

**Field Comparison
of Shallow P-Wave Seismic Sources
near Houston, Texas**

by

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SUMMARY

Choosing a seismic source can be a pivotal decision for a shallow-reflection survey. The intent of this paper is to summarize preliminary results of a shallow P-wave seismic source comparison conducted in an area with a water table depth of approximately 7 m and near-surface materials consisting of clays, sands, and gravels. Data were acquired from 12 different sources in November, 1991, at a single site near Houston, Texas. Reflection events can be interpreted at about 40 ms on some 220 Hz analog low-cut filtered field files and at 60 ms on most field files with either 110 or 220 Hz analog low-cut filters. The geologic units responsible for these events are not known. Our previous work and that of our colleagues suggests that, given a specific set of site characteristics, any source could dominate the comparison categories addressed here.

INTRODUCTION

To assist investigators with selection of the optimum seismic sources for particular applications, geologic conditions, and site logistics, a representative group of sources needs to be compared in a variety of settings with consistent testing procedures and equipment. The Source Comparison Subcommittee of the SEG Engineering and Groundwater Committee has been active since 1985, publishing results from two previous source comparisons in New Jersey and California in *Geophysics* (Miller et al, 1986; 1992).

During November, 1991, a group of shallow-seismic P-wave source owners, in cooperation with the Geological Survey of Canada and the Kansas Geological Survey, gathered at a golf course approximately 40 km southwest of Houston near Richmond, Texas, to continue the comparison tests (Figure 1). The preliminary results from those tests are summarized in this paper.

There are many factors to consider in a source evaluation. This experiment was designed to be as consistent as possible with the 1985 New Jersey and 1988 California tests, primarily addressing the questions of energy, frequency content, and signal-to-noise ratio. Other factors significant to the selection of the optimum source relate to source wavelet, portability, cost (both initial and per shotpoint), site preparation requirements, source cycle time and repeatability, environmental damage, and safety requirements.

In an attempt to quantify significant characteristics of some of the more popular shallow, P-wave seismic sources, source comparisons have been conducted in New Jersey during 1985 (Miller et al., 1986) and California during 1988 (Miller et al., 1992). Under the geologic conditions at the New Jersey site the main distinction among the 26 different sources and variations of sources tested was the total energy recorded for each source. The upper several hundred meters of material was unconsolidated interbedded sands, clay, and silt of Quaternary age with water table depth of about one meter. Very little diversity in recorded seismic characteristics could be deduced from analysis of the data generated during those tests. These data suggest that at an excellent seismic-data site, source selection is critical only in relation to total energy necessary to image the geologic target.

The geologic conditions at the California site were less conducive to the propagation of high-frequency seismic energy than the New Jersey site. Testing prior to the 1988 comparison identified this site as fair-to-poor with respect to recording of shallow-seismic reflections. The water table was in excess of 30 m and the near-surface velocity was less than the speed of sound in air (330 m/s). Data from 13 different sources were acquired, each displaying unique characteristics. A probable reflecting event can be interpreted at about 70 msec (Miller et al, 1992). The geologic unit responsible for this event is not known. Data from the California site represent the opposite end of the data quality spectrum relative to the New Jersey data.

The Geologic conditions at the site near Houston, Texas were more conducive to the propagation of high-frequency energy than the California site but less conducive than the New Jersey site. Limited information was available prior to acquisition of these comparison data. The water table in a domestic well adjacent to this site was at a depth of approximately 7 m with alternating clays, sands, and gravels in the upper 30 m. The clay/sand contacts and the water table could represent potential reflection horizons.

The acoustic properties of the near-surface at the site were unknown prior to initial walk-away tests. The observed surface and very shallow near-surface material consisted of a layer of vegetation overlying fine-grained sands with variable compaction to depths of at least 1 m. Cultural noise was virtually nonexistent. The only noise source outside of the an occasional gust of wind were source owners preparing sources in the staging areas and spectators. In both cases, data were only recorded when noise levels were low. The site was unobstructed by surface barriers that could possibly act as reflecting interfaces for source-generated air waves. The site was easily accessible to vehicles.

FIELD PROCEDURES

An Input/Output, Inc. DHR 2400 seismograph recorded the data digitally on half-inch magnetic tape in modified SEG-Y format and also on paper (Figure 2). The record length was 250 ms with a sample interval of 1/4 ms. Analog-to-digital (A/D) conversion is 11 bits plus sign. The amplifiers have a factory noise specification of 120 nV root-mean-square (rms), providing a fixed gain instantaneous dynamic range of 72 dB.

Receiver offsets and spacings were determined after a series of walkaway noise tests conducted the first day of the comparison (Figure 2). The nearest geophone to the source area was 3 m and the receiver interval was 0.5 m. The receivers were single OYO-Geospace 40 Hz geophones, on 0.07 m spikes. The geophones were firmly planted and left in place throughout the comparison.

Each source was fired on, into, or within previously undisturbed ground. All field parameters were held constant for each source except for analog low-cut (high pass) filters and amplifier gains. Each source was fired three times, recording with no low-cut filtering, 110 Hz low-cut filtering, and 220 Hz low-cut filtering, each with a 24 dB per octave roll-off from the selected -3 dB point of 110 or 220 Hz. The fixed gains were adjusted with each shot to nearly maximize the 12-bit A/D converters. The intent of the amplification process was to maintain a minimum of at least one 8-bit digital word on all traces with no word using the full 11 bits (relative

amplitude plots in the field were used to verify no signal was clipped). The total surface area disturbed during testing was less than 16 m².

The center of the source area was in-line with the spread and 5 m from the first live geophone. The source area was a 4 m square in which each source had a spot specifically prepared for its individual needs (Figure 3). Due to the required size of the source area, source-to-nearest and furthest receiver distances were not the same for all sources. However, of the 24 offsets recorded for each source, 15 were the same for all sources. Only the 15 source-to-receiver offsets inherent to all sources were used so display and analysis information was representative and comparable.

RESULTS

The participants brought and tested a total of 12 sources with multiple configurations of some sources (Table 1). The effects of low-cut filtering is evident in the relative values of recorded amplitude for the various sources (Figure 4). Eleven primary types of sources were tested with variations including wet holes, dry holes, types of explosive, amounts of explosive, type of projectile, weight of projectile, and drawback on rubber band.

The wiggle trace data for this report are plotted in a true amplitude format. Gain applied to each trace is presented across the top of each file, allowing direct relative comparisons. With the exception of the data recorded with low cut filters out using the EWG and high explosives, any wavelet clipping observed on wiggle trace plot is presented on display only. The final report will contain all the data plotted with true amplitude, frequency spectra, power spectra, photographs, and physical information.

Reflections are interpretable on some raw field data at approximately 40 and 60 ms (Figures 5 through 20). The reflections can best be observed on data acquired with 220-Hz analog low-cut filters. The first-arrival information on all the field data at these offsets is interpreted as refractions with linear velocities of about 500 m/sec. The reflection with an origin time of approximately 40 ms calculates to be from a depth of about 8 m using a calculated NMO velocity of 390 m/s. The reflection with an origin time of about 60 ms was determined to be from a depth of about 14 m using a calculated NMO velocity of 470 m/s. The field files displayed here are representative examples from the data set.

DISCUSSION

Choosing the seismic source for a shallow-reflection survey can be a pivotal decision for the engineering geophysicist. The intent of this report is to present the preliminary results from an area with a moderate water table depth and slow near-surface velocity and to allow comparison with data acquired in an area with a water table very near the surface and a much higher near-surface velocity and data acquired in an area with a deep water table and a very low velocity near-surface layer. We hope the final results of this comparison (to be submitted to *Geophysics* for consideration for publication) will prove useful to the engineering geophysics community.

