Preliminary Testing of Shallow Seismic Reflection Techniques at Dover AFB

Preliminary shallow seismic reflection testing on April 21 and 22, 1995 at the Dover Air Force Base primarily targeted the surface of an approximately 15 m deep aquitard believed to be continuous beneath the recently established Groundwater Remediation Field Laboratory (GRFL) at the base. The GRFL is a well manicured 3 1/2 acre site located immediately north of the North Gate (Figure 1). This approximately triangular shaped site is bounded by the west perimeter fence, the running track, and a transformer station (Figure 2). A pair of boreholes along the western boundary of the site penetrate the top of the 15 m clay and are cased with small diameter PVC pipe. The water table depth at the time of this test was estimated to be approximately 3 to 4 m below ground surface. The site was free of surface obstacles and possessed only minor (< 0.5 m) topographic undulations on otherwise uniformly dipping ground surface.

All seismic reflection test data acquired during the April 20-21, 1995 site visit were recorded with University of Delaware's 24-channel Geometrics StrataView, 12 pair refraction cables, and 5.5 kg sledgehammer. The geophones were single Mark Products L40A 100 Hz with 14 cm spikes spaced at either 0.5 or 0.25 m, depending on the spread. Due to the extremely attenuative nature of the sod and its tendency to enhance the bounce of the sledgehammer, small divots were cut to allow an improved plate couple to the ground surface. A single impact as well as 5 to 7 vertically stacked impacts were recorded at each shotpoint. In an attempt to minimize the effects of the extremely large ratio of ground roll to body waves, a small (< 0.5 kg) hammer was also tested. Three unique spreads were deployed to ensure a reasonably representative acoustic sample was obtained (Figure 2). Reversed walkaway gathers were acquired for each spread. Considering the dynamic range of the seismograph and the dominant recorded frequency of wave energy, no digital acquisition filters were used. Digital display filters were heavily used to accommodate on-site QC and analysis.

To maximize event coherency on walkaway gathers, data were recorded with source-to-nearest-receiver spacing of 0.25, 0.375, 6.25, 6.375, 12.25, 12.375, 18.25, and 18.375 m for receiver spreads deployed with 0.25 m station spacing. As a result, gathers have 192 traces evenly distributed between a minimum offset of 0.25 m and maximum offset distance of 24.125 m. Considering the target reflector is about 15 m deep, this spread interval should be sufficient to image the reflector.

The display of data is based on spread number, number of impacts, and relative source offset direction. As well, each walkaway gather was subjected to post-acquisition processing that included AGC scaling (50 msec and 25 msec windows) and trapezoidal bandpass filtering (50, 100, 500, 750; 75, 150, 500, 750; 100, 200, 500, 750; and 15, 300, 500, 750 [all values in Hz]). Also, an f-k filter targeting the ground roll was applied to the 50, 100, 500, 750 Hz filter and 25 msec scaled data.

The following list of files has numerical identification numbers that are printed above the last trace of each gather to distinguish each unique source and receiver configuration.

File 0 48 traces recorded off the south end of spread number 1. This is the only file with 0.25 m trace spacing. Ground roll, air coupled wave, direct wave, and refractions can be identified on this gather. Data from single impact.

File 10 48 traces recorded off the south end of spread #1 with geophones moved into 0.125 m separations. Subtle suggestions of horizontal events below 100 msec can be interpreted. Sledgehammer and/or plate bounce is represented by the left to right sloping events consistent with the ground roll velocity. Data from a single sledge hammer impact on the aluminum striker plate.

File 11 48 traces recorded off the south end of spread #1 with 0.125 m geophone spacing. Stacking has reduced the relative coherency of geophone spacing. Stacking has reduced the relative coherency of the hammer bounce, but did little else to boost the signal-to-noise ratio.

File 15 Same as 10 except source location was off the north end.

File 16 Same as 11 except source location was off the north end.

File 20 This 192-trace gather recorded off the south end of spread #2 clearly shows the air-coupled wave as the first arrival at close offsets, the ground roll and direct wave originating at approximately the same t_0 but diverging with the ground roll velocity being about 200 m/sec and the direct wave at approximately 315 m/sec. The refraction cross-over is at approximately 9.5 m with a refraction velocity of about 1800 m/sec. It is very likely that the 1800 m/sec refractor is the water table.

File 21 This 192-trace gather was recorded off the south end of spread #2 and is the vertical summation of 5 sledge hammer impacts. The primary difference between a single impact and a 5-shot stack is the subtle decrease in relative amplitude of the pre-first arrival noise at the longer offsets. A reduction in the amplitude of the hammer bounce is also evident. Other than an ever-so-slight suggestion that the relative amplitude of ground roll might be a little higher, the records are extremely similar with respect to signal-to-noise.

File 25 This 192-trace gather is a single sledge hammer impact recorded off the north end of spread #2. Except for the relative location of the hammer bounce, little difference can be readily detected between the north and south ends. One subtle difference might be the appearance of a curved event arriving just after the air coupled wave but just before the ground roll, between 30 and 40 msec and with an offset of between 6 and 12 m.

File 26 This 192-trace gather was recorded from the north end of spread #2 and represents a 5-shot vertical stack. As with file 25, the apparent curved event is evident. As well, consistent with the south end stacks, the relative pre-first arrival noise is slightly less on the multi-shot stacks as compared to single impacts.

File 30 A 192-trace gather with the source located off the west end of spread #3. This single shot gather possesses some artifacts of equipment problems. The dead traces are actually a single bad takeout on one of the 12-channel cables. Due to the multi-source location shooting style the single bad takeout presents itself eight different times on the gather. Acoustically there is little dramatic change with the change in spread and orientation.

File 31 This 192-trace gather is the result of 5 vertically stacked shots of the west end of spread #3. Besides the relative decrease in pre-event noise there is little that distinguishes this gather from those on spread #2. A significant similarity is the reverse slope events possessing ground roll velocity and is most pronounced after the primary ground roll arrival. There is no evidence of these events in the quiet portion of the record before the first arrivals and they do not possess a change in slope regardless of spread orientation; these two observations suggest they are related to source energy.

File 35 This 192-trace gather was acquired with the source on the east end of spread #3. The equivalent to a single impact was recorded to produce this record. Little in the way of confidently interpretable reflection arrivals can be interpreted on this gather.

File 36 This 5-shot vertical stack acquired with the source on the east end of spread #3 possesses 192 traces. Aside from a slight decrease in the relative amount of pre-first arrival noise, this gather is very equivalent to file 35.

The previous set of shot gathers represents as complete a series of tests as possible with the equipment and time available. The following set of figures/figure captions discuss the various processing (i.e., digital filters and an f-k filter) that were applied to 25 msec AGC scaled data. The following figure captions are intended to only touch on the significant points of the particular processing applied to the data set.

Figure 3. This data has had a 50 msec AGC scale applied. The scaling has boosted the relative amplitudes of arrivals so identification of ground roll, air coupled wave, and refractions are easily identified. Of interest are the flat, coherent events on files 10 and 11 at about 100 to 110 msec. These could be reflections from an interface as deep as 50 to 60 m.

Figure 4. The data have had an AGC scale of 25 msec applied. This smaller AGC window was used to enhance extremely low amplitude arrivals in the presence of large amplitude arrivals. The divergence of the refraction on files 25 and 26 at about 6 m of offset and 30 msec is quite pronounced. This could be either reflection energy becoming asymptotic to and interfering with refractions, or it could be refracted energy between the critical distance and crossover distance.

Figure 5. This 25 msec AGC scaled and 50, 100, 500, 750 digitally filtered data set is very similar to Figure 3. The similarity is a result of the site and the 100 Hz geophones. The geophones attenuate energy less than 100 Hz and at 50 Hz energy is reduced by about 9 dB.

Figure 6. The 25 msec AGC scaled and 75, 150, 500, 750 digital filter applied to this data set has decreased the bandwidth of ground roll sufficiently to introduce another complete cycle.

Figure 7. This 25 msec AGC scaled and 100, 200, 500, 750 digitally filtered data set dramatically reduces the ground roll energy. The air wave has become a bit more pronounced and anomalies in the direct/refracted arrivals are becoming more evident. At long offset on files 31 and 35 there appears to be a horizontal coherent event at about 95 msec. This event could be a reflection, but it would be from a depth significantly deeper than the target of this survey.

Figure 8. The high frequency energy dominates this 25 msec AGC scaled and 150, 300, 500, and 750 digitally filtered data. The direct wave and refractions are very difficult to interpret with the large amounts of high frequency air coupled wave present on these data. Little in the way of file-to-file consistent reflection candidates are interpretable.

Figure 9. To retain as much of the bandwidth as possible and reduce the dominant effects of ground roll an f-k filter was applied to the 25 msec AGC scaled and 50, 100, 500, 750 digitally filtered data. The ground roll was very effectively removed. The recorded amplitude of ground roll was so great very little in the way of coherent events are present beneath the ground roll. Near horizontal events can be interpreted in several places on most of the files. Missing is the file-to-file consistency that is critical for a confident identification. File 20 appears to have an

event at about 35 msec that possess some degree of hyperbolic curvature. Reflection events on 1/8 of a meter trace spacing would need to be very nearly horizontal, at least at velocities reasonable for real earth materials.

Figure 10. File 20 with a 500 m/sec hyperbolic curve with a t_o of 35 msec, which would represent a reflection from 8.8 m (a) and a 710 m/sec hyperbolic curve with a t_o of 38 msec representative of a reflector at 13.5 m (b). These curves are calculated theoretical based on the apparent interference in the refraction that appears to have some curvature. Without uphole velocity information it is impossible to confidently determine if the velocity used to calculate these hyperbola are representative of this area. No other coherent events could be interpreted with a shape, arrival time, and to some degree file-to-file consistency on the gathers that could be at least proposed at this time to be reflections.

Conclusions

Based on the testing done with the sledge hammer at the DAFB, this site is going to be very difficult acoustically. Data collected by the Kansas Geological Survey at other sites on the Coastal Plain have produced significantly higher quality reflections from depths as shallow as 9 m. The strong ground roll contribution in association with the extremely low velocity near-surface puts the realistic time/offset optimum window for recording reflection arrivals from depths less than 20 m coincident with the air-coupled wave, ground roll, direct wave, and between refraction critical and crossover distances. To have any hope of effectively recording reflections from less than 20 m at this site one or, if possible, all of the following must happen: the amplitude of the recorded ground roll must be reduced, the high end corner frequency and bandwidth of the reflected energy must increase, the relative amplitude of the reflected energy must increase, and the air coupled wave must be reduced. Of course, it is no secret these are the keys to recording high quality reflections from any site.

Accommodating the previous requirements for an effective reflection survey will probably entail a more extensive test prior to acquisition of any production-style CDP data. The following should probably be tested:

1) explosive style source (anything from a blasting cap to black powder)
2) vibratory source would be interesting to test
3) maybe a larger weight drop (this may/probably will make the ground roll problem worse)
4) different style weight drop maybe worth an experiment (e.g., slide hammer)
5) S-waves might very well be worth testing

6) velocity check shot survey
7) short CDP test survey (processed on-site)
8) multiple geophones/station, possibly with a lower natural frequency
9) another area maybe closer to the river on the west or off the end of the runway. Moving to another test area is just to get a better understanding of how representative this site is with repect to others is this area. A potential look at a nearby (less than a couple km away) seismogram with high confidence reflections would help constrain the acoustic model proposed for this area and might help determine the feasibility of the technique at this site.

These suggestions may help produce meaningful seismic reflection data from this site. Also, consideration must be given to recording when road traffic is at a minimum and air traffic is significantly outside the audible range. A lot of things can be tested and these suggestion represent just a few.

