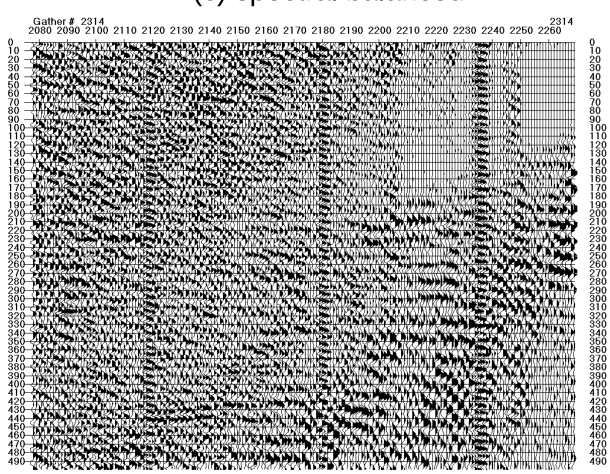
(b) filtered



(c) spectral balanced



(d) fk ground roll



(e) fk guided and GR

Figure 14 Shot Station 2314. (a) raw data, (b) digital filter (30-60-125-180), (c) spectral balancing across the same frequency parameters as the digital filter, (d) fk filtering focusing on the ground roll arrivals, (e) an additional fk filter targeting the guided wave energy, and (f) a combination guided wave and ground roll filter of the spectral balanced data.