REFERENCES

- Miller, R.D., Pullan, S.E., Waldner, J.S., and Haeni, F.P., 1986, Field comparison of shallow seismic sources: *Geophysics*, 51, 2067-2092.
- Miller, R.D., Pullan, S.E., Steeples, D.W., and Hunter, J.A., 1992, Field comparison of shallow seismic sources near Chino, California: *Geophysics*, 57, 693-709.

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TABLE 1
Description and variation of sources and site preparation requirements

<u>Source</u>	<u>Variation</u>	<u>Site Preparation</u>
1) 9.1 kg hammer onto steel plate		Seated steel plate with several impacts.
2) surface .30-06-cal. rifle silenced	shot into water-filled hole 180-grain bullet	water poured into shaft poked 1/3 m deep hole 0.03 m shaft
3) downhole .30-06-cal. rifle	shot into wet hole 180 grain projectile.	Auger drilled 0.05 m hole 0.6 m deep and water poured in.
4) Betsy Seisgun M3 8 gauge	shot 3 oz slug into wet hole	Poured water in 0.05 m auger hole 0.6 m deep
5) .50-cal. rifle downhole	a) dry hole	Auger drilled 0.05 m hole 0.66 m deep.
	b) wet hole	Poured water in virgin augered shot hole and placed condom on end of barrel.
6) 8-ga. Auger gun	300-grain black powder blanks	Screwing auger flite into ground 0.66-m deep.
7) 8-ga. Downhole Firing Rod	a) black powder (blank) 300-grain, wet hole	Auger drilled 0.05 m hole 0.66 m deep, load gun in hole, pour in water (wet shots), compression detonation rubber mallet.
	b) black powder (blank) w/PVC casing 300-grain.	
	c) black powder (blank) 300-grain, dry hole	
8) 12-ga. Buffalo Gun /wet hole	black powder (blank) WIN VW12BL, 165 grain.	Same as source 7
9) Bison EWG IV Generator (accelerated weight drop)	a) high energy 1 m drop with several impacts. b) low energy 0.5 m drop	Seat 2.6 cm steel plate
10) USGS Rotator	100 rpm setting	Single impact seating of steel plate.
11) Explosives	30 grams of high explosive	Same as source 7.
12) Seismic Blasting Cap		Same as source 7.



Figure 1 Site map indicating the location of the source comparison near Houston, Texas.

ACQUISITION PARAMETERS & EQUIPMENT

- 1) I/O DHR-2400 12 bit, fixed gain seismograph
- 2) Single geospace 40Hz geophones, dug-in
- 3) 1/4 msec sample rate
- 4) 1/2 meter station spacing
- 5) Analog lowcuts: out, 110, & 220 Hz
- 6) Source area offset = 3m
- 7) Source area 4m x 4m

Figure 2 Acquisition parameters and equipment.

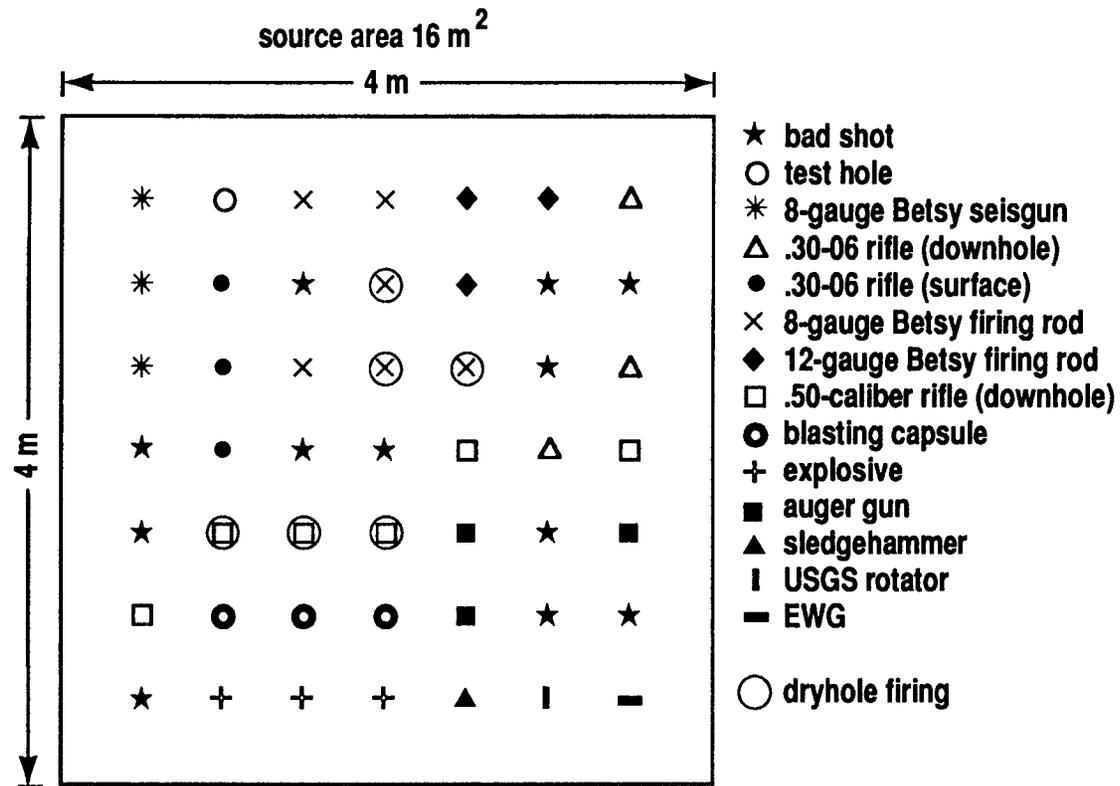


Figure 3 Source and location of each source. Due to the relatively small optimum window for the target reflection, fifteen of the twenty-four recorded offsets were identical for each source.