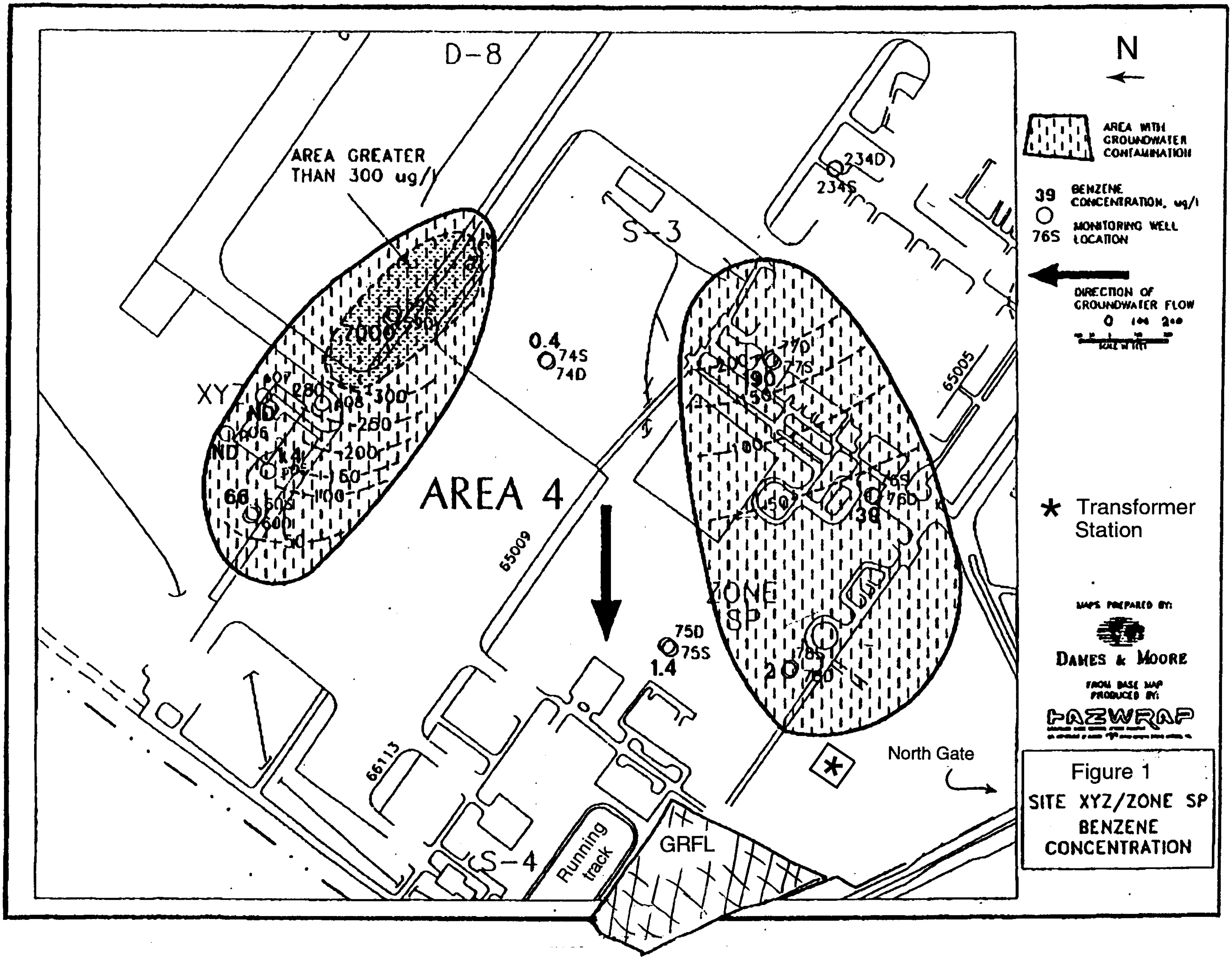

Figure 1
SITE XYZ/ZONE SP
BENZENE CONCENTRATION

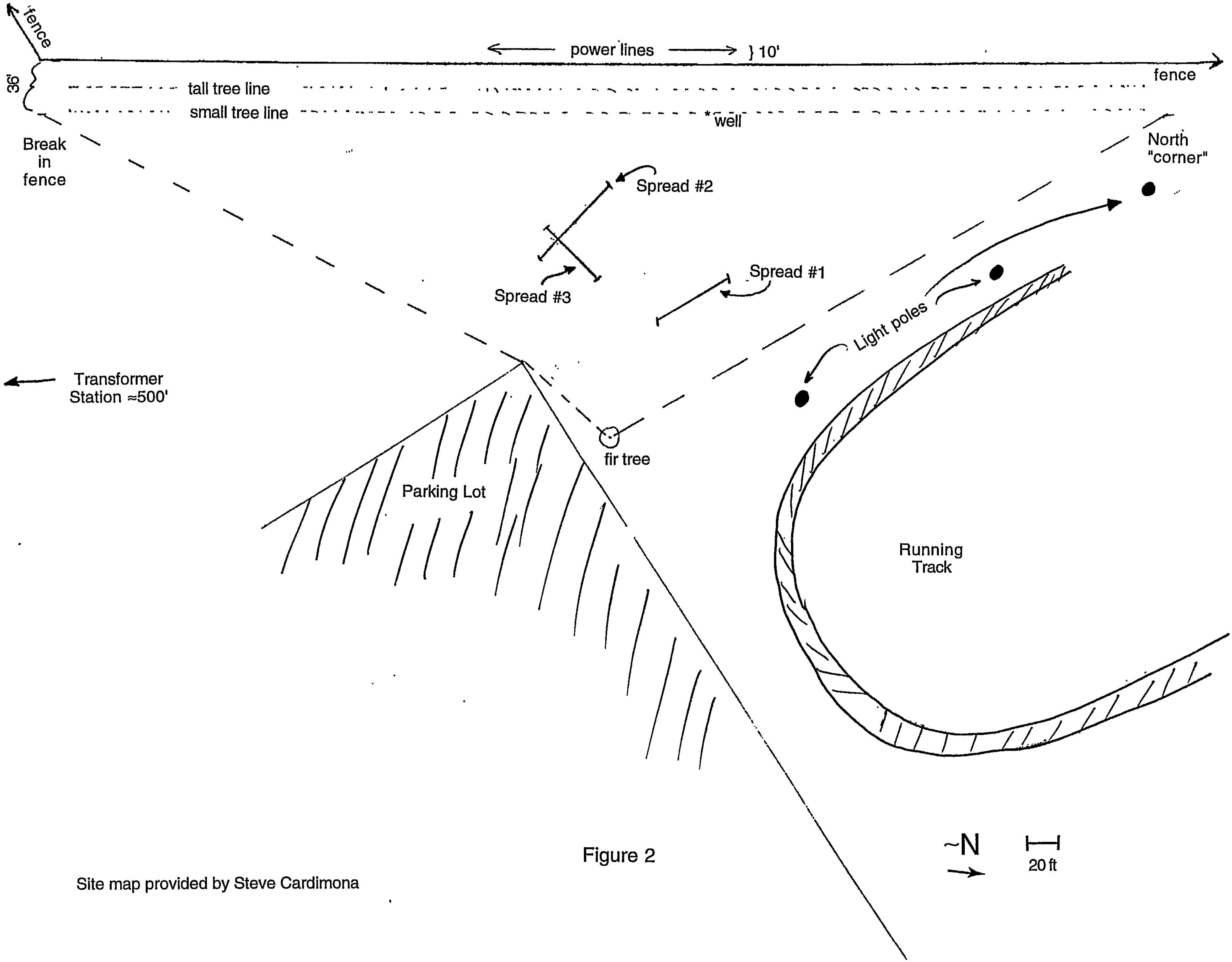

Figure 2

Site map provided by Steve Cardimona

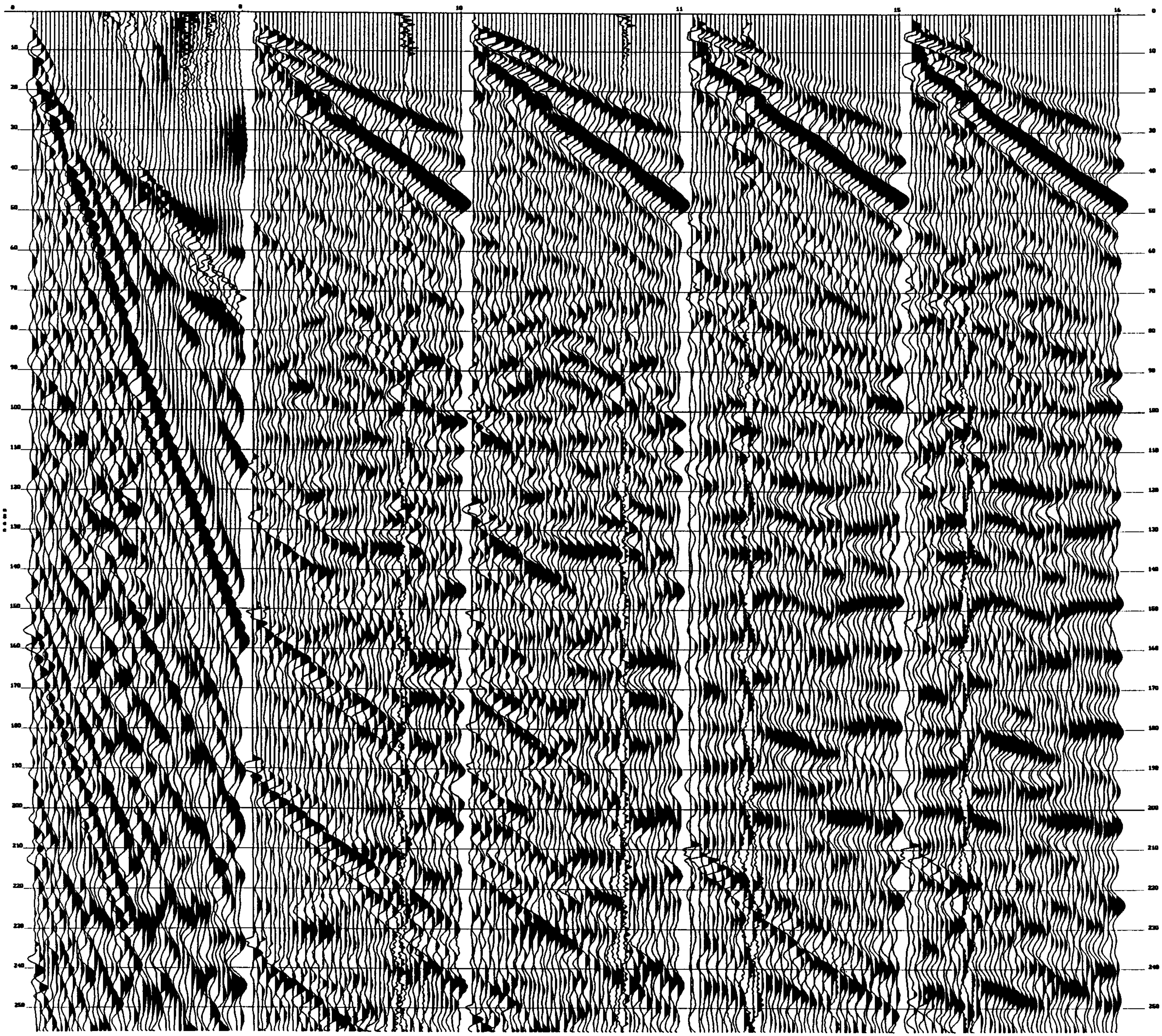

Figure 3

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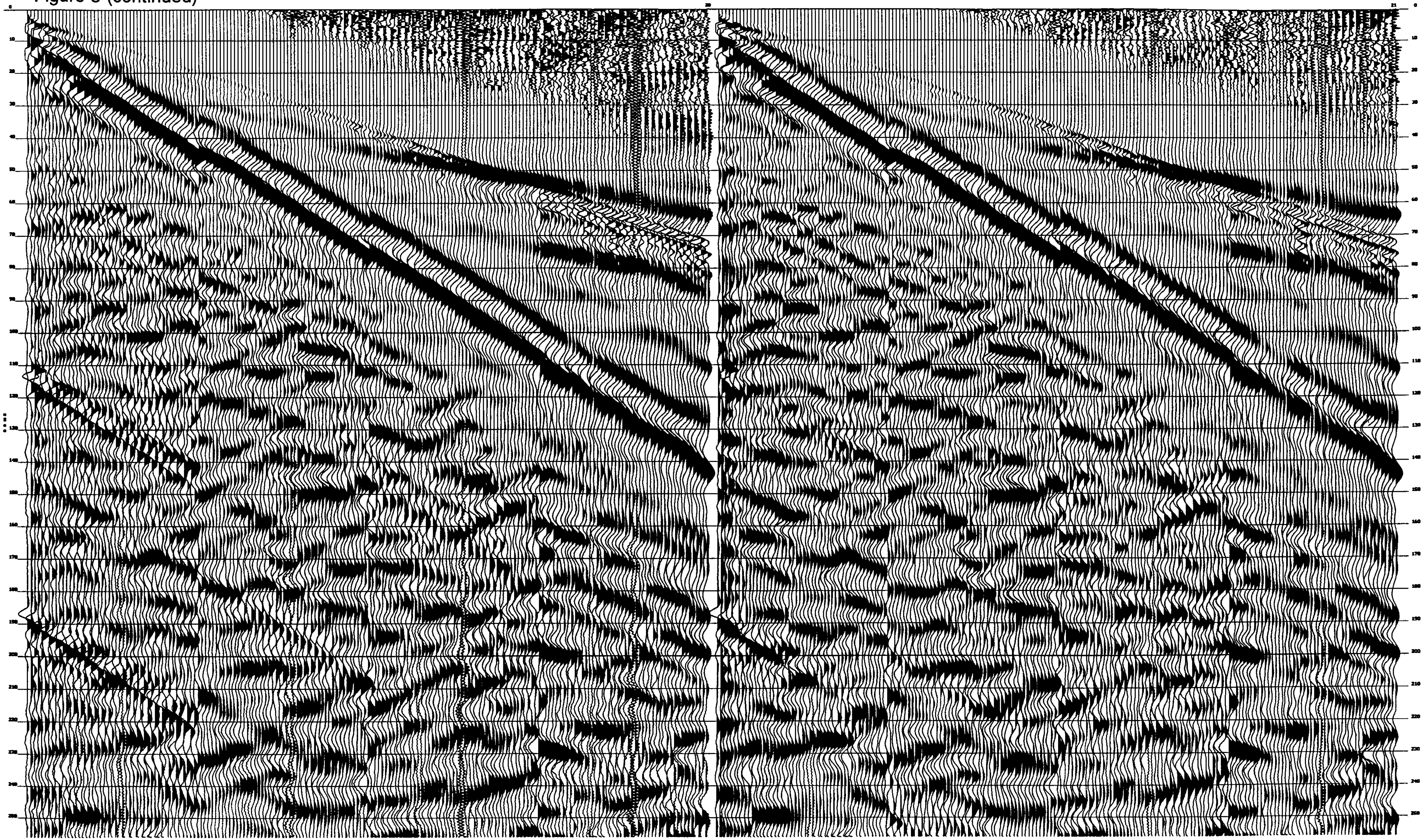

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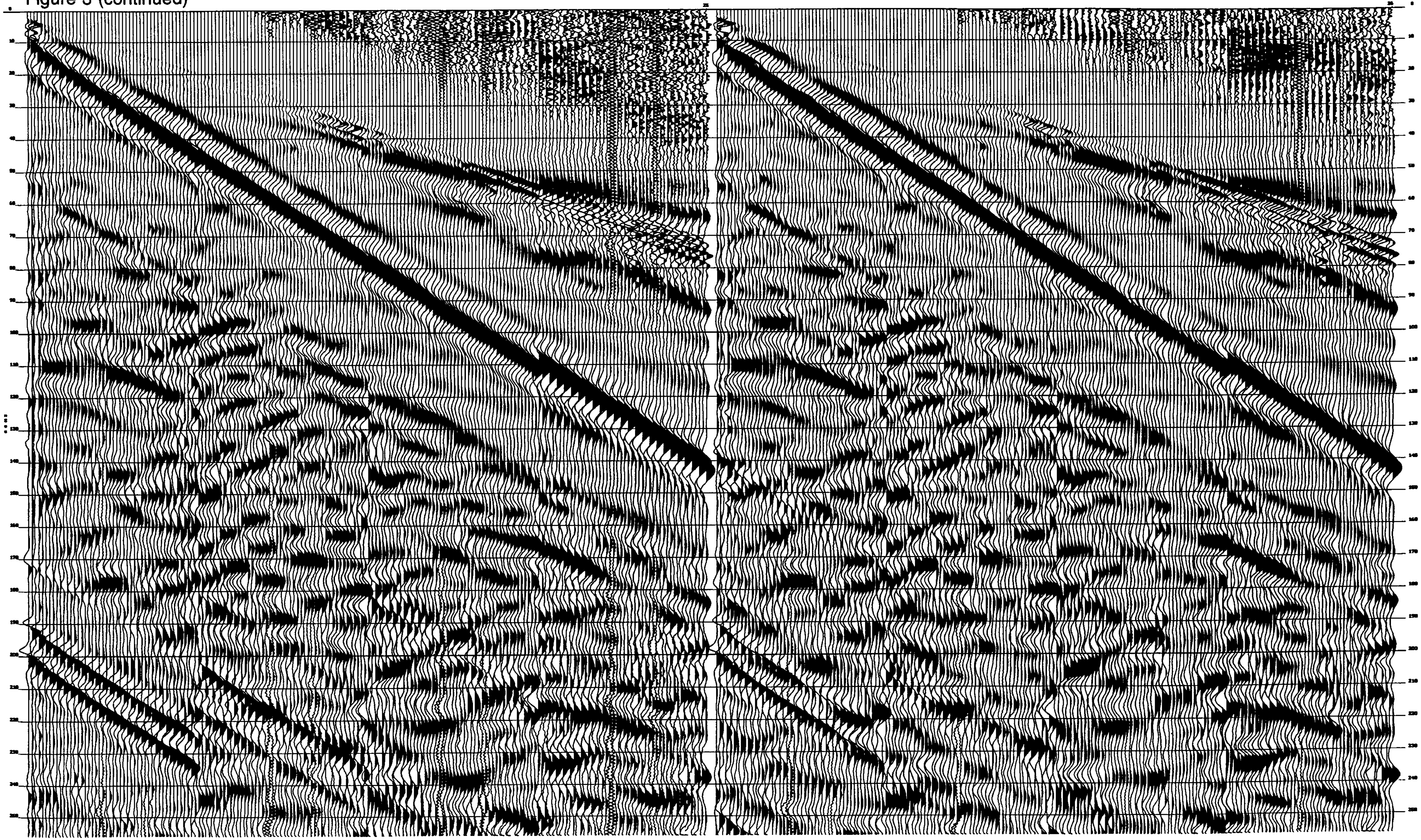

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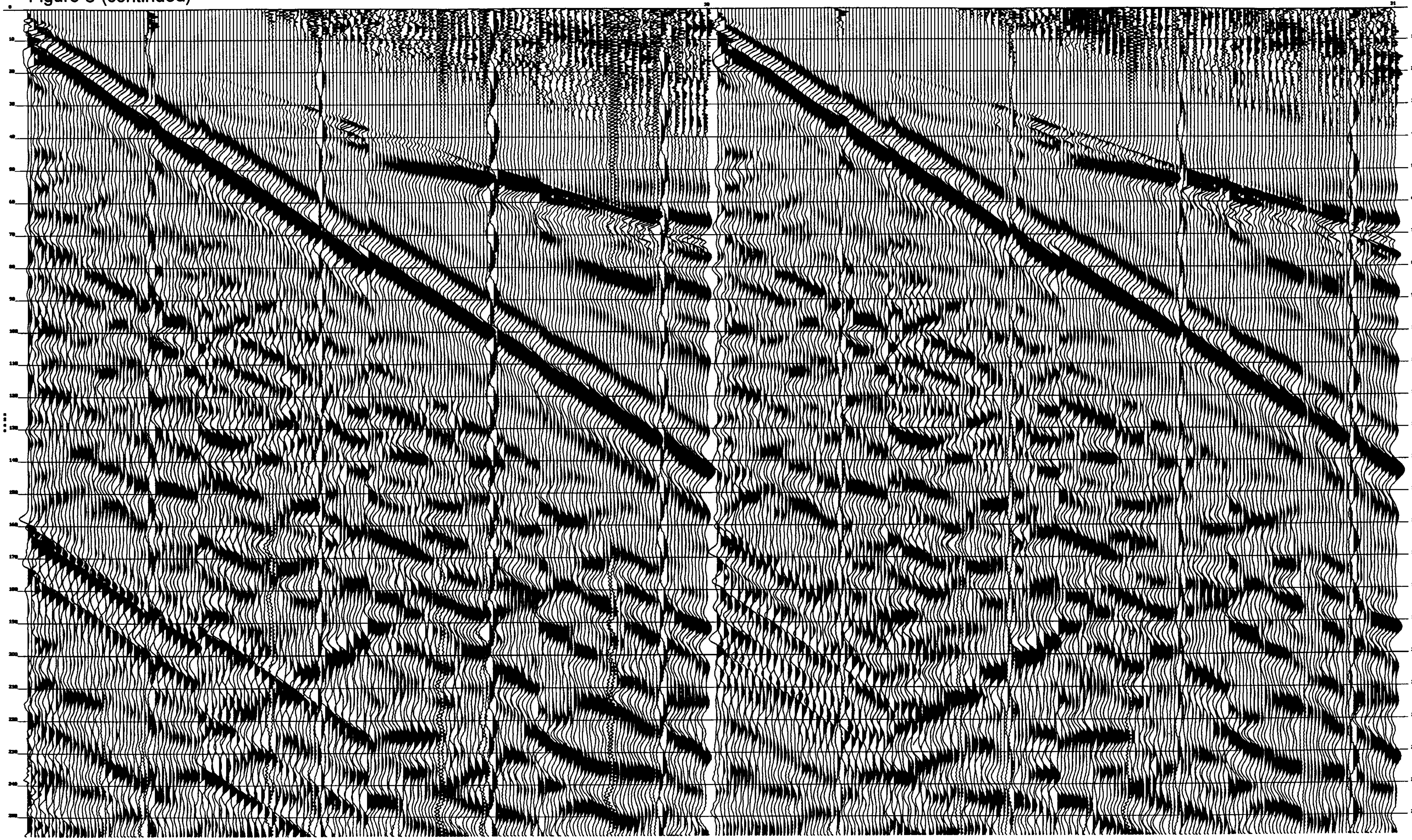

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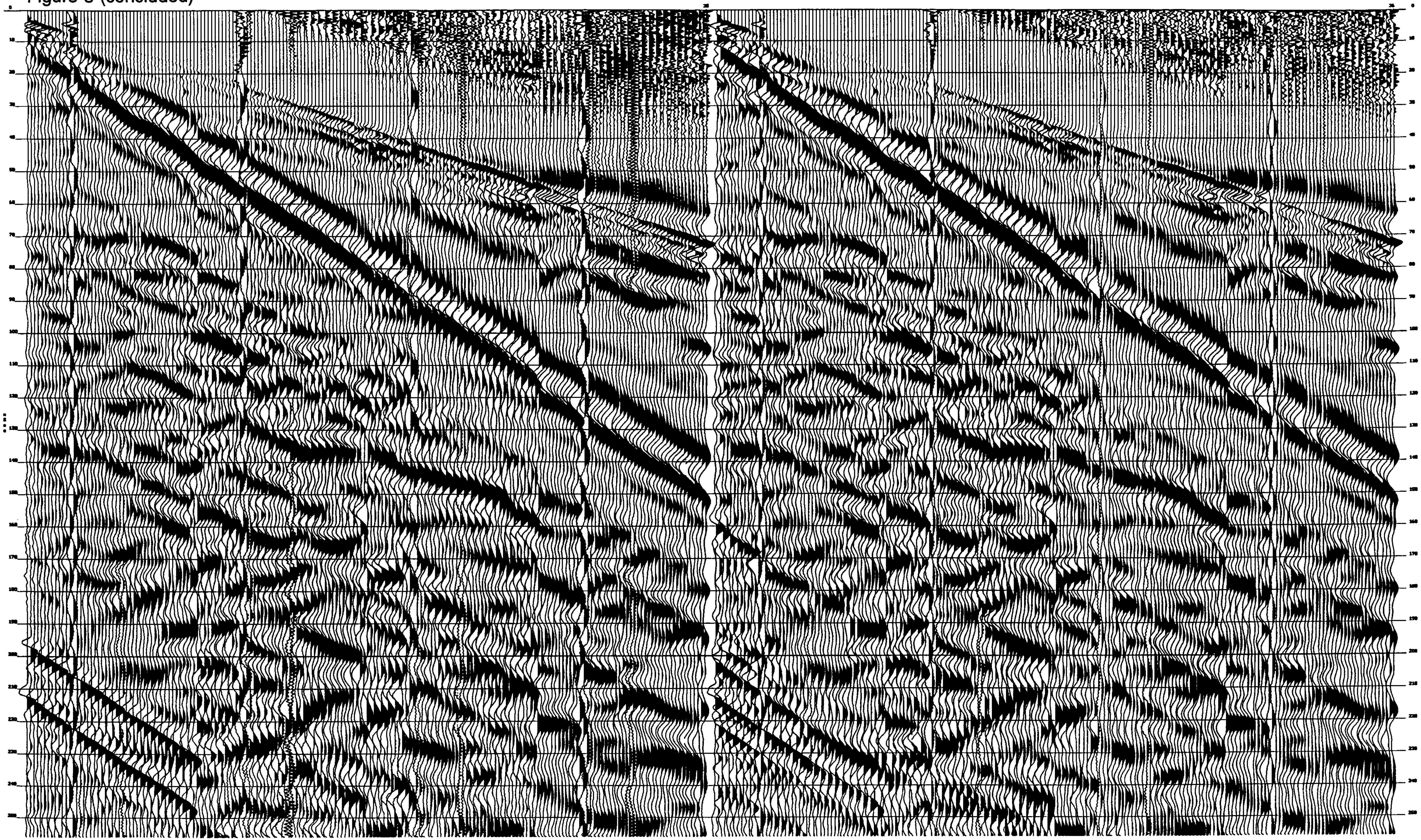