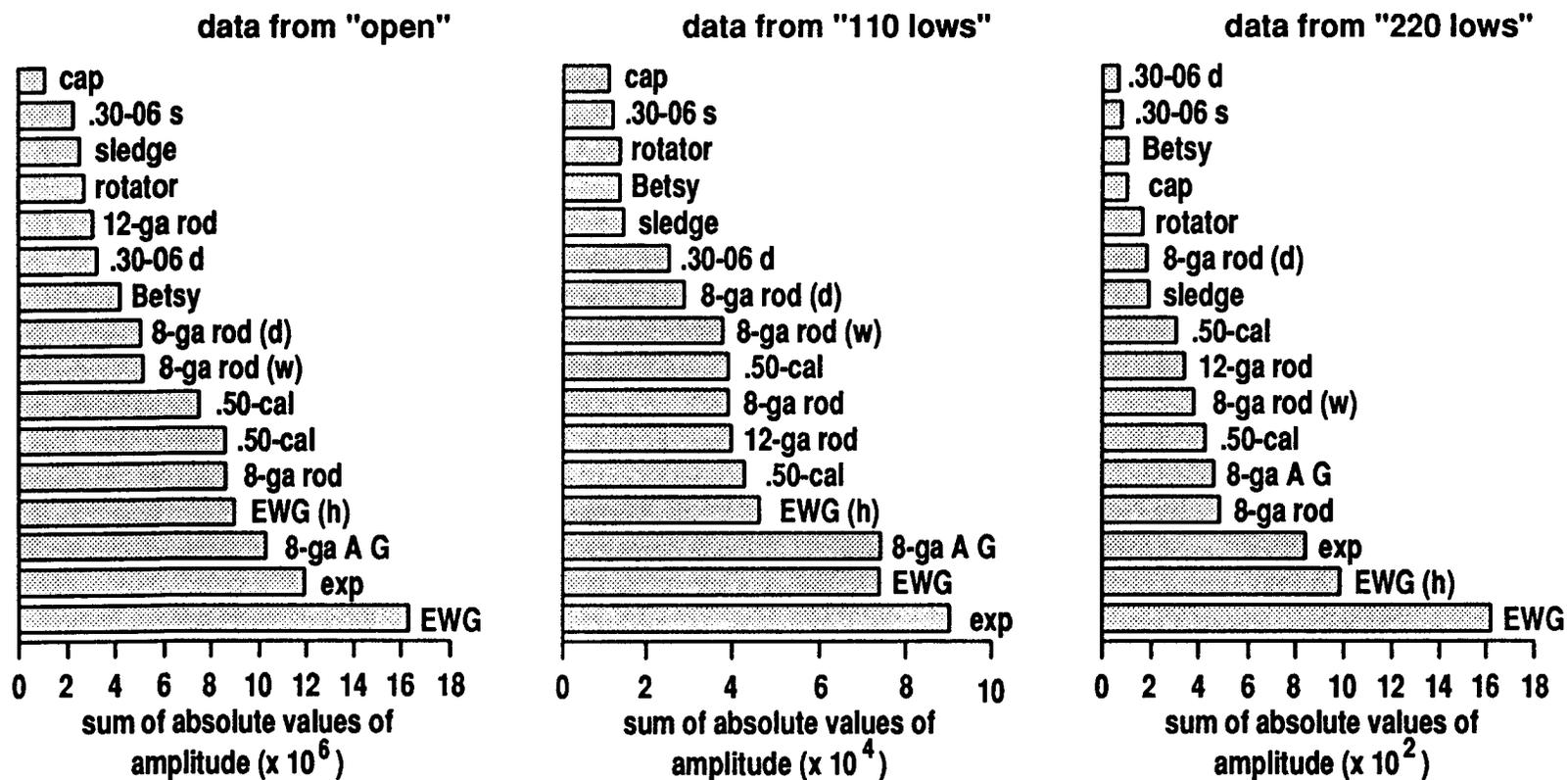


Figure 4 Sum of the absolute values of amplitudes for the fifteen offsets that were identical for each source at each of the indicated low cut filter settings.

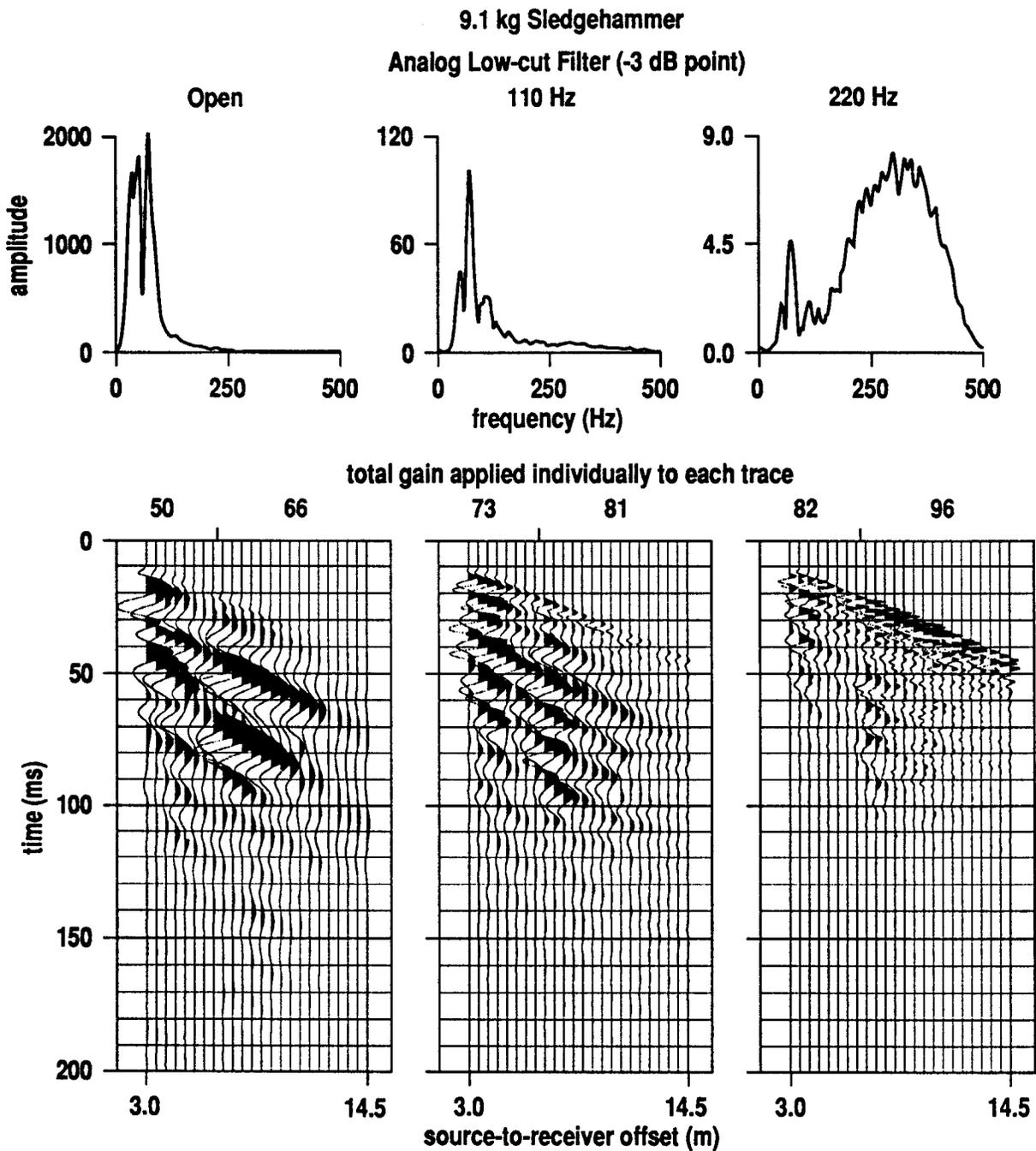


Figure 5 9.1 kg hammer impacting seated steel plate of approximately the same weight.

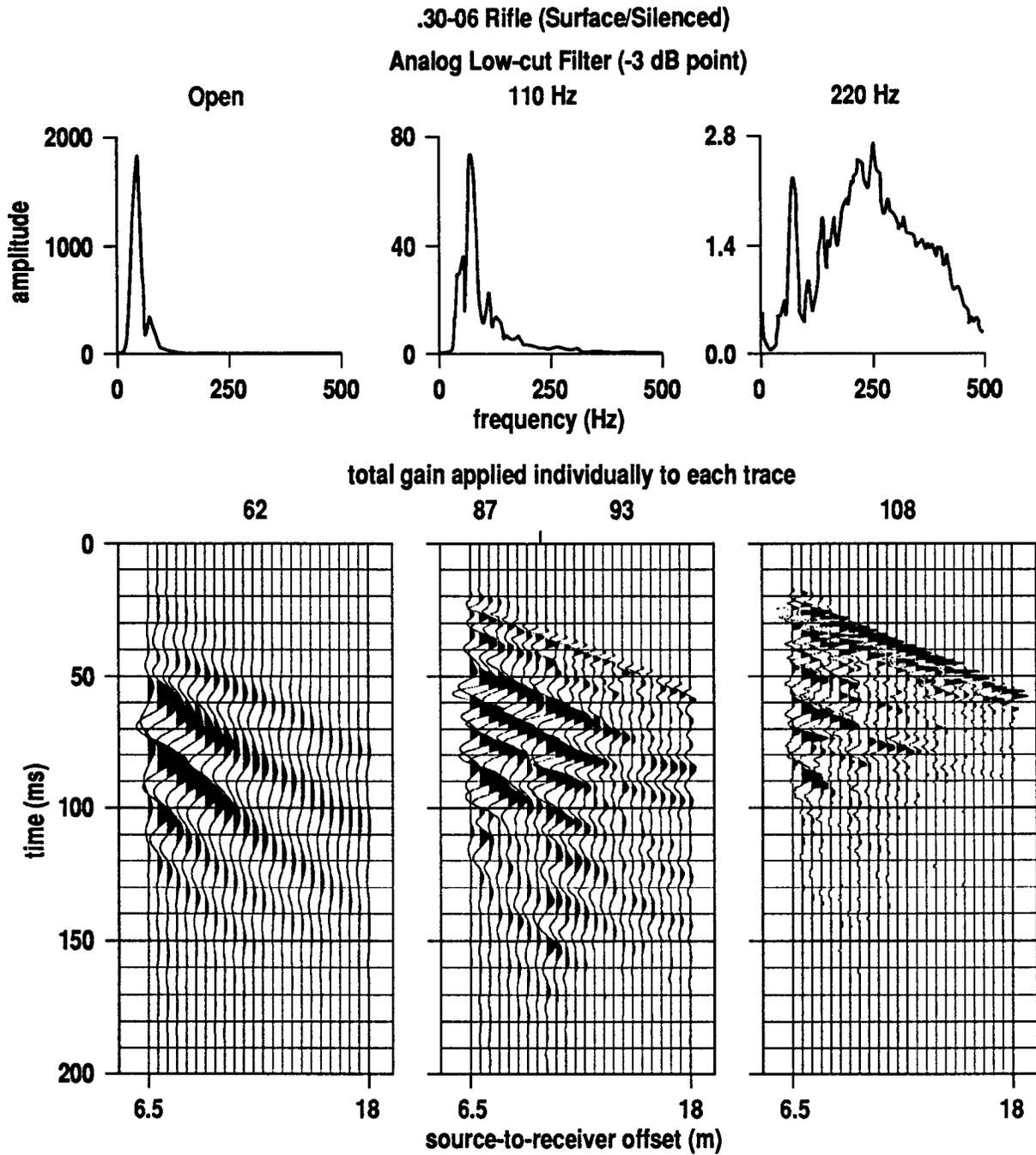


Figure 6 Surface .30-06 with silencer fired into a water filled hole approximately 0.3 m deep.

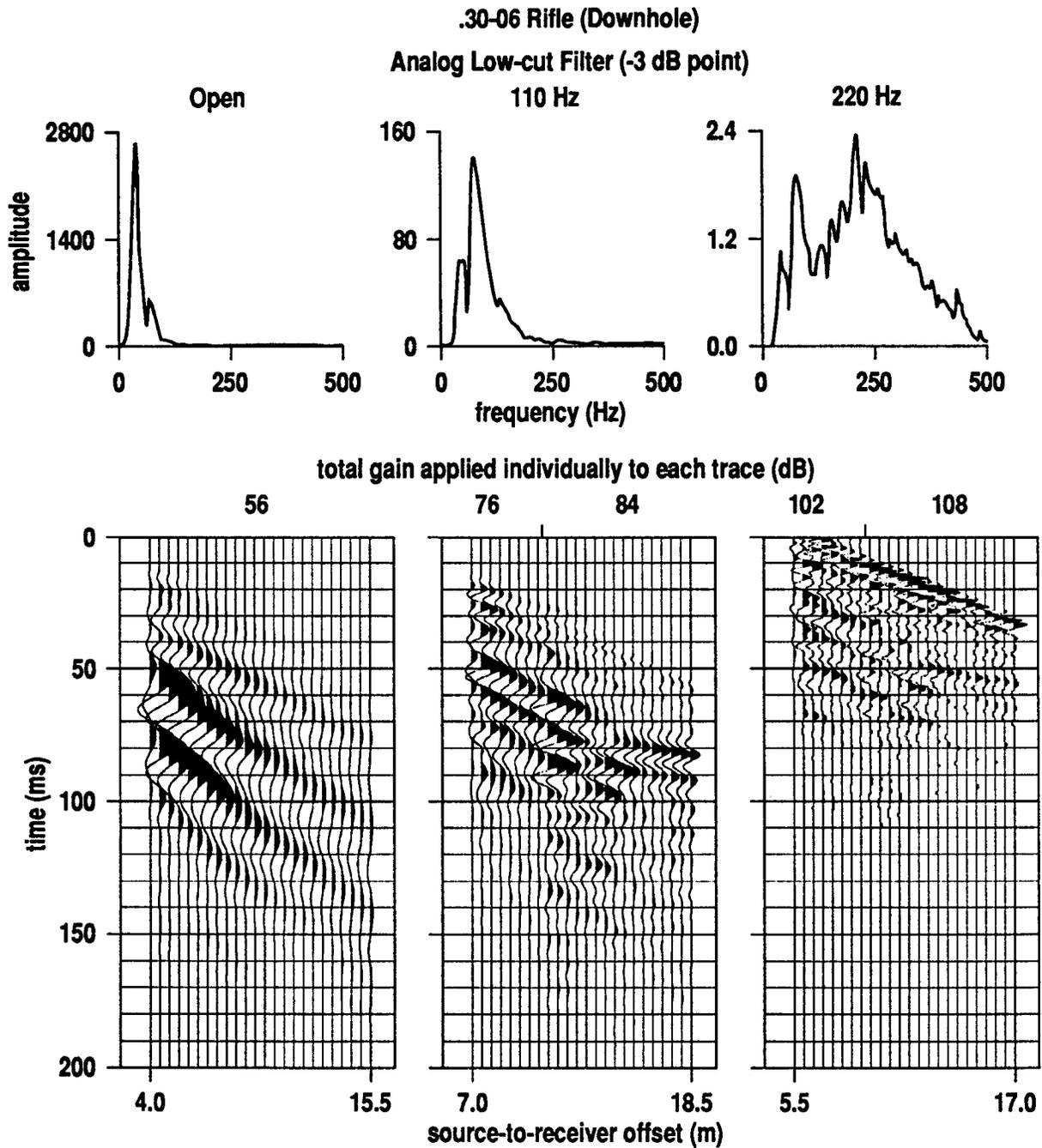


Figure 7 Downhole .30-06 rifle fired into a water filled hole approximately 0.6 m deep.