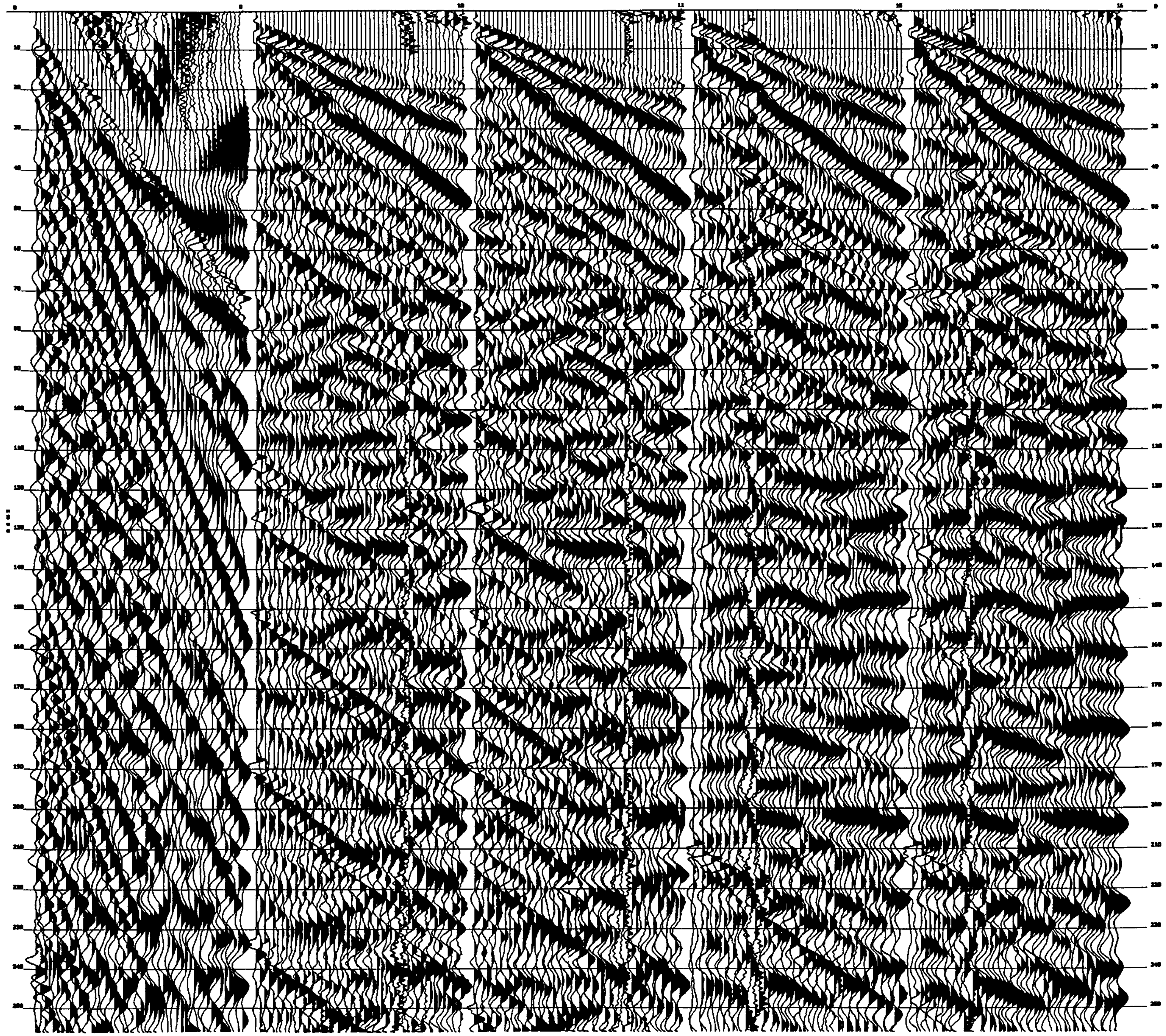
Figure 4

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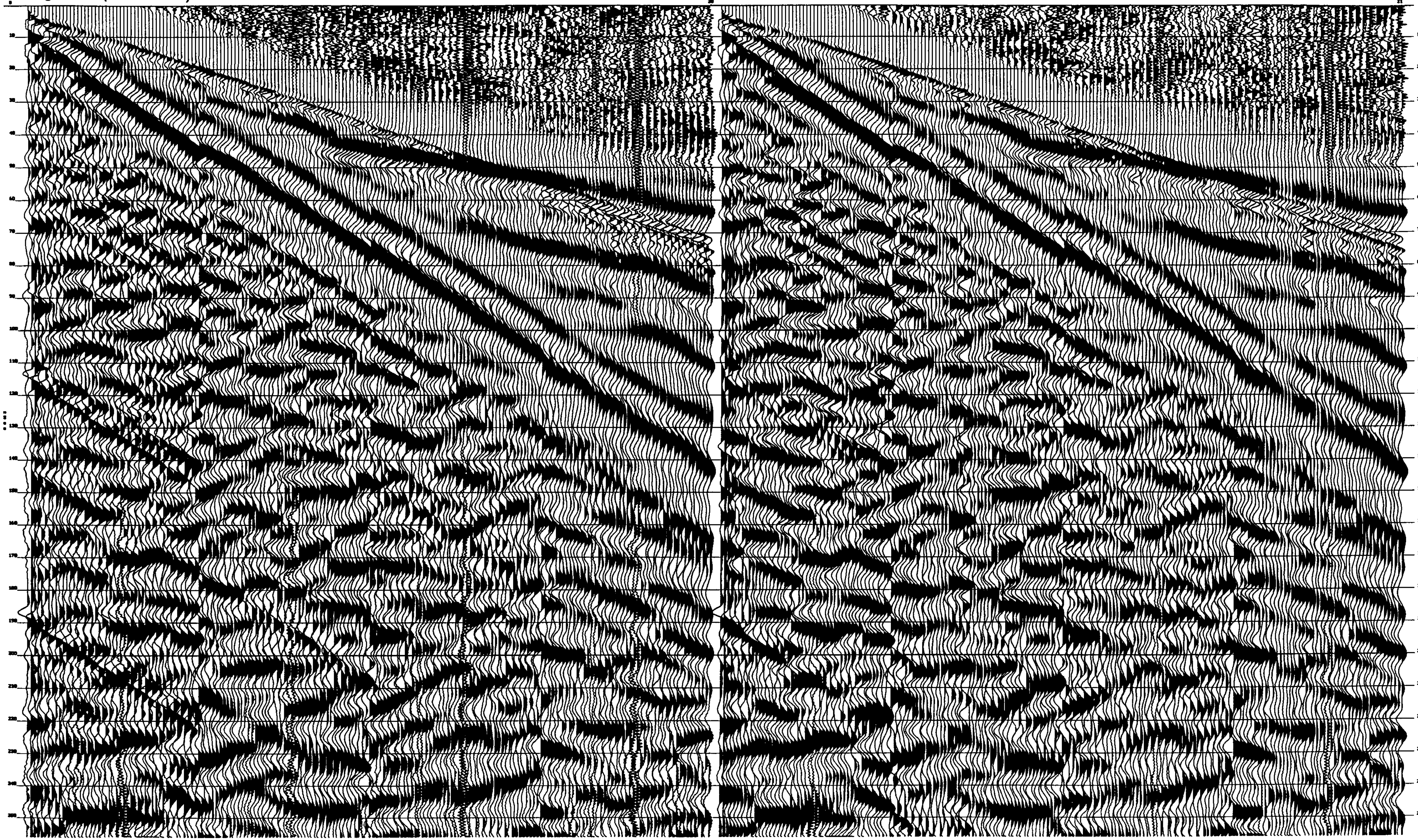

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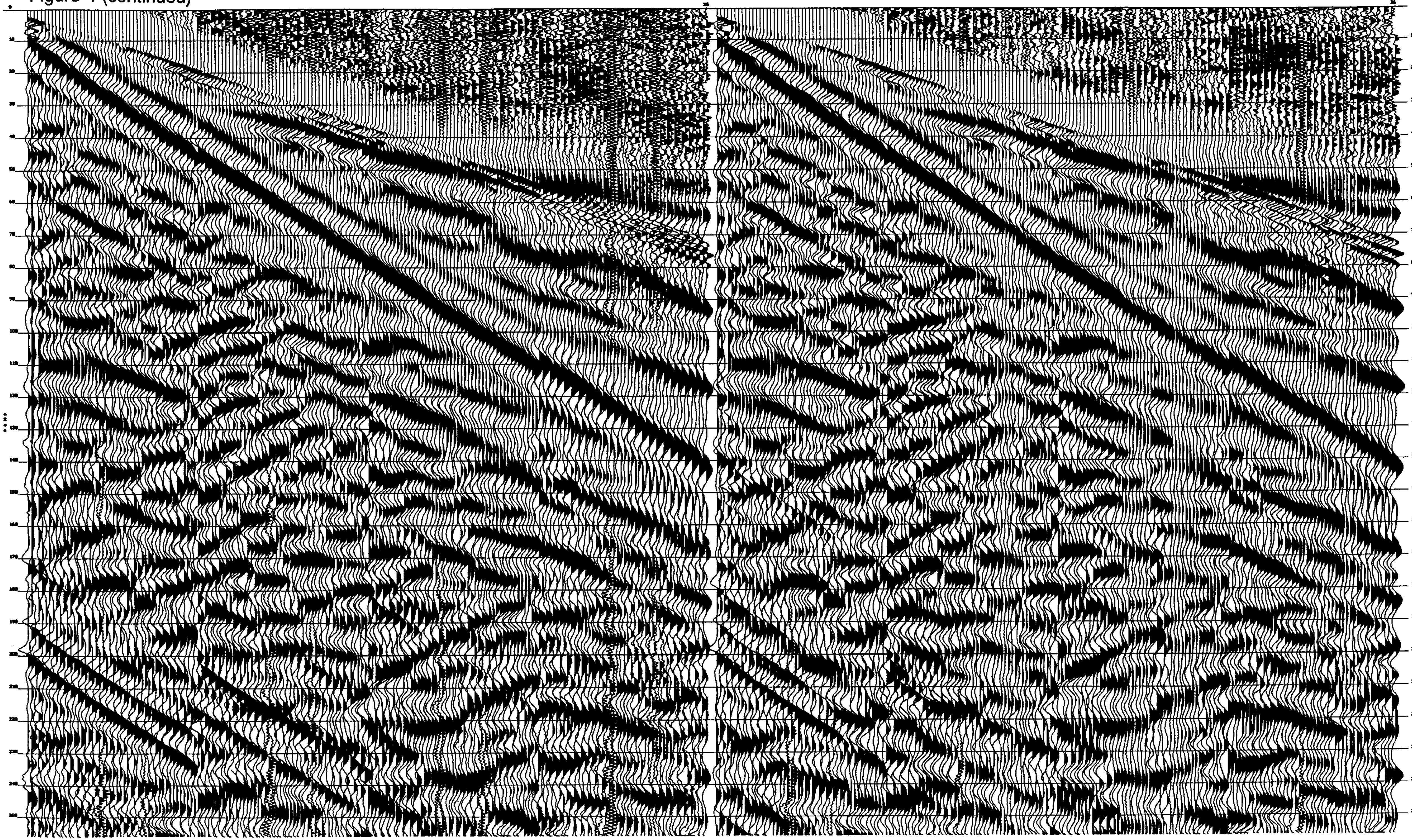

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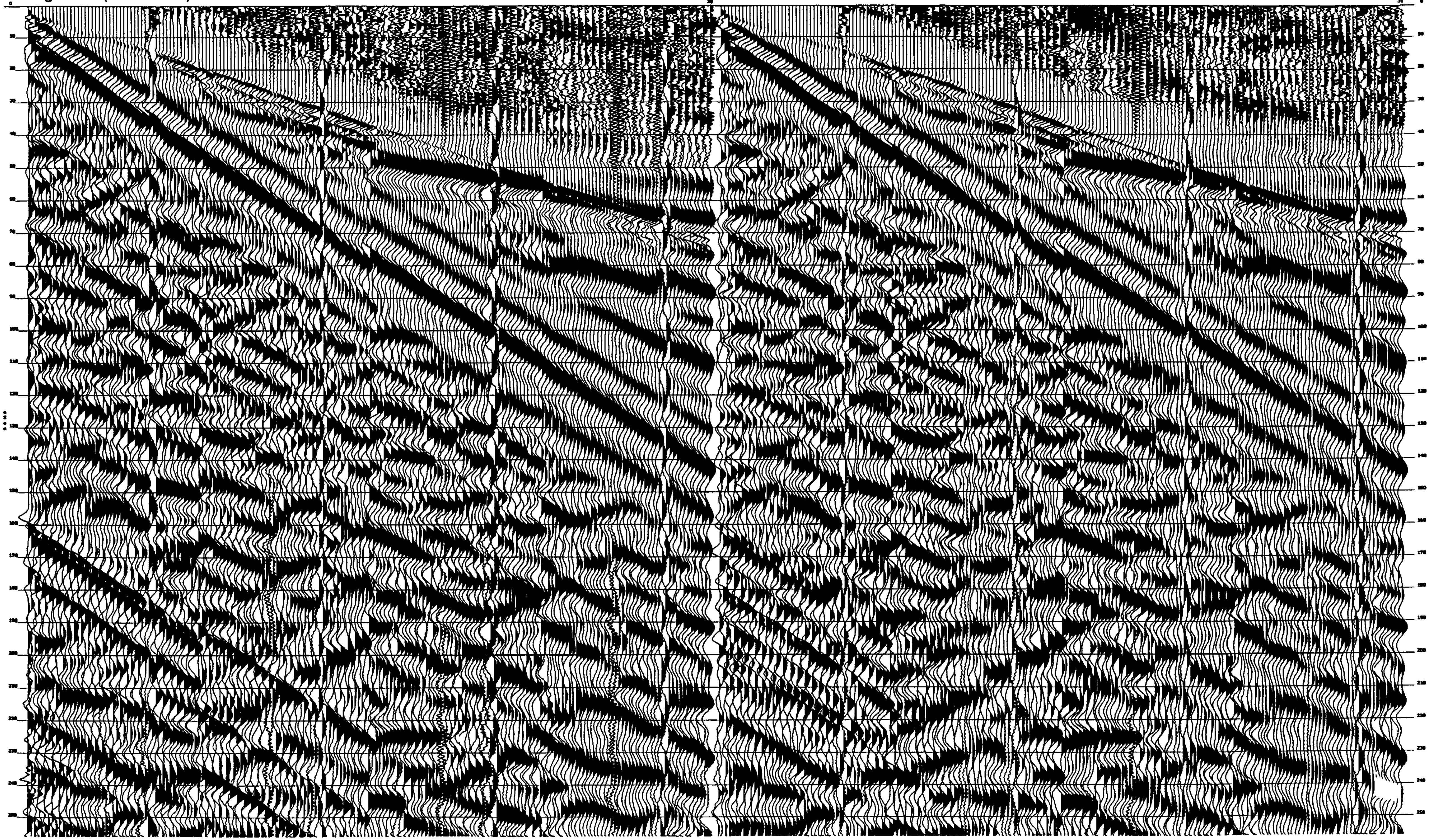

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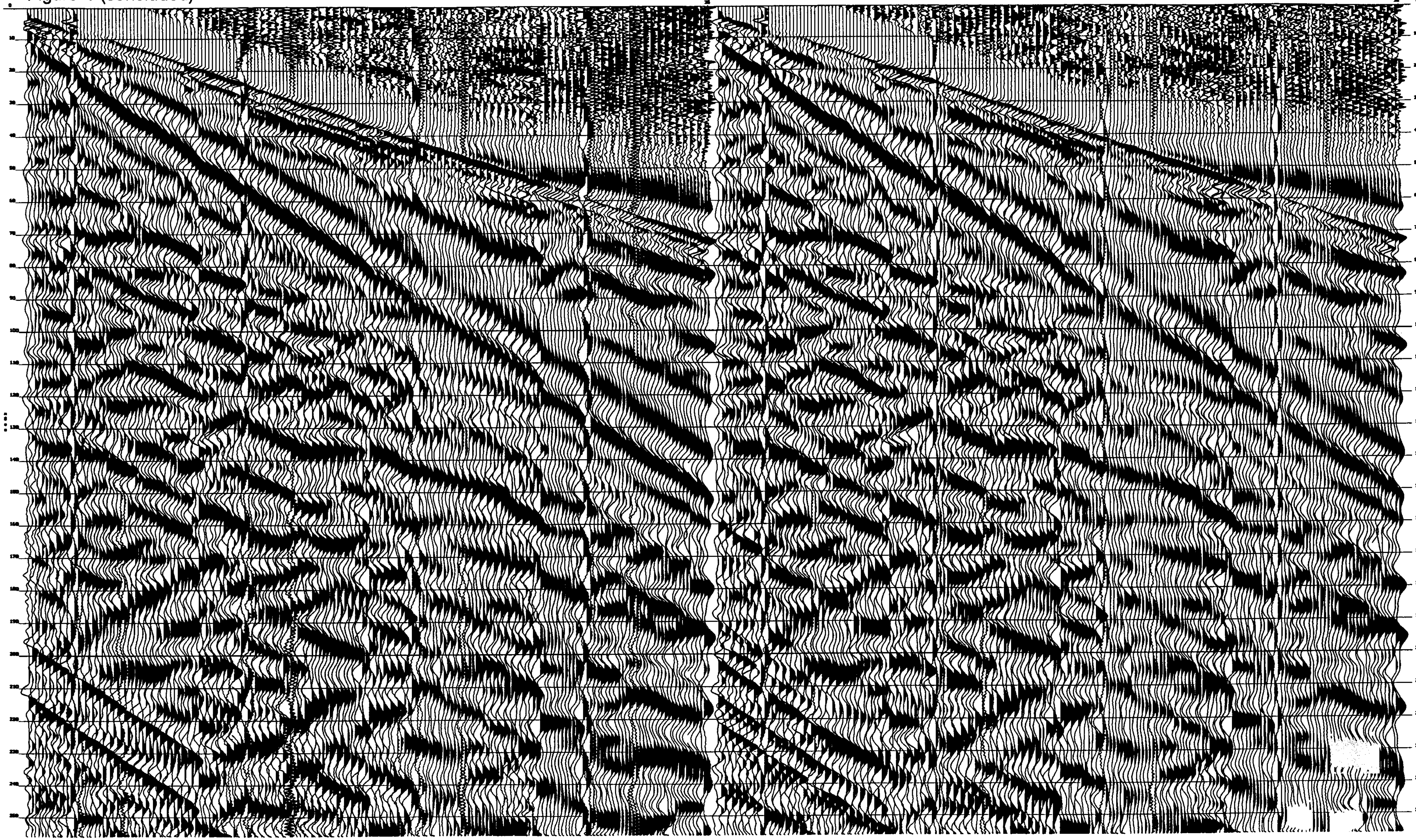