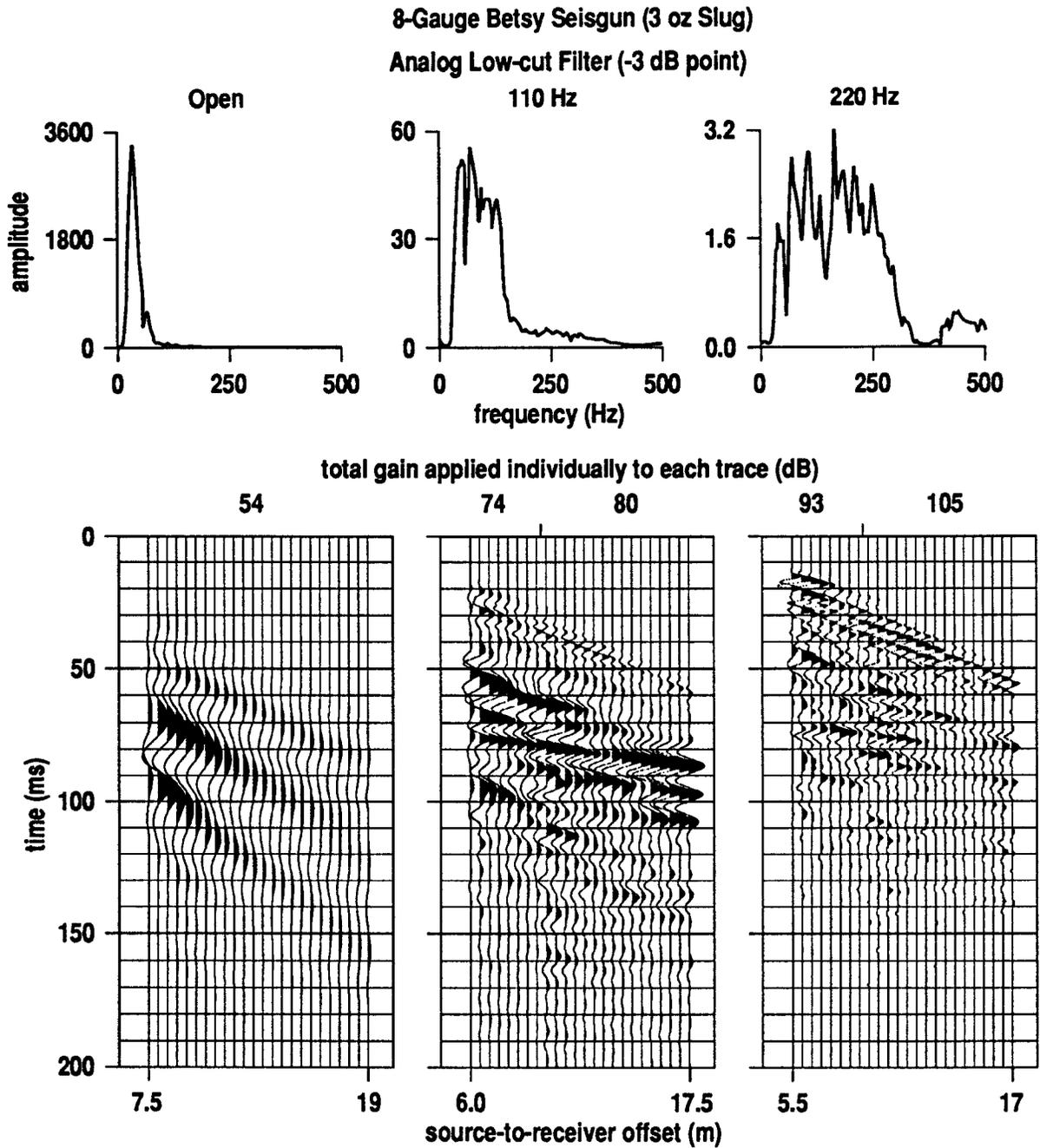


Figure 8 Betsy Seisgun M3, 8-gauge firing a 3 oz lead projectile into a 0.6 m water filled hole.

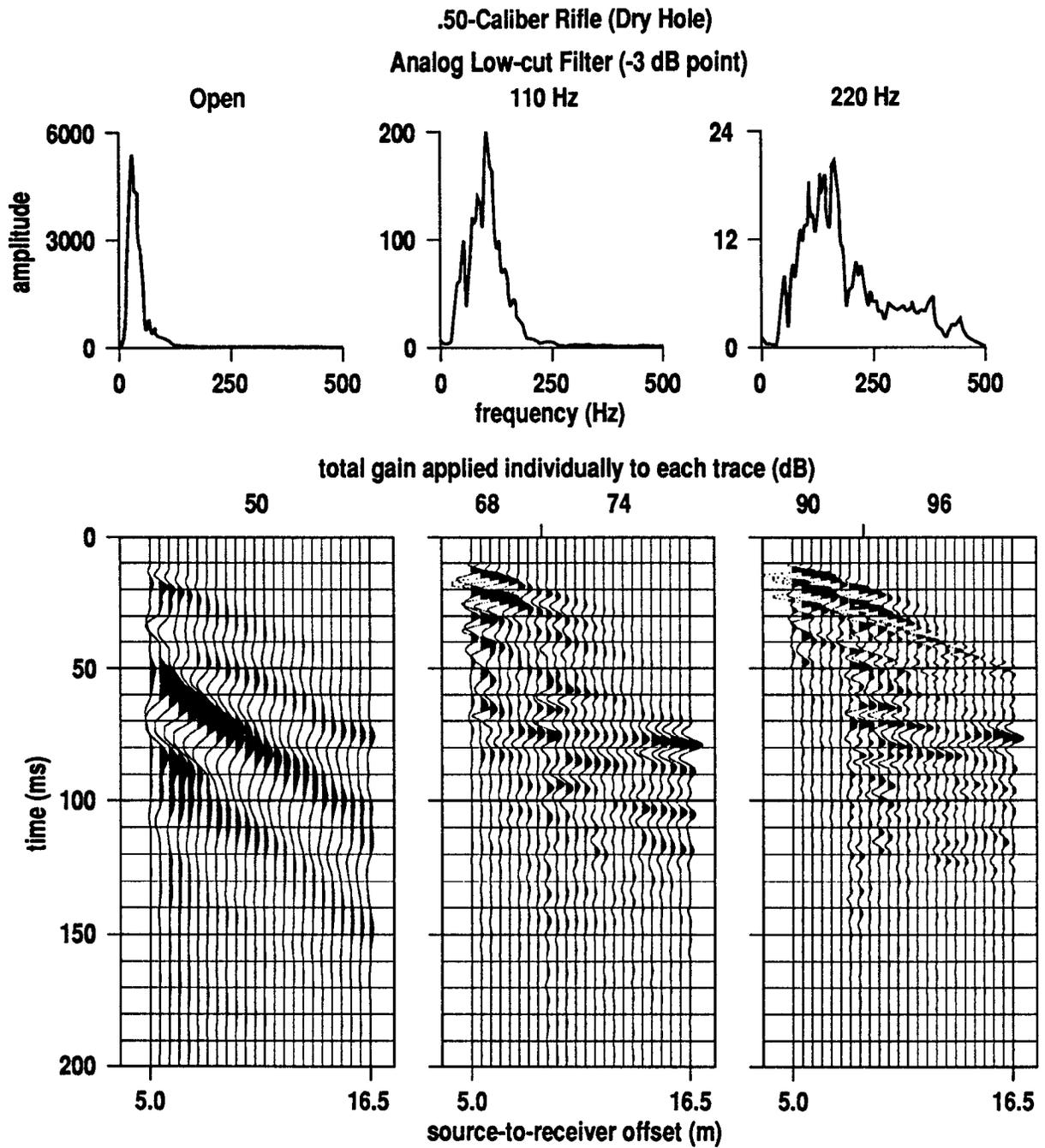


Figure 9 Downhole .50-caliber rifle firing a 750 grain ball load projectile into an air filled 0.6 m deep hole.