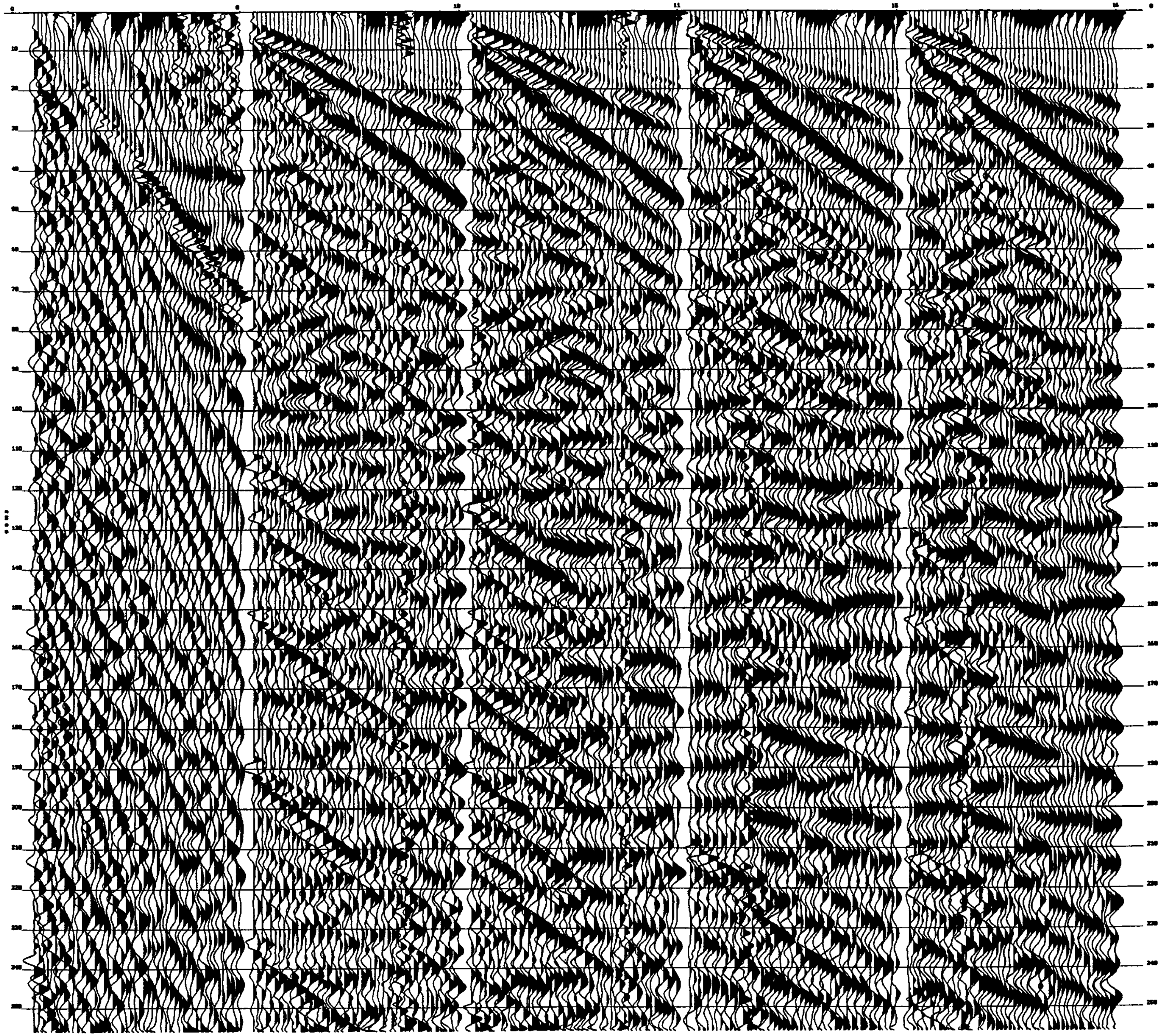

Figure 5

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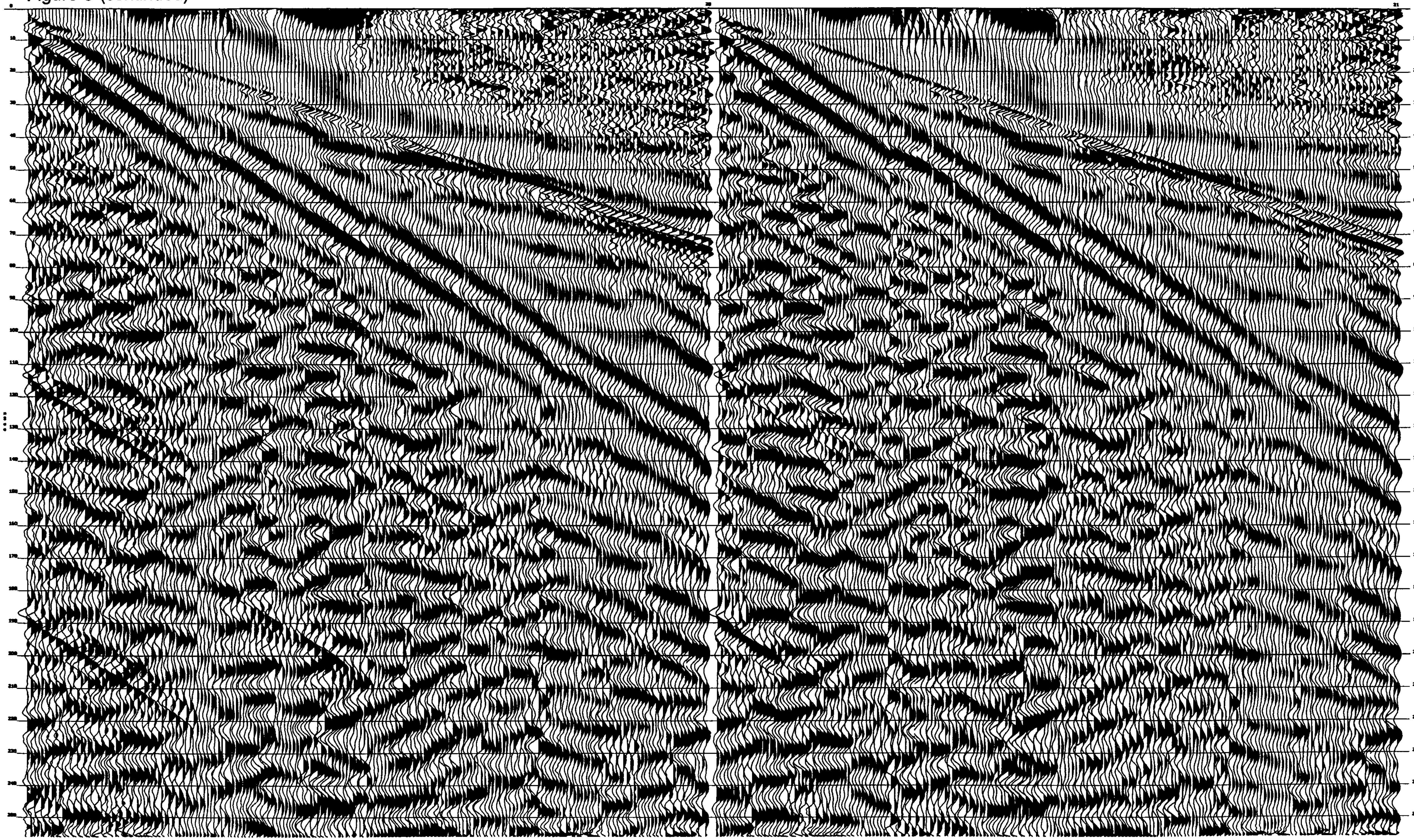

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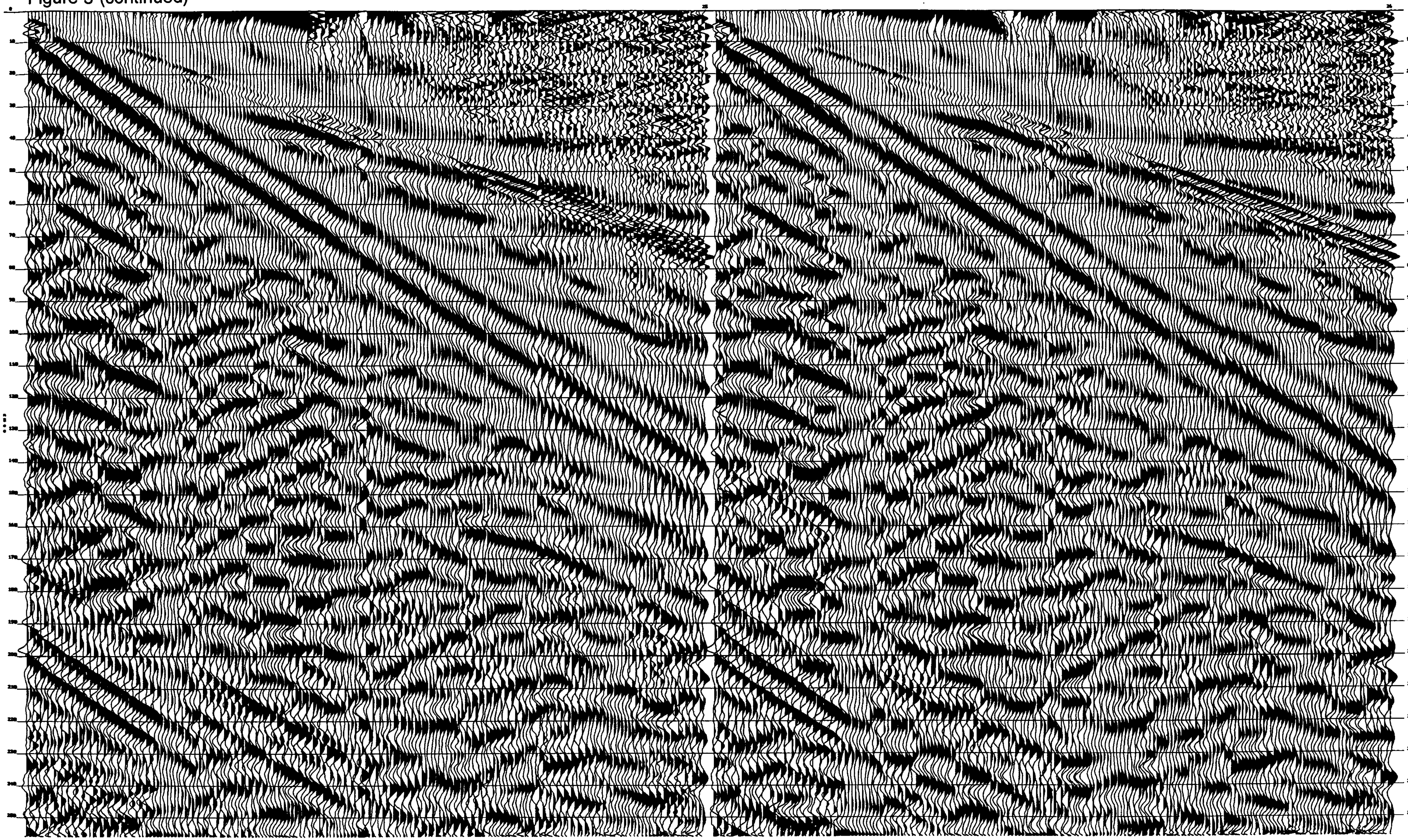

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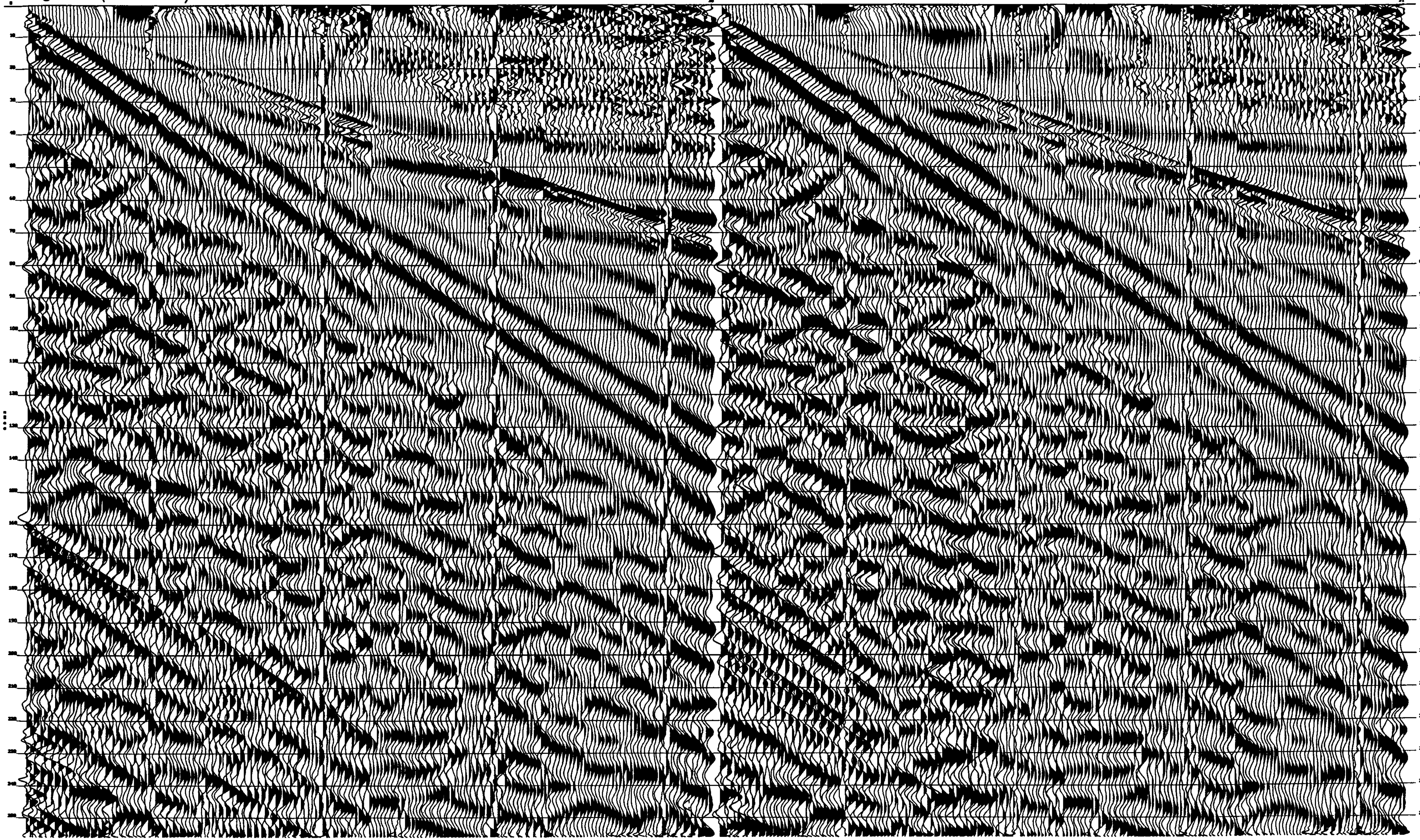

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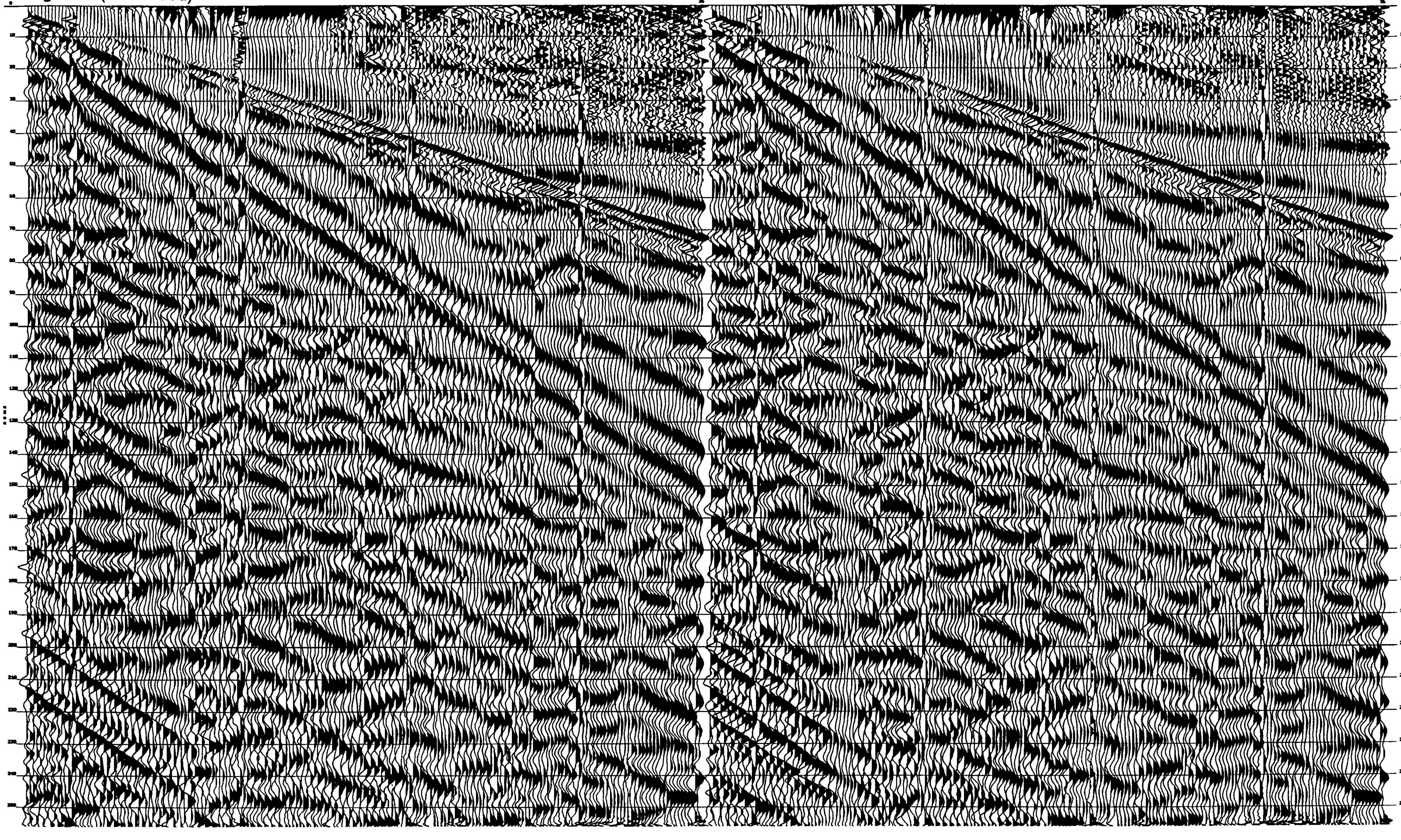

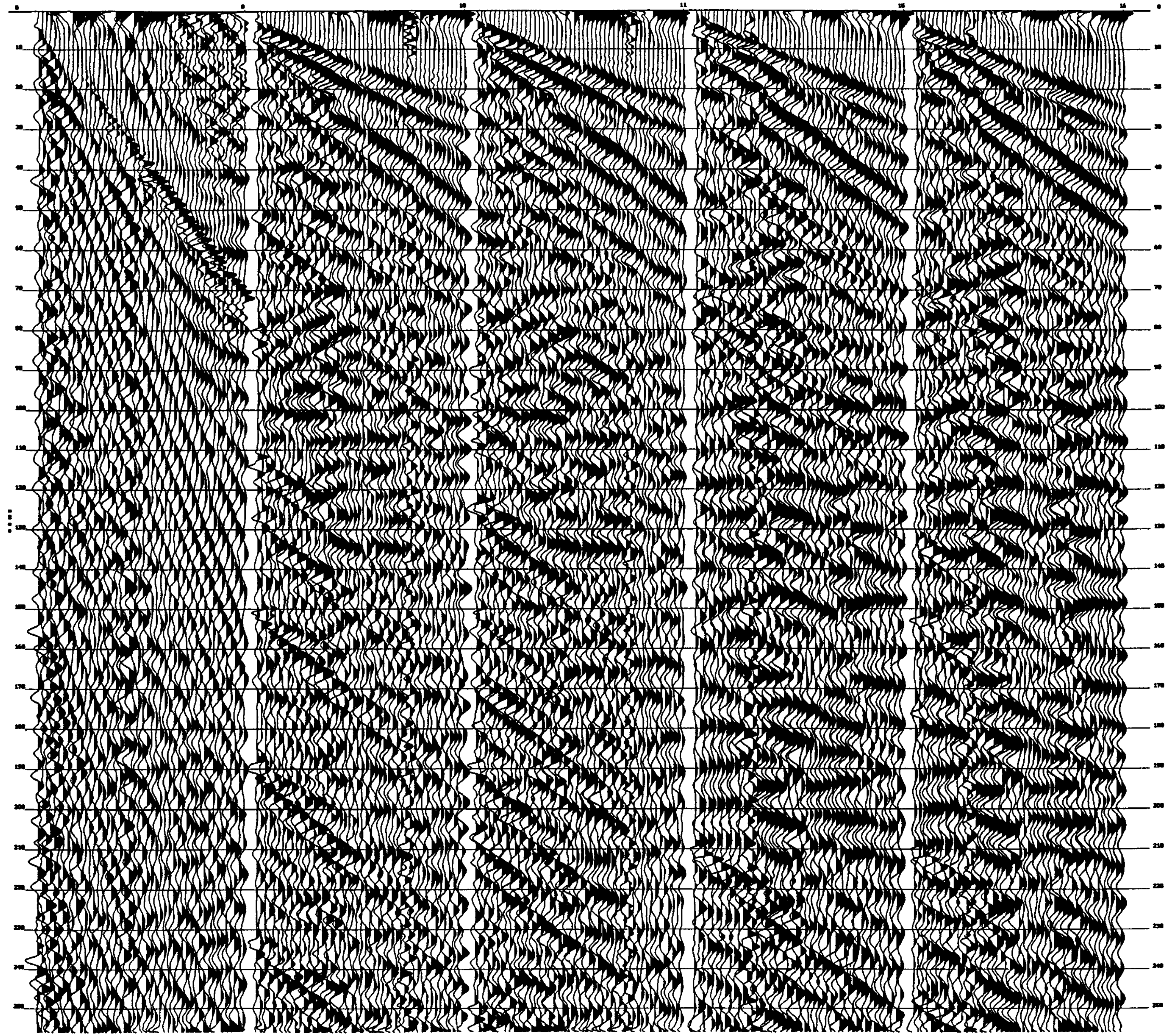

Figure 6

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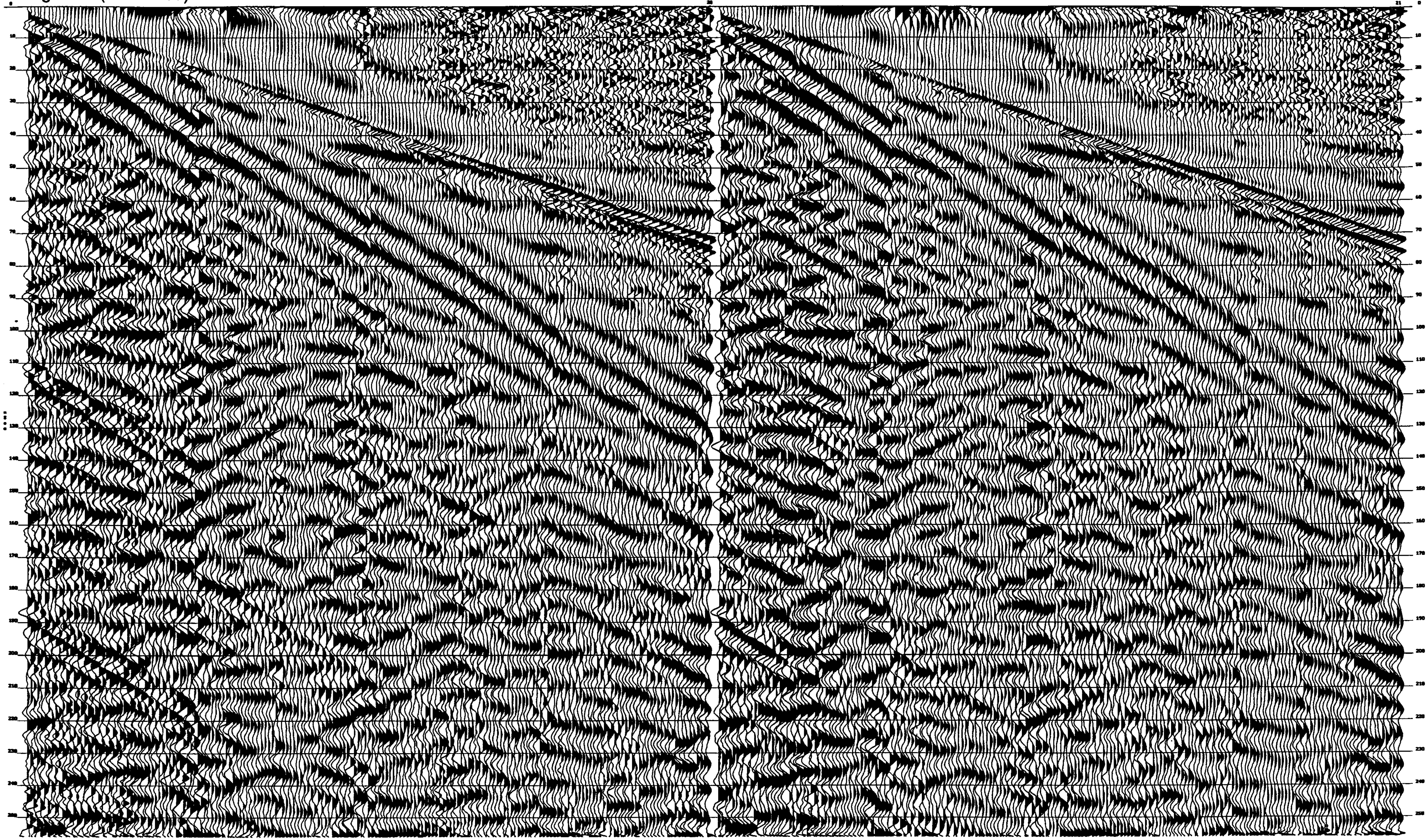

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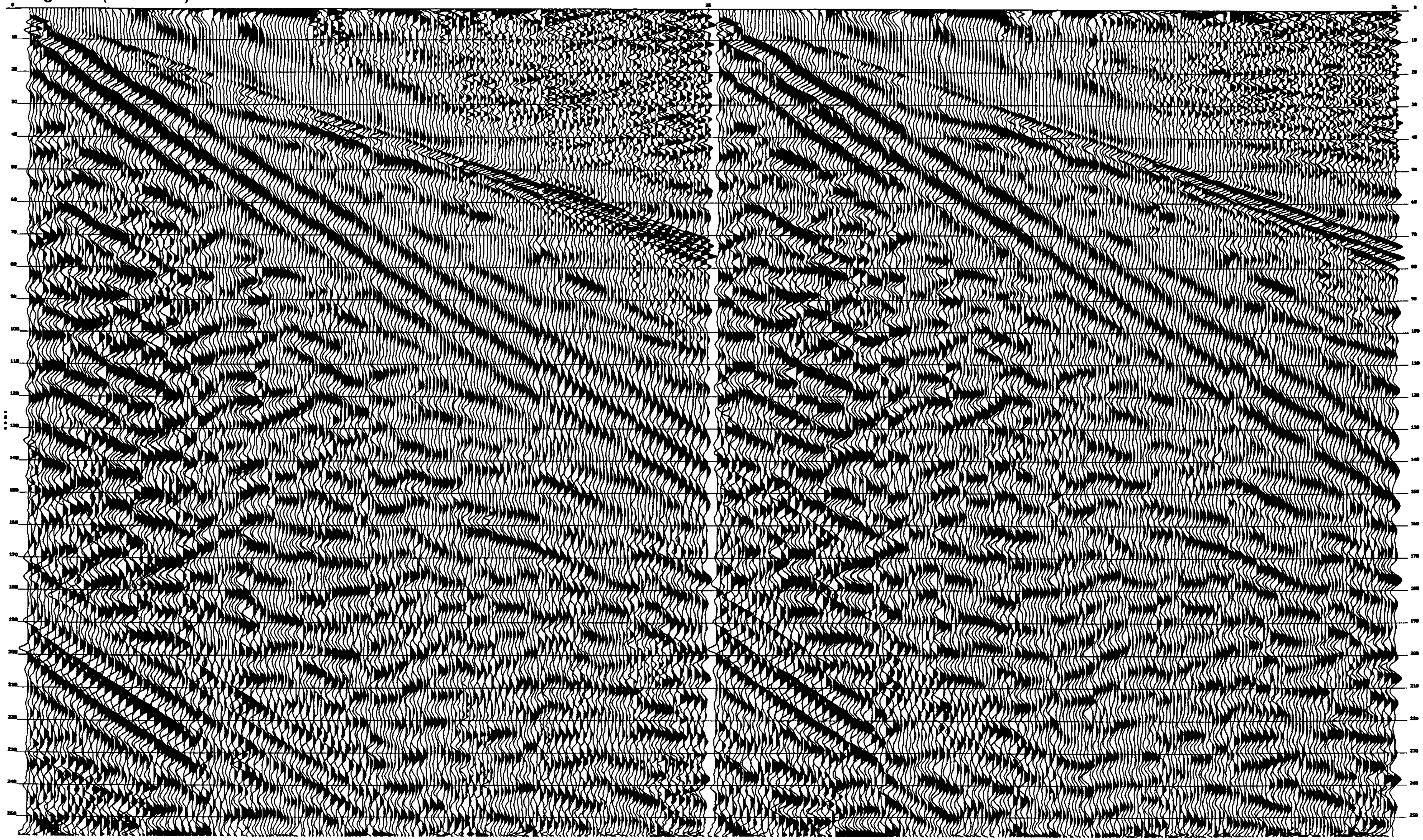

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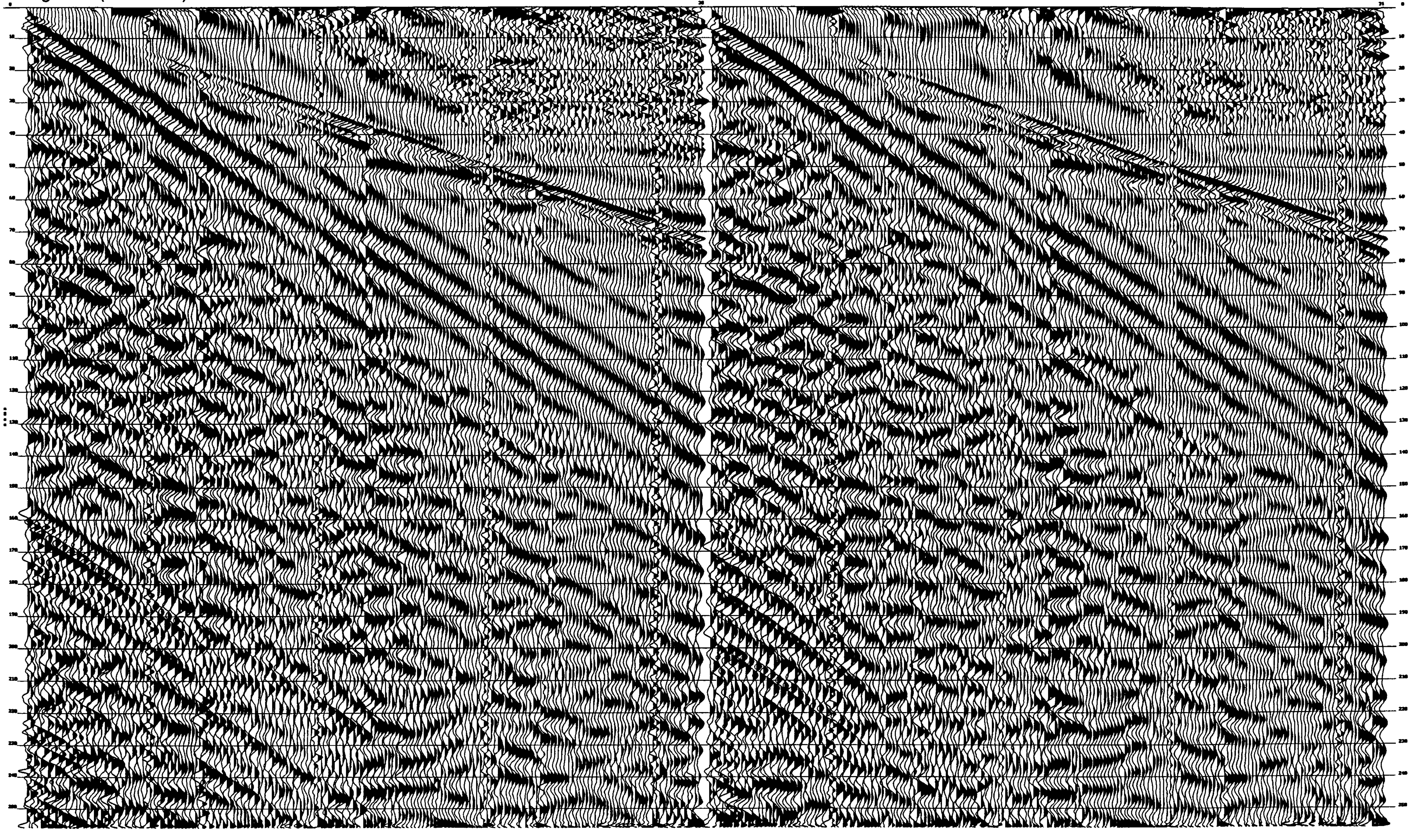

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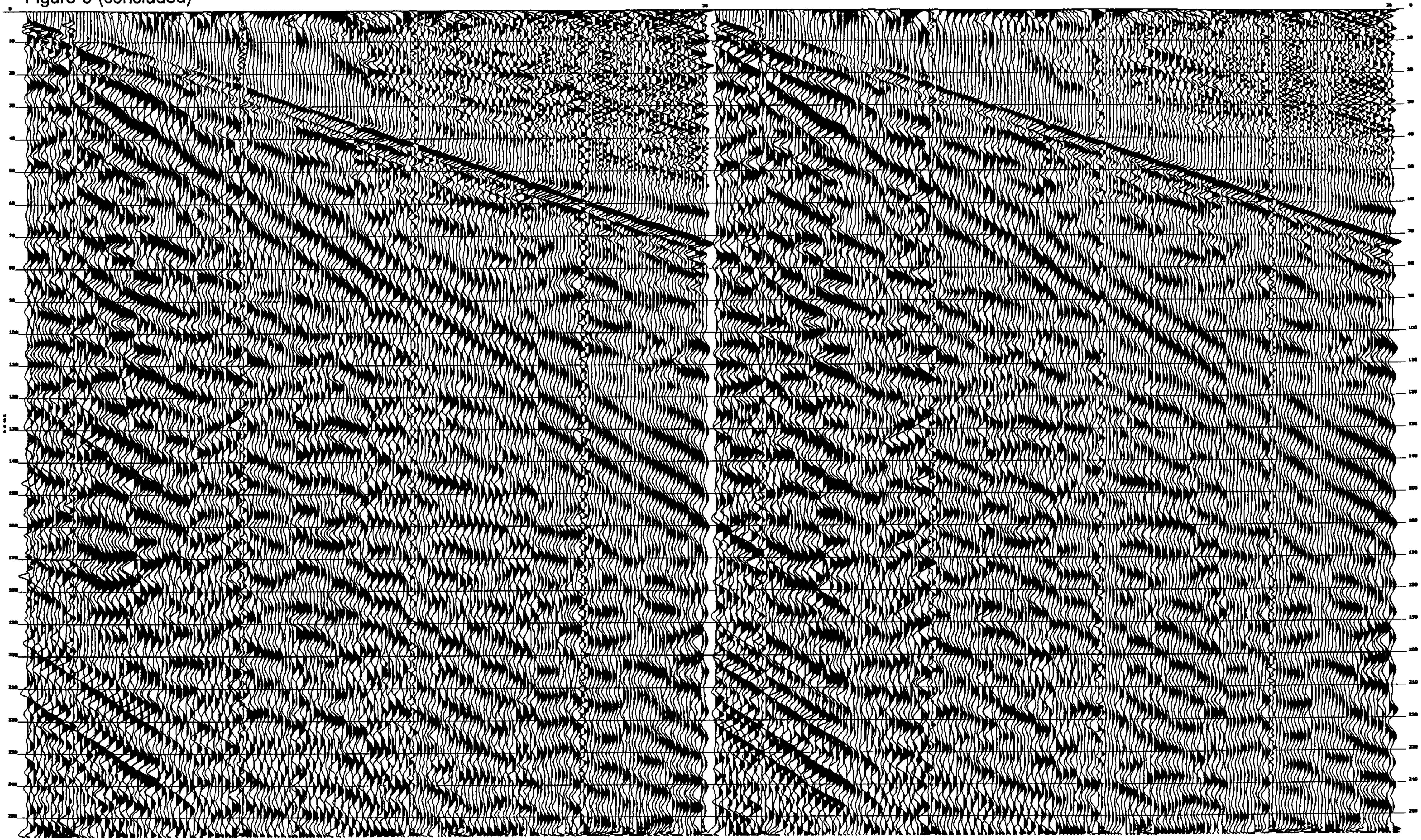