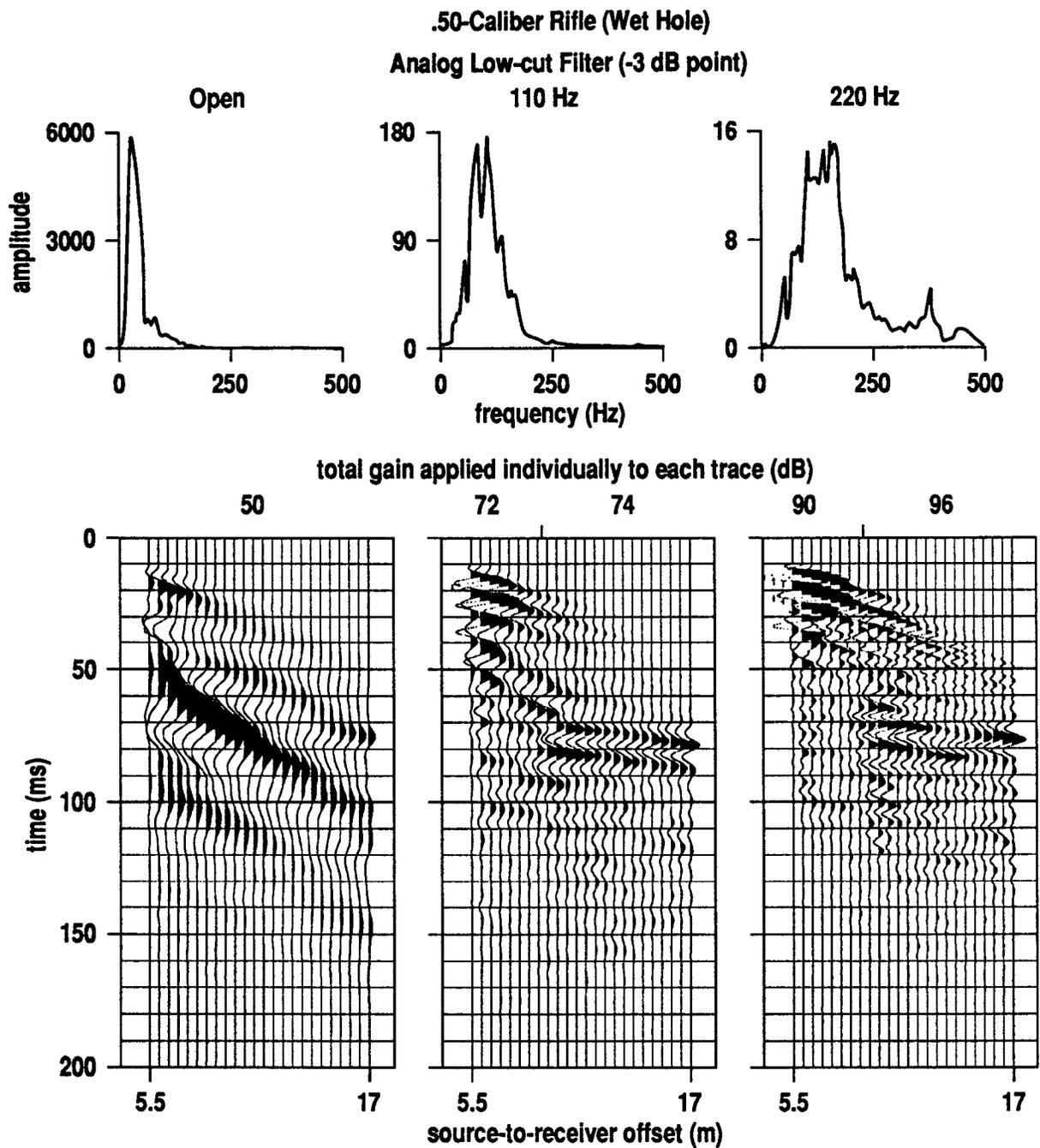


Figure 10 Downhole .50-caliber rifle firing a 750 grain ball load projectile into a water filled 0.6 m deep hole.

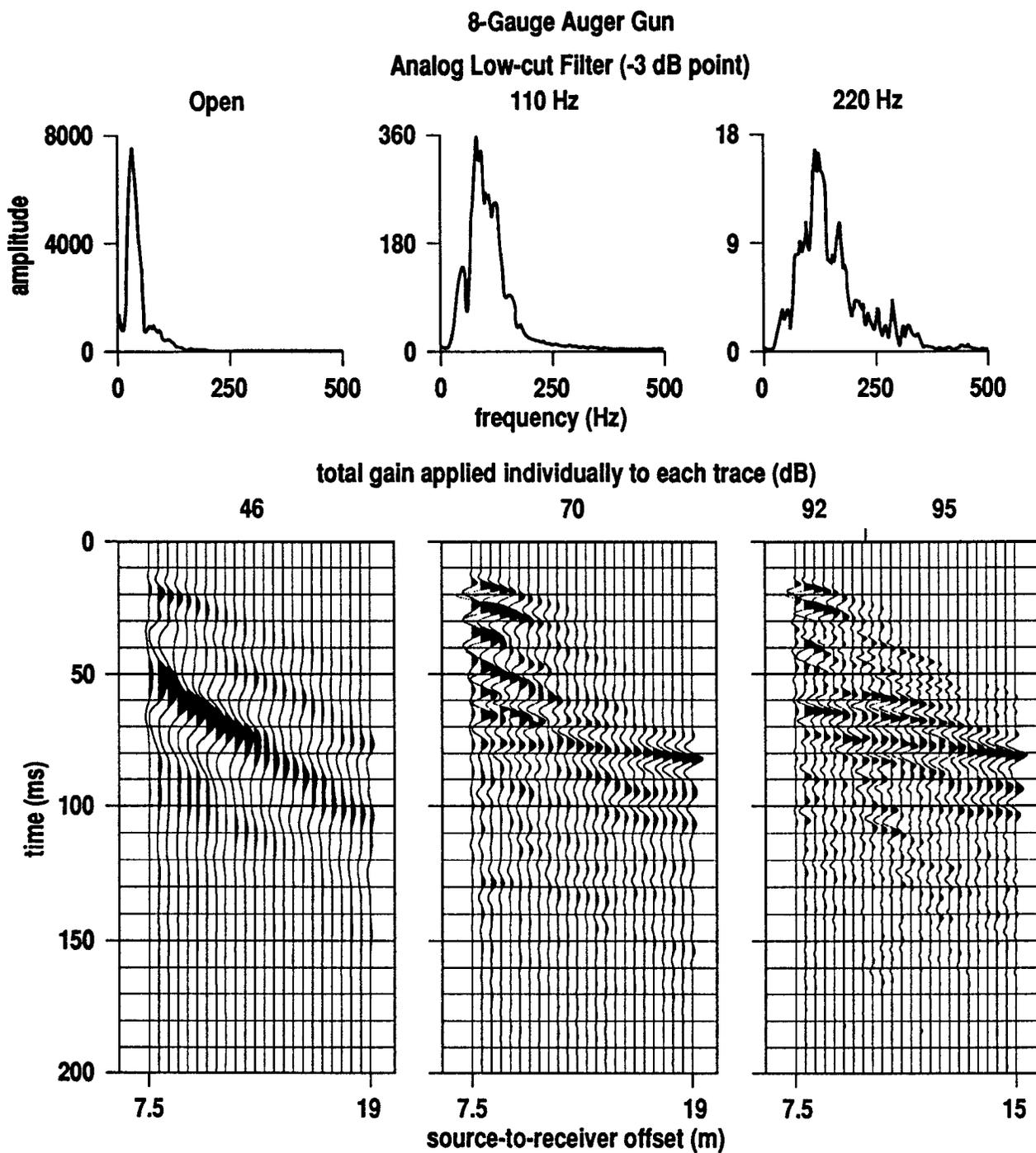


Figure 11 Auger gun detonating a 300 grain black powder load at base of a 0.6 m deep screw hole filled with water.