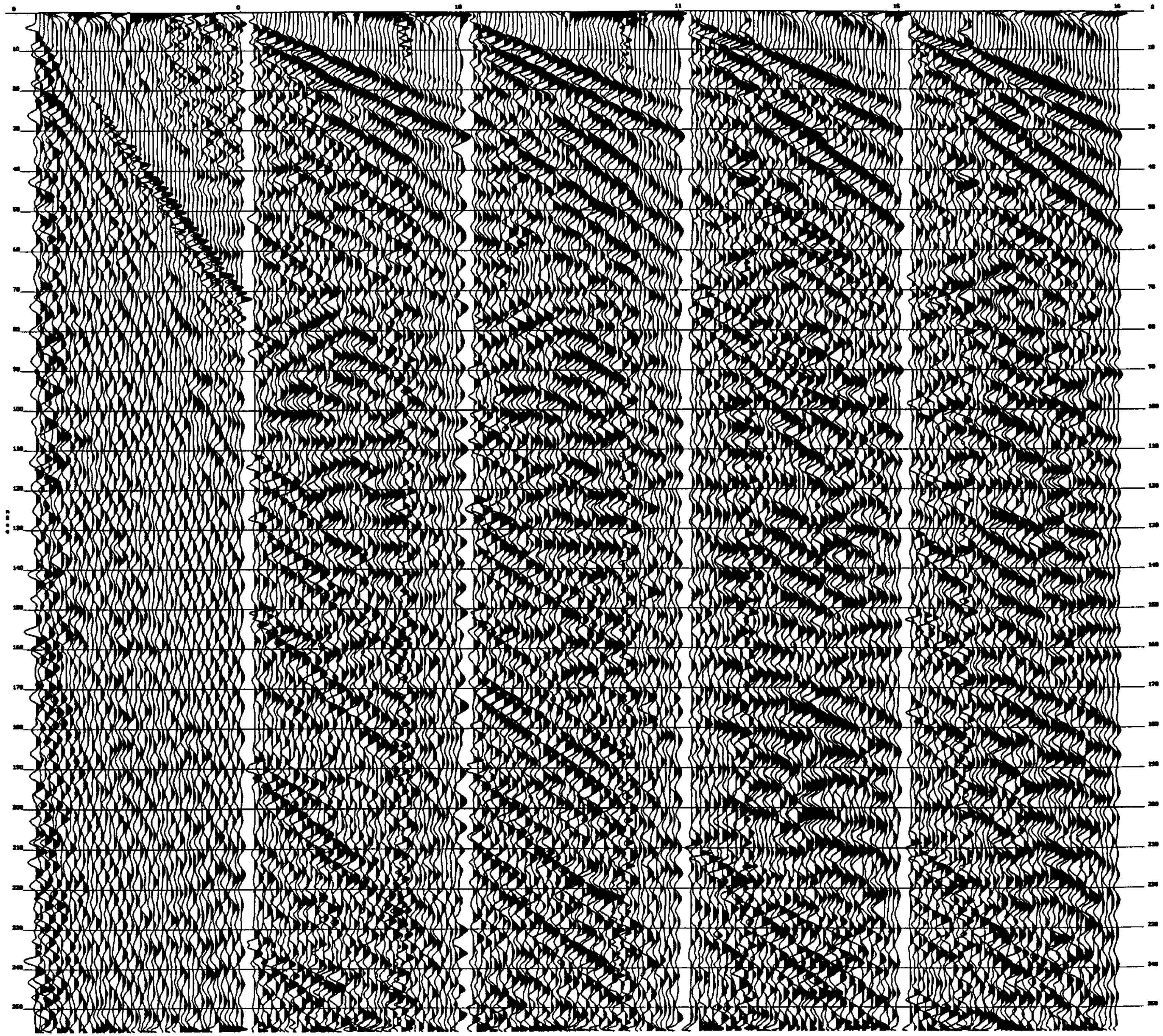

Figure 7

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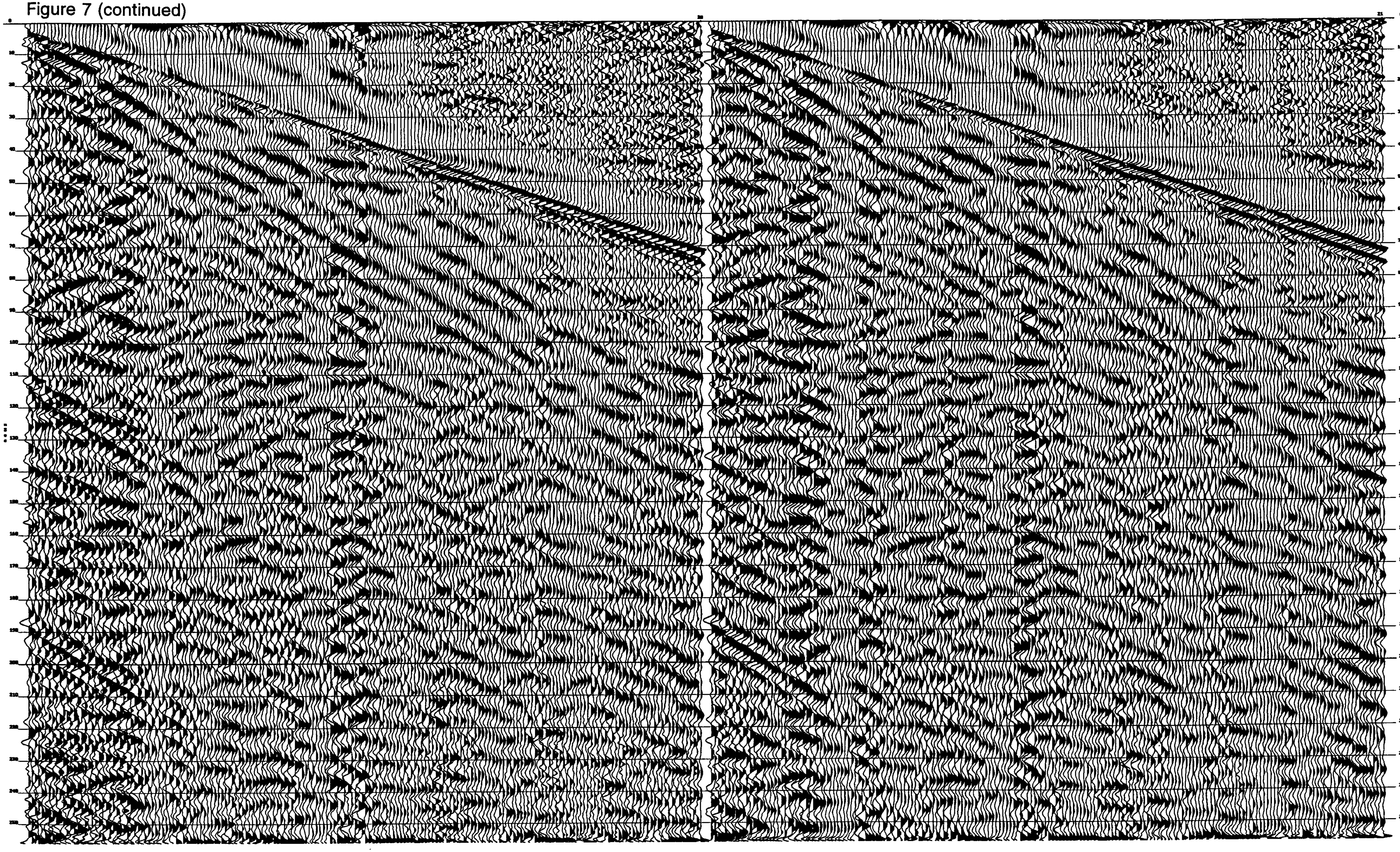

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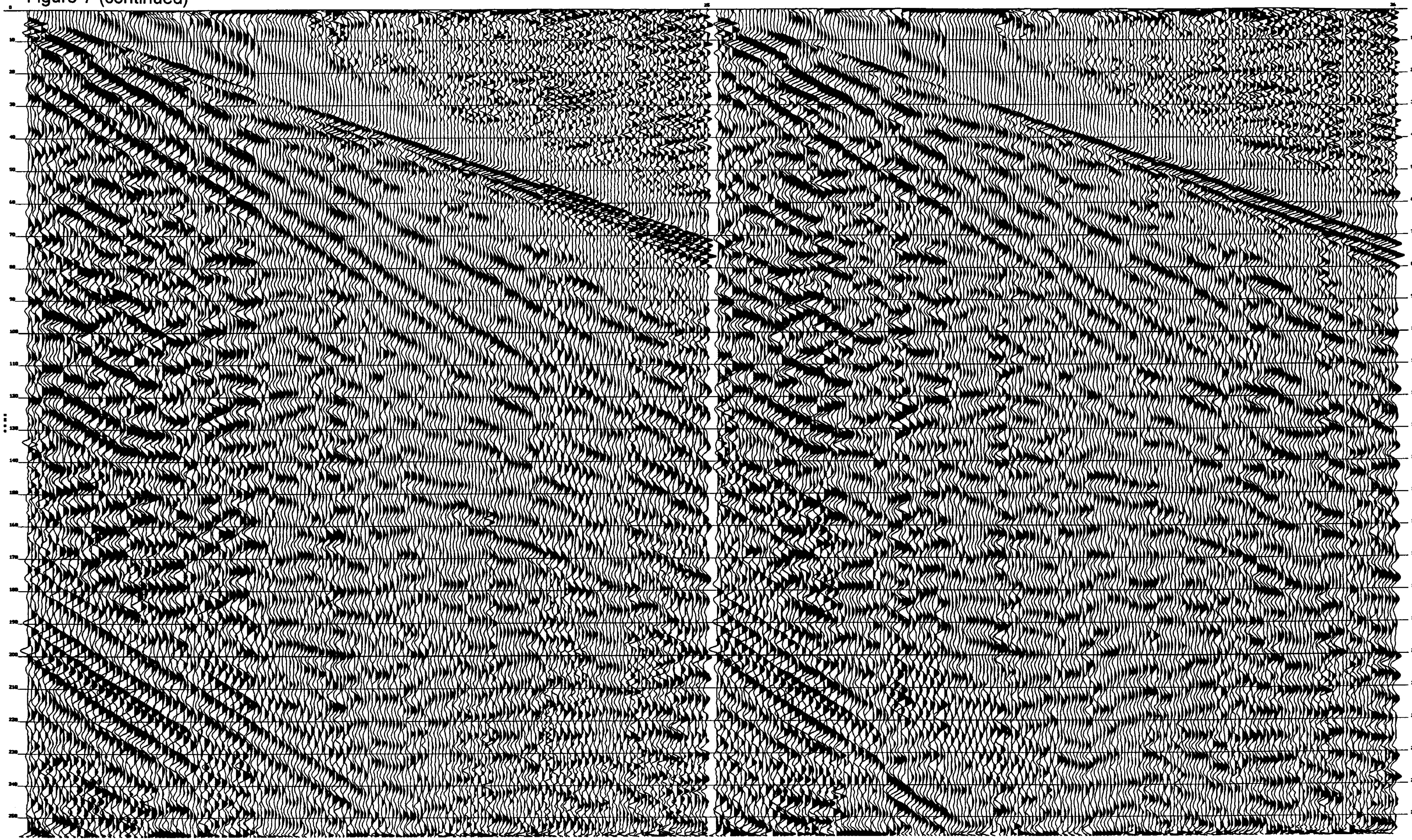

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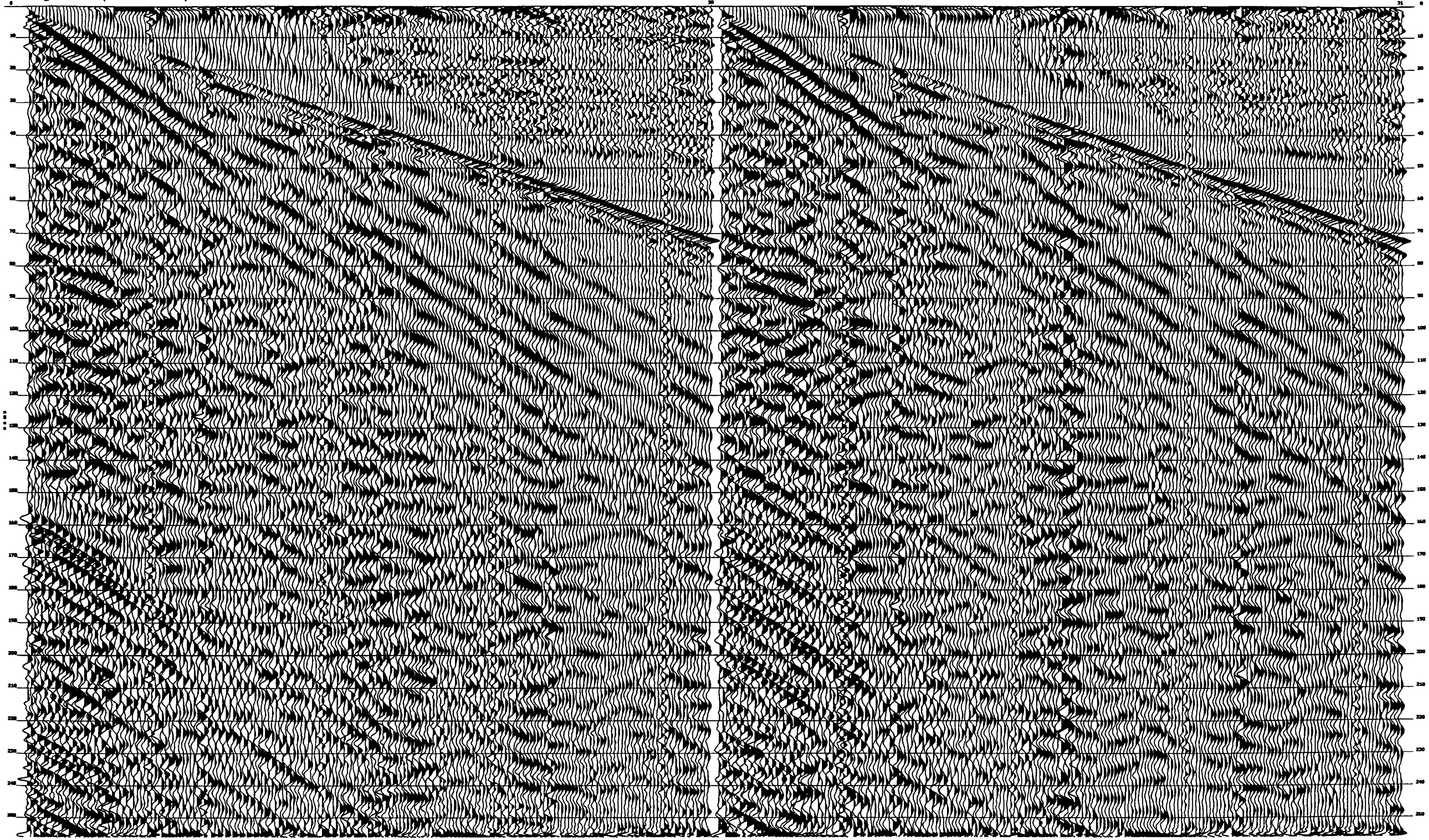

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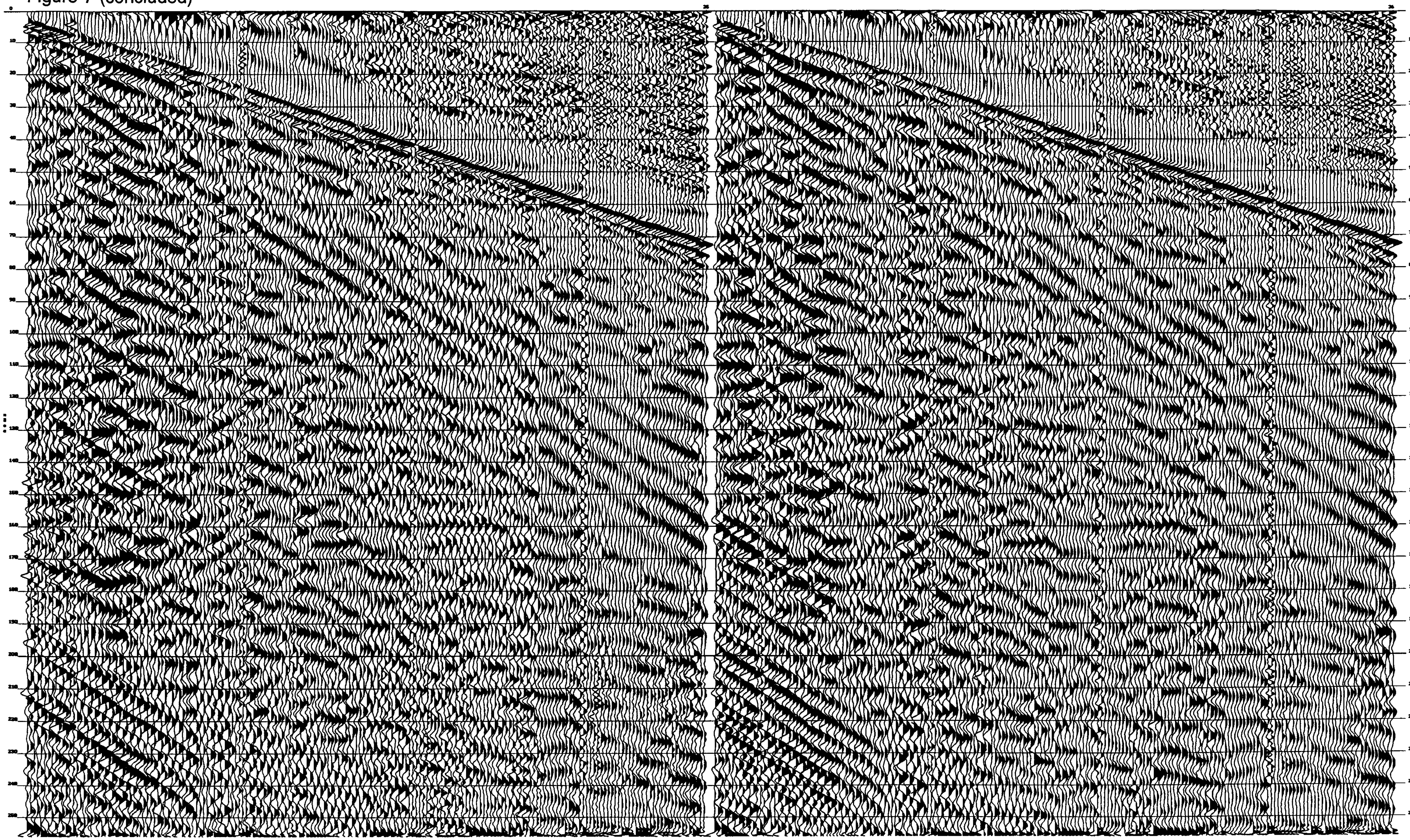