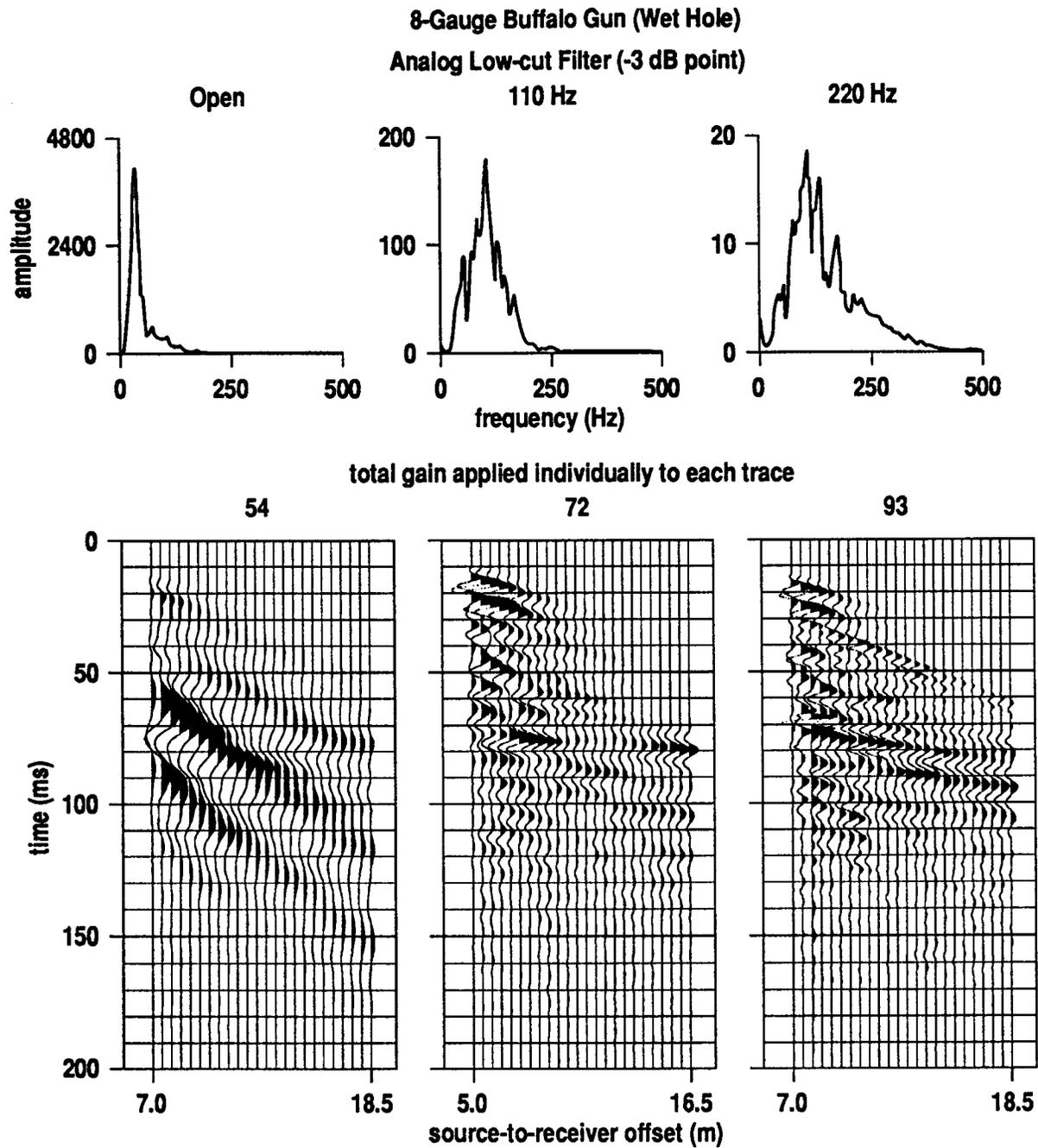


Figure 12 Betsy 8-gauge firing rod detonating a 300 grain black powder load at the base of a 0.6 m deep hole filled with water.

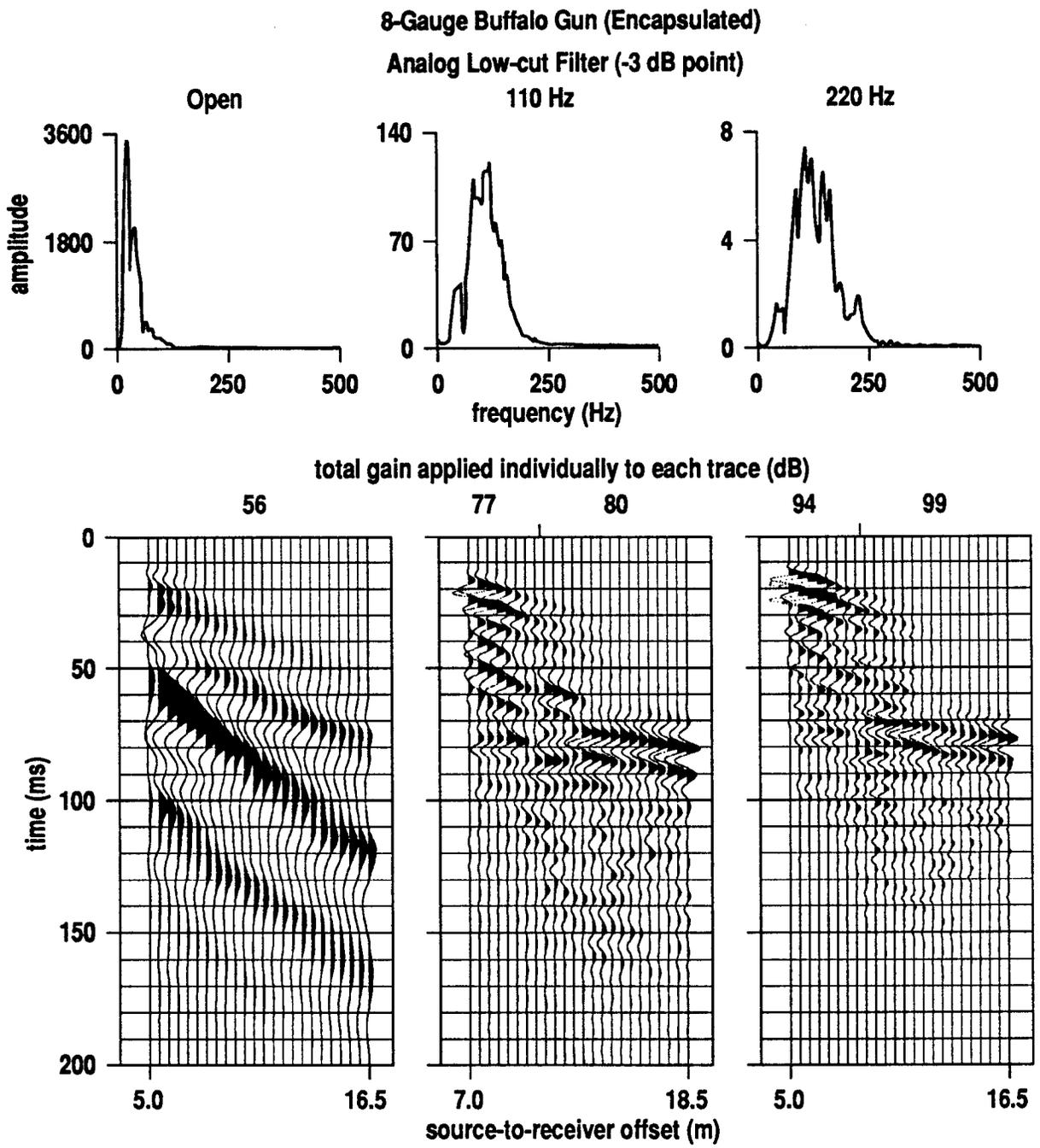


Figure 13 Betsy 8-gauge firing rod detonating a 300 grain PVC encapsulated black powder load at the base of a 0.6 m deep hole filled with water.