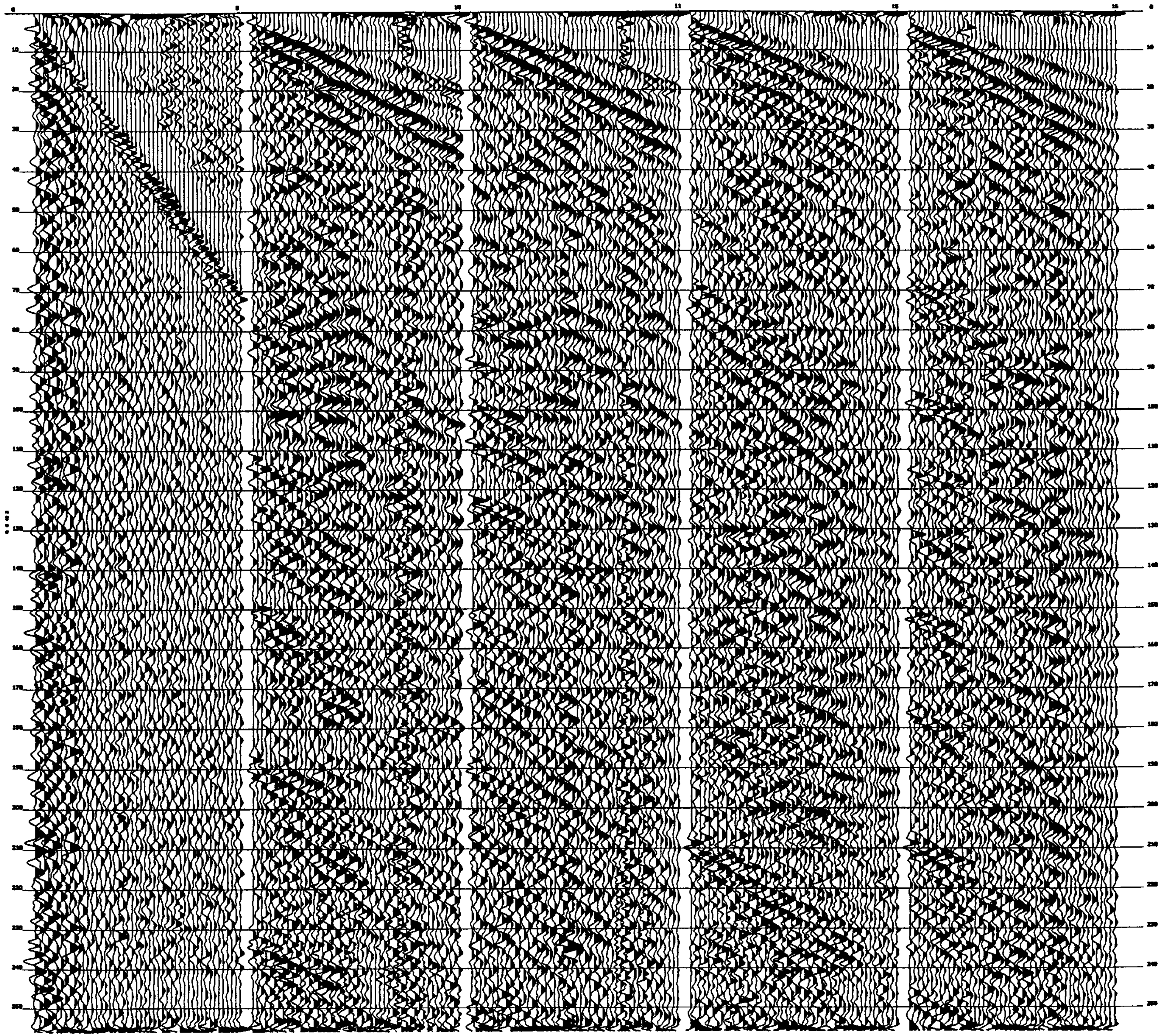

Figure 8

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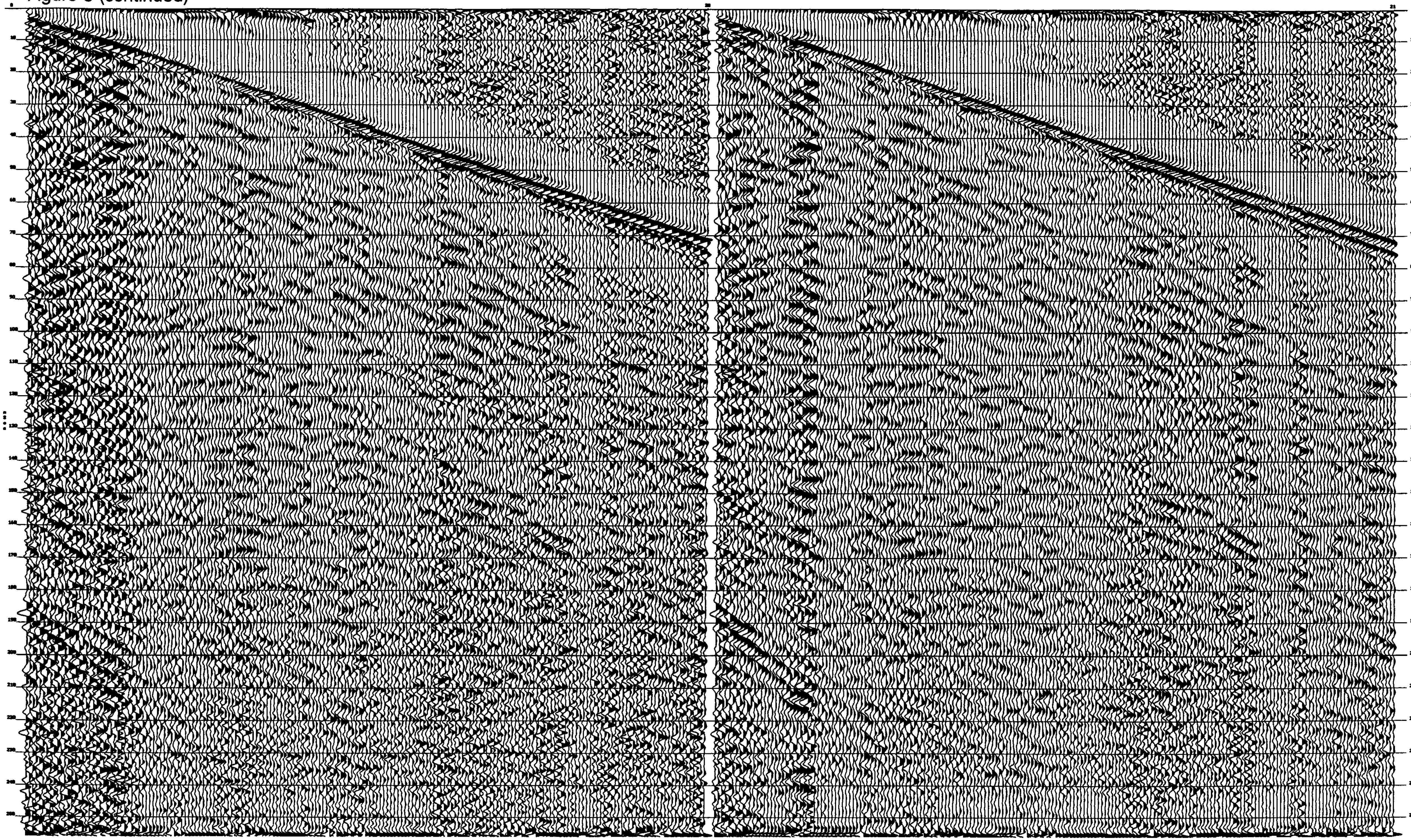

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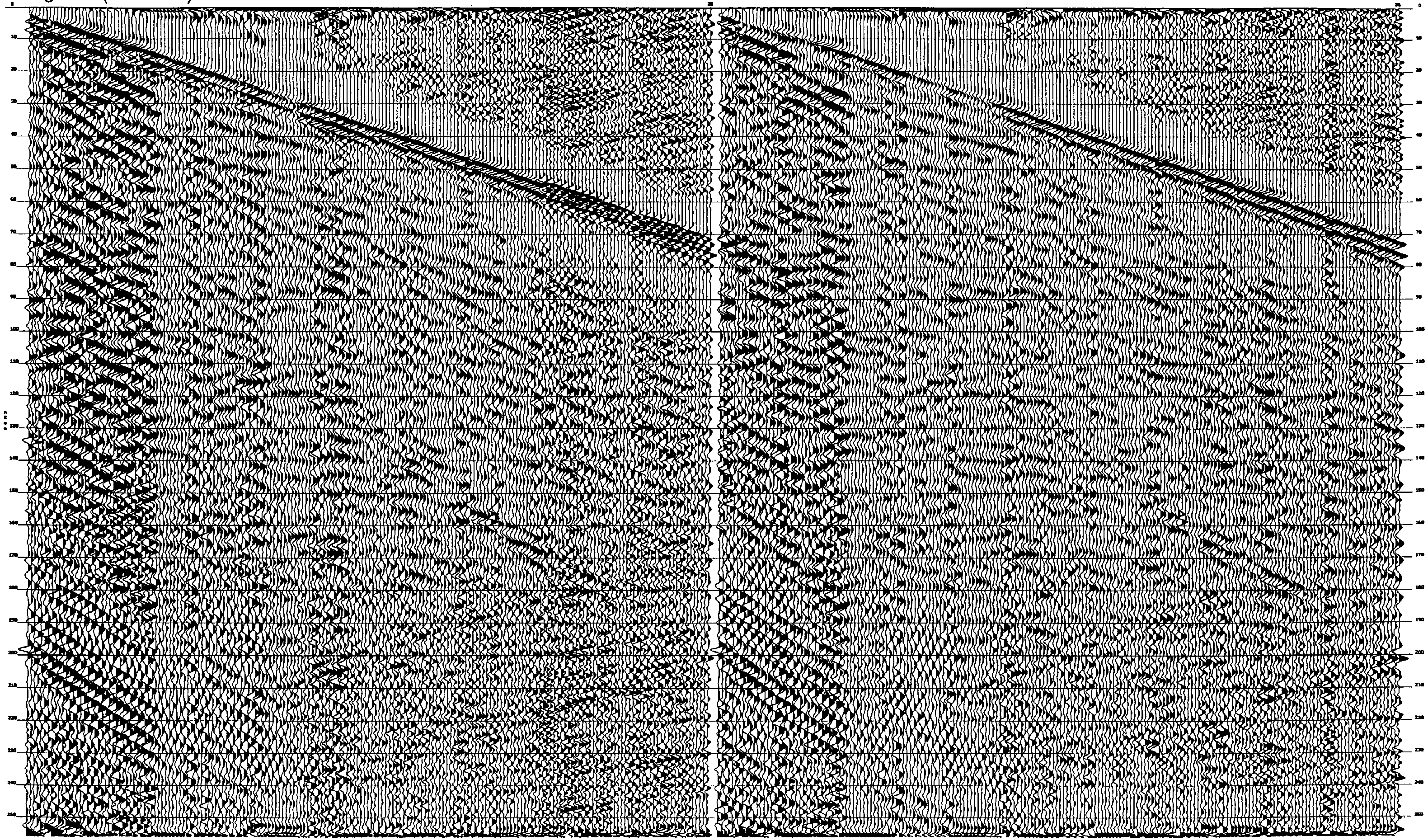

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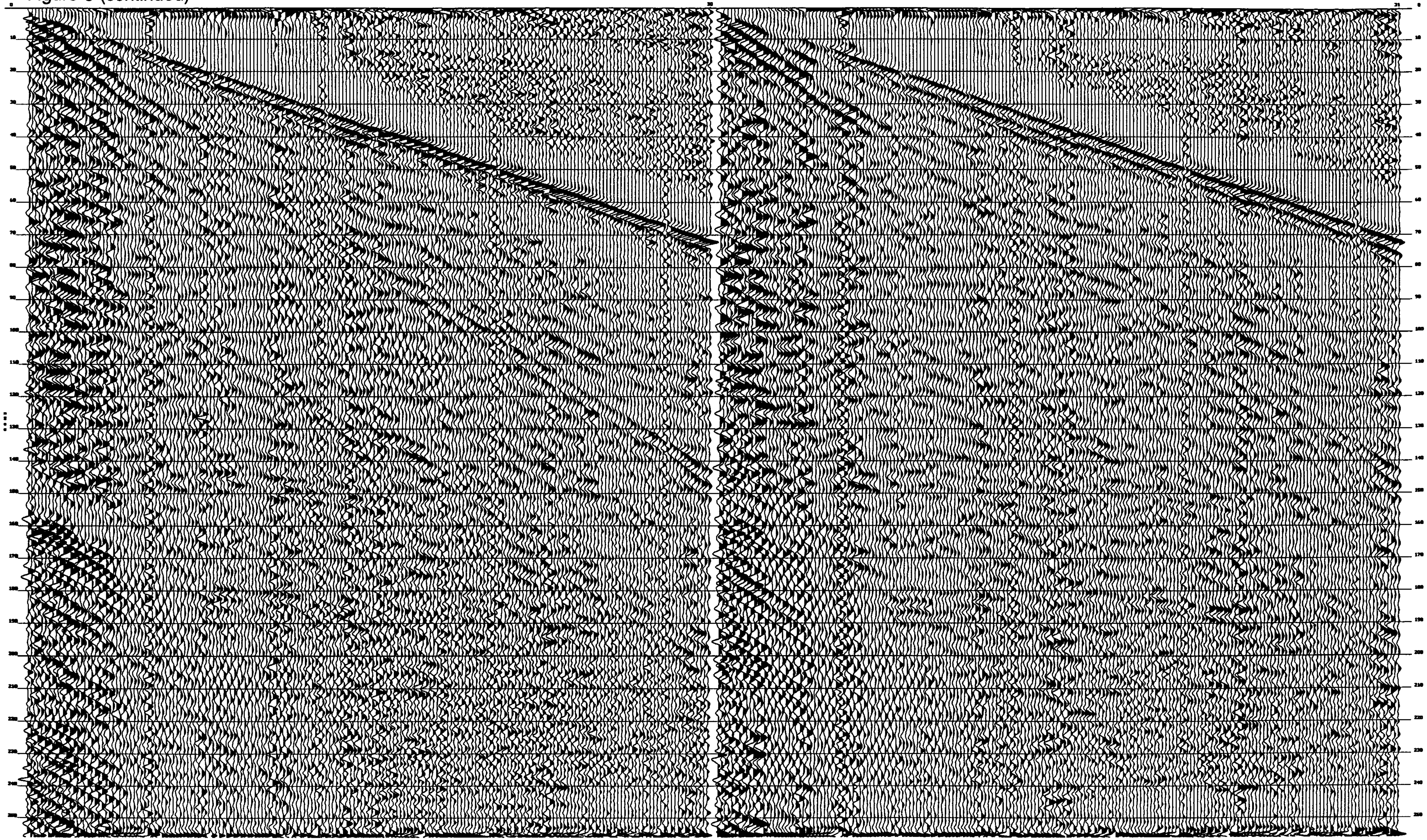

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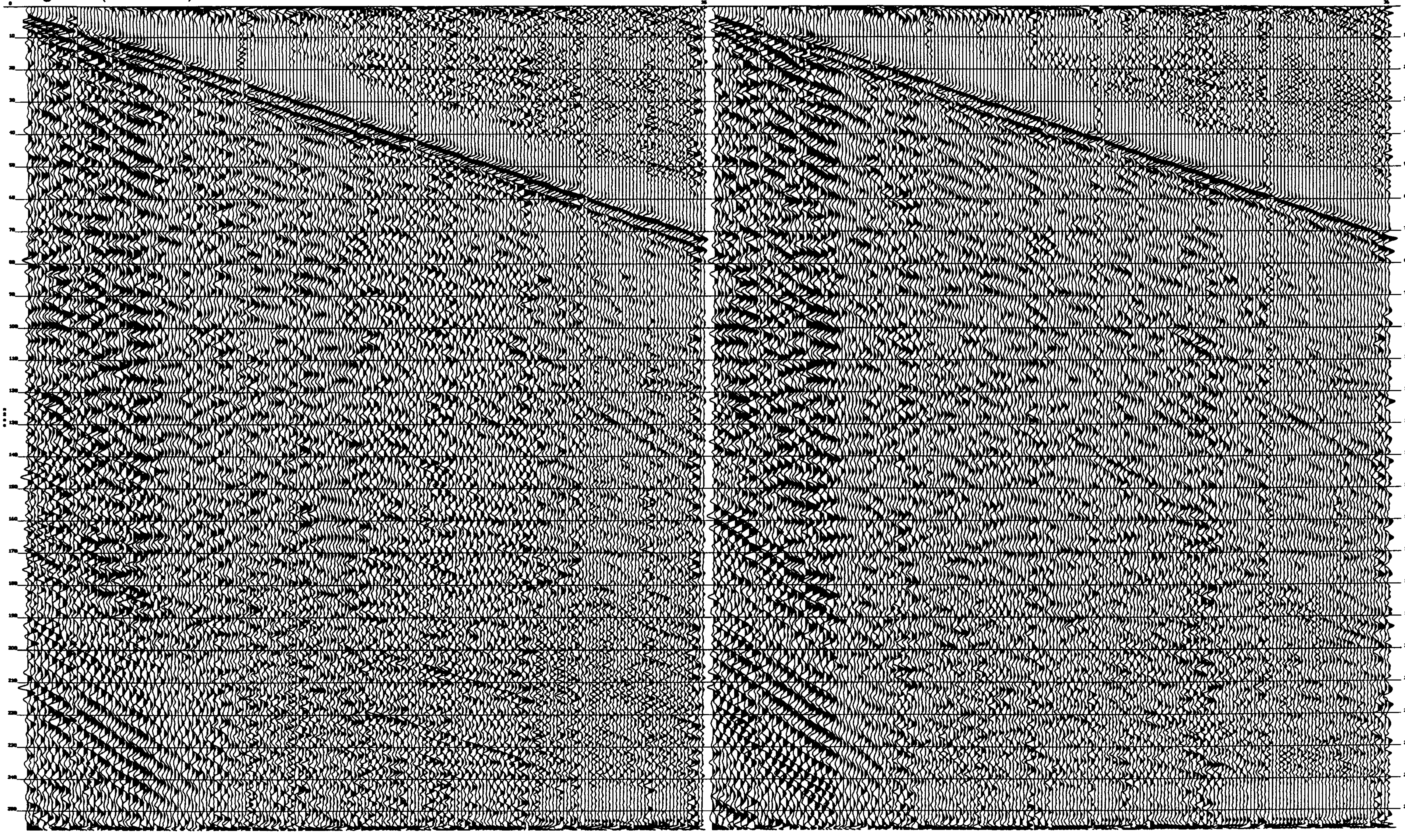

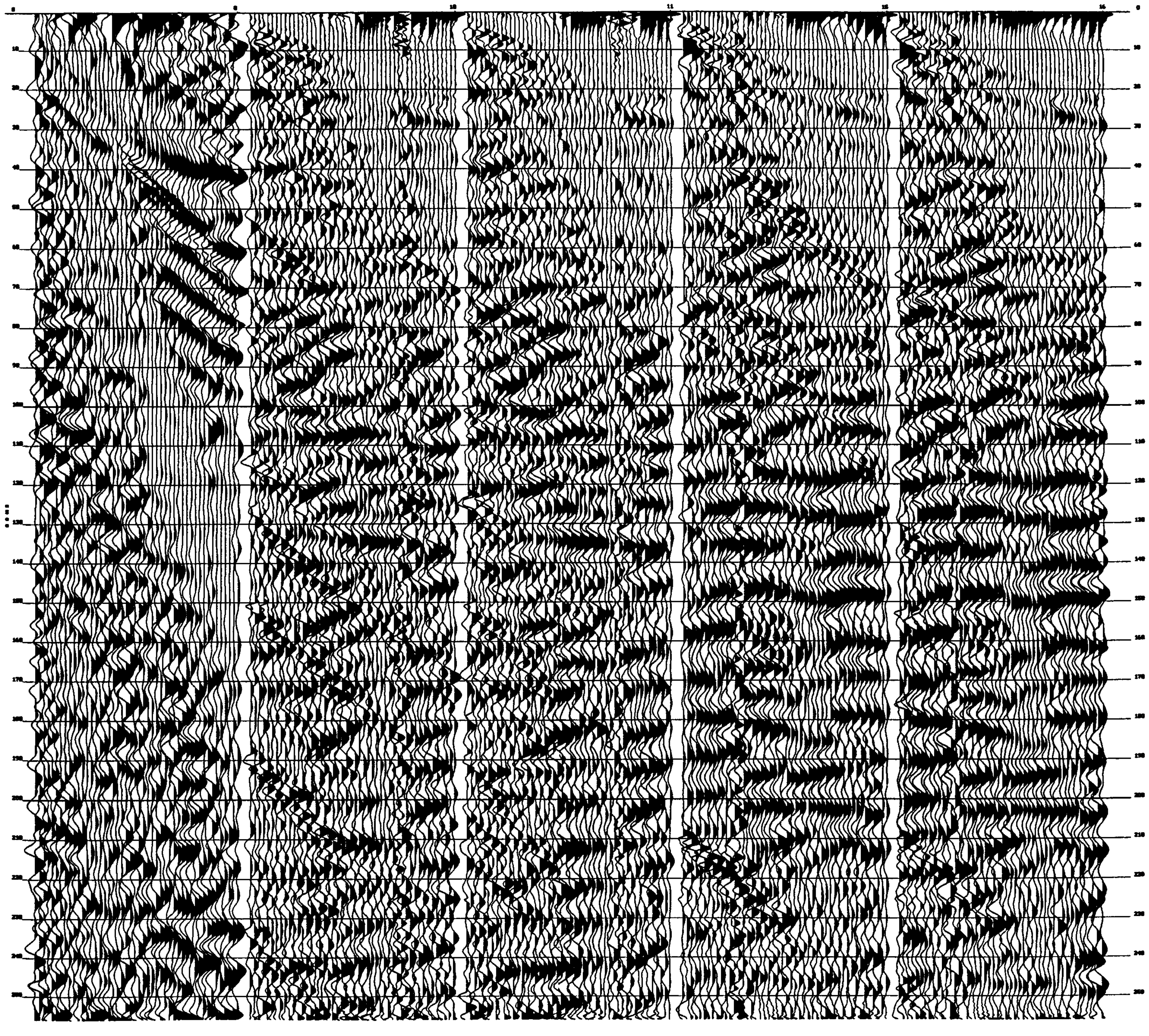

Figure 9

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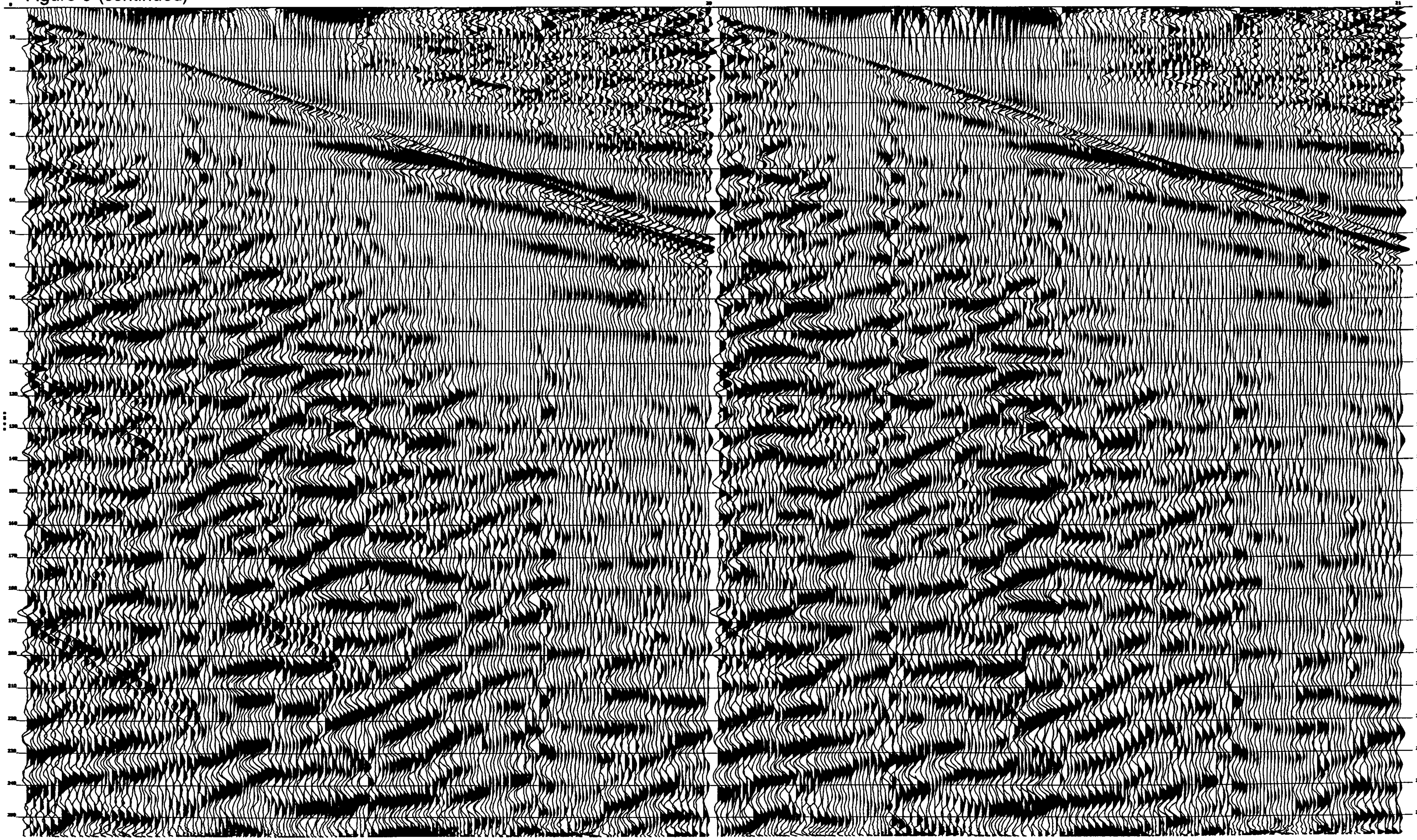

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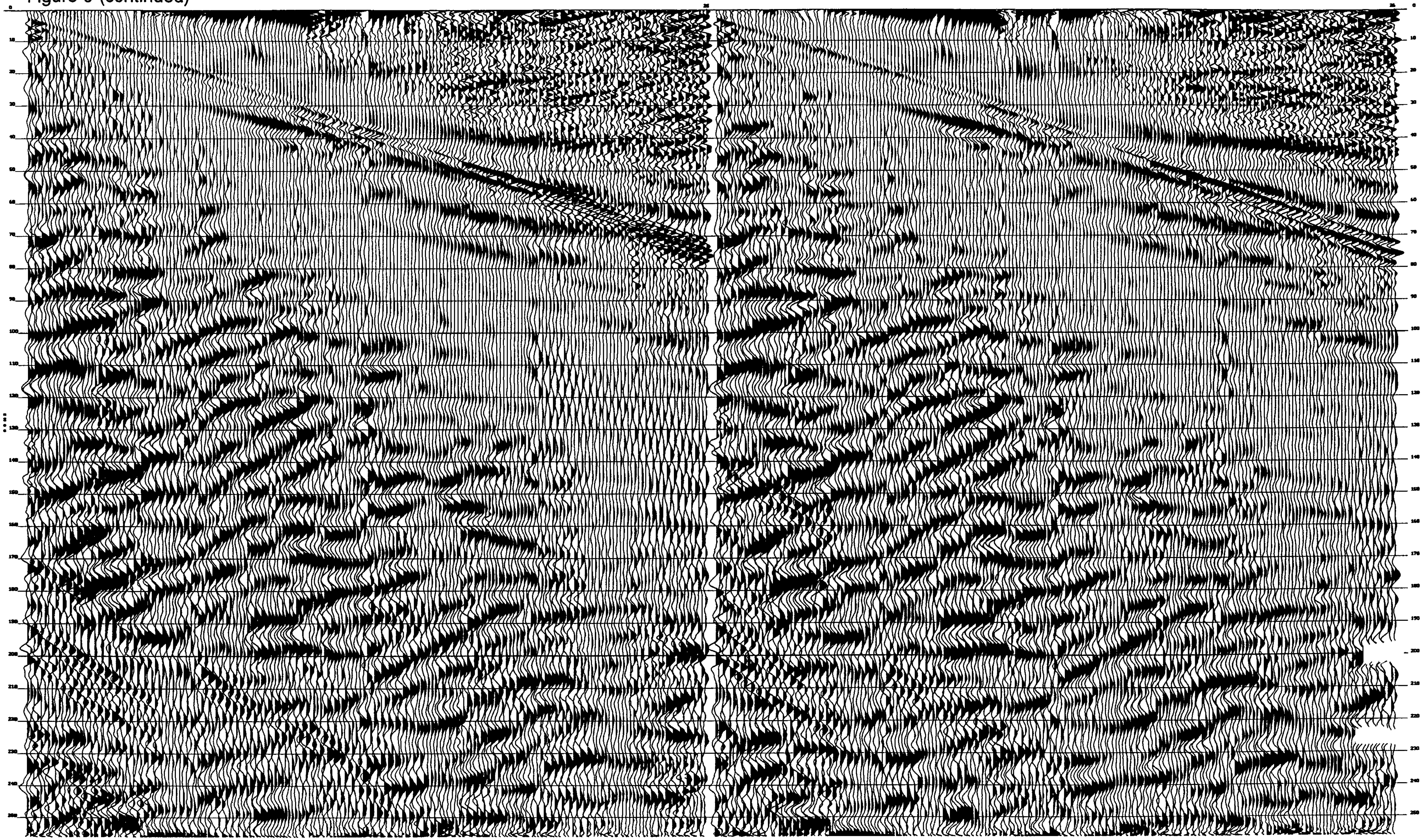

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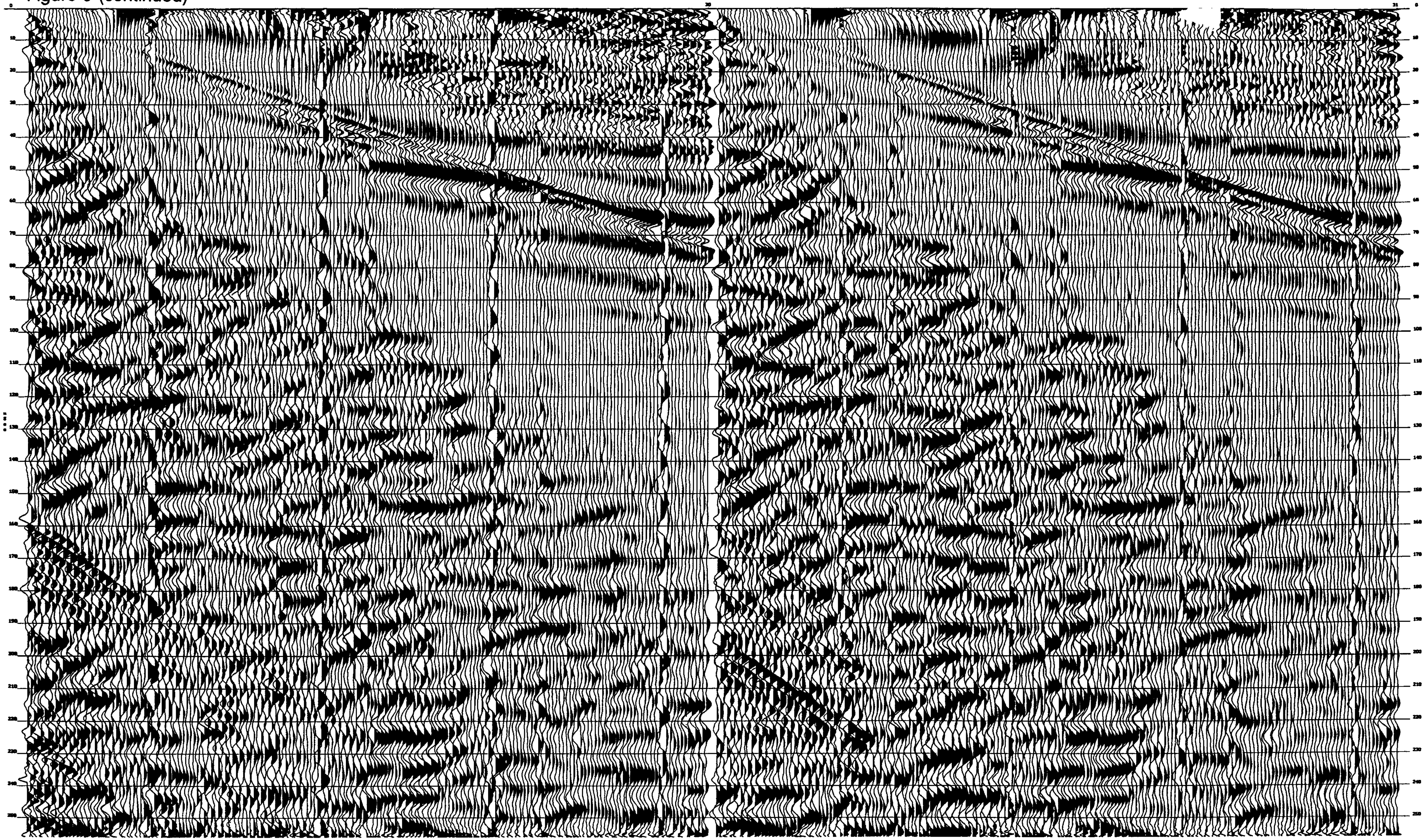

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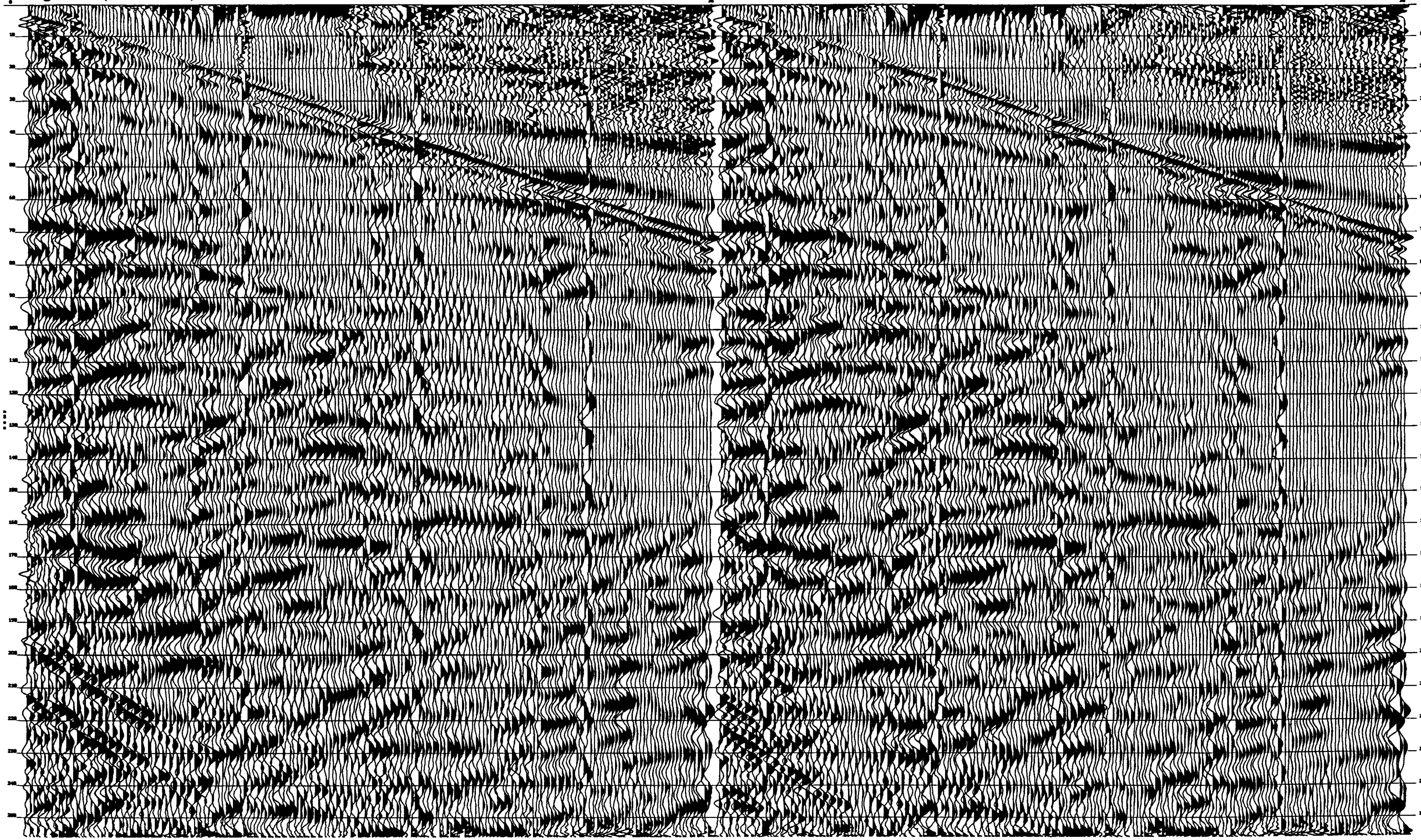
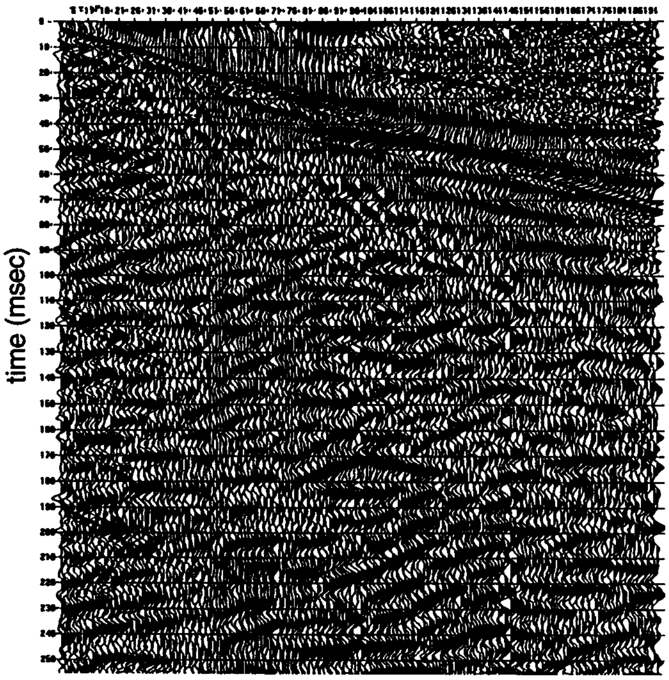


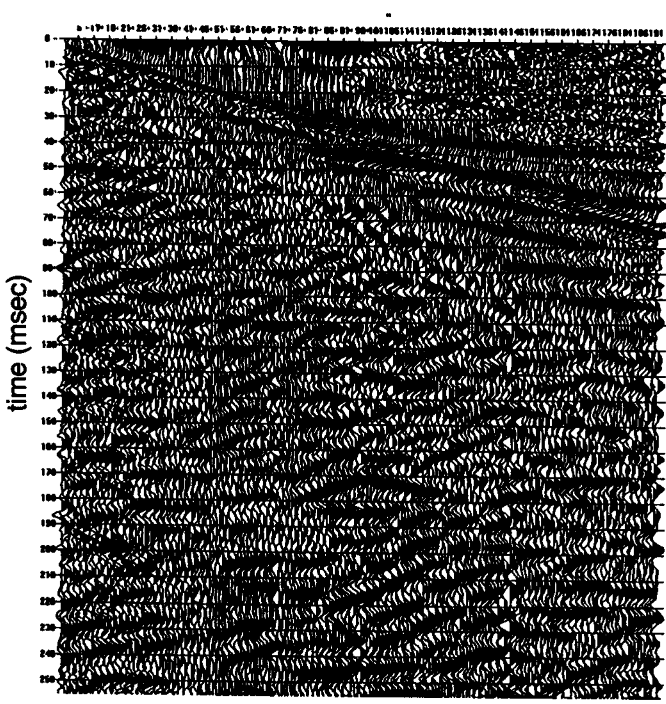
Figure 10

0.125 m separation between traces



Hyperbolic curve
500 m/sec = V_{nmo}
35 msec = T_o
8.8 m = z

(a)



Hyperbolic curve
710 m/sec = V_{nmo}
38 msec = T_o
13.5 m = z

(b)