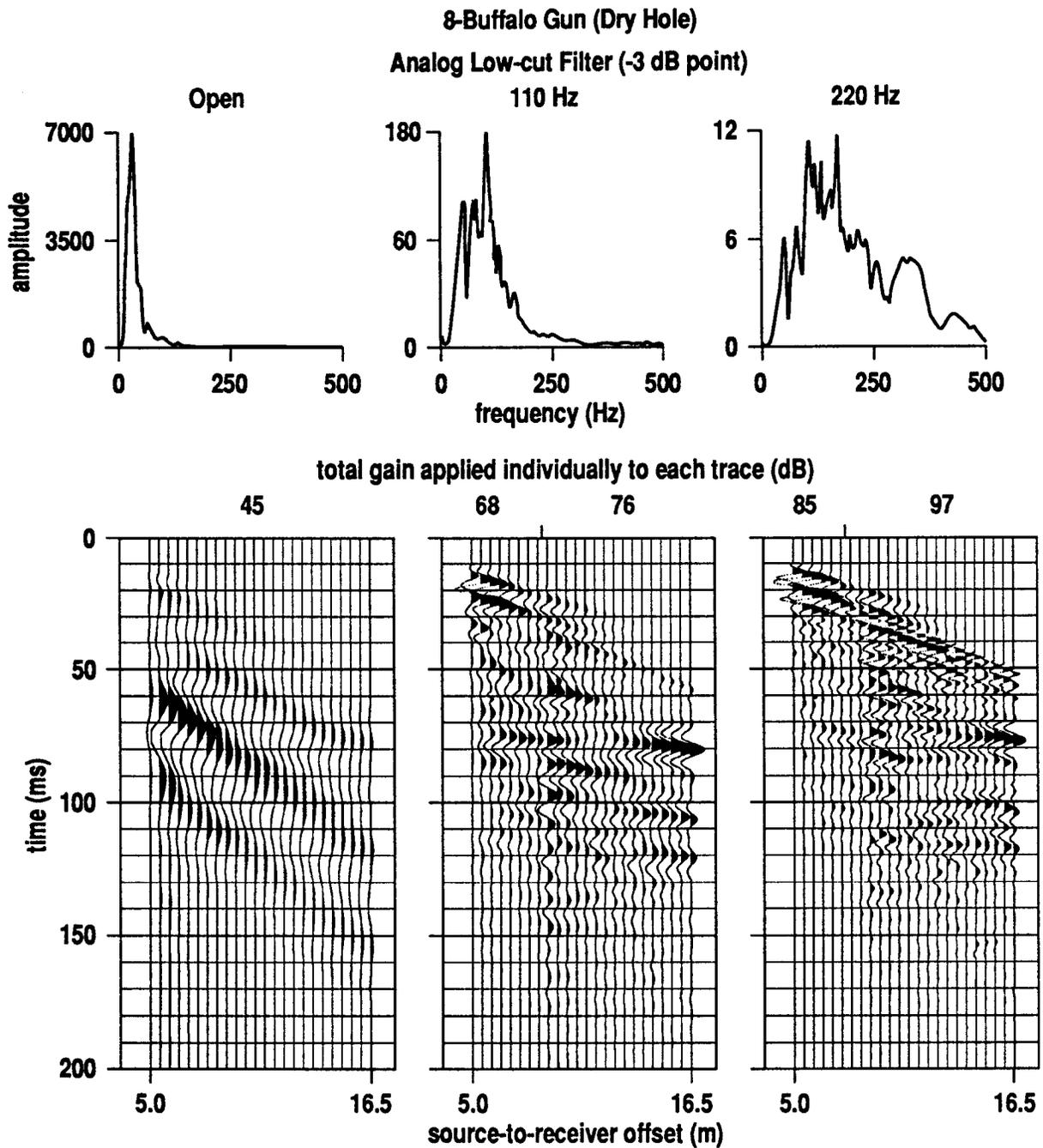


Figure 14 Betsy 8-gauge firing rod detonating a 300 grain black powder load at the base of a 0.6 m deep hole.

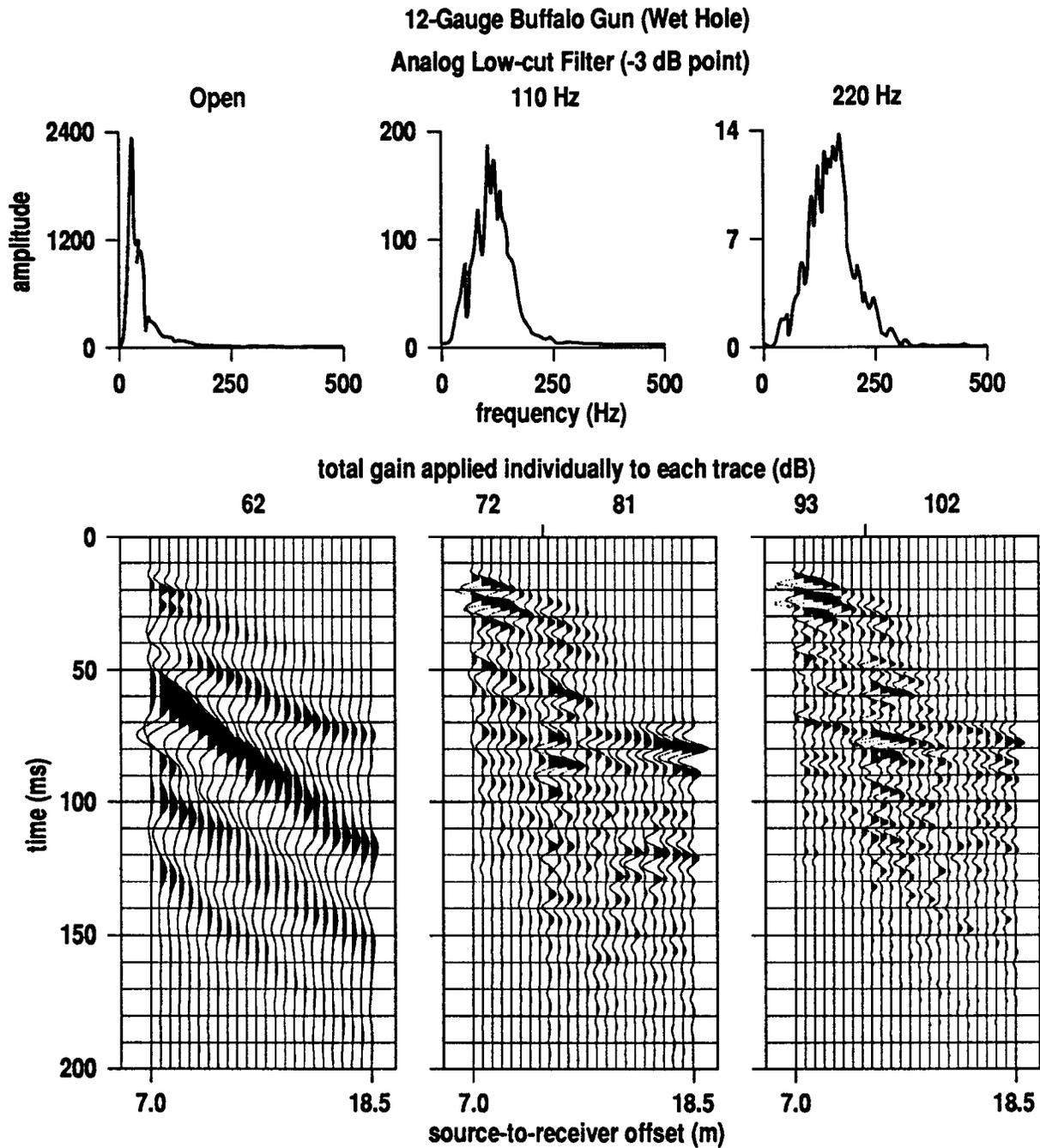


Figure 15 Betsy 12-gauge firing rod detonating a 165 grain black powder load at the base of a 0.6 m deep water filled hole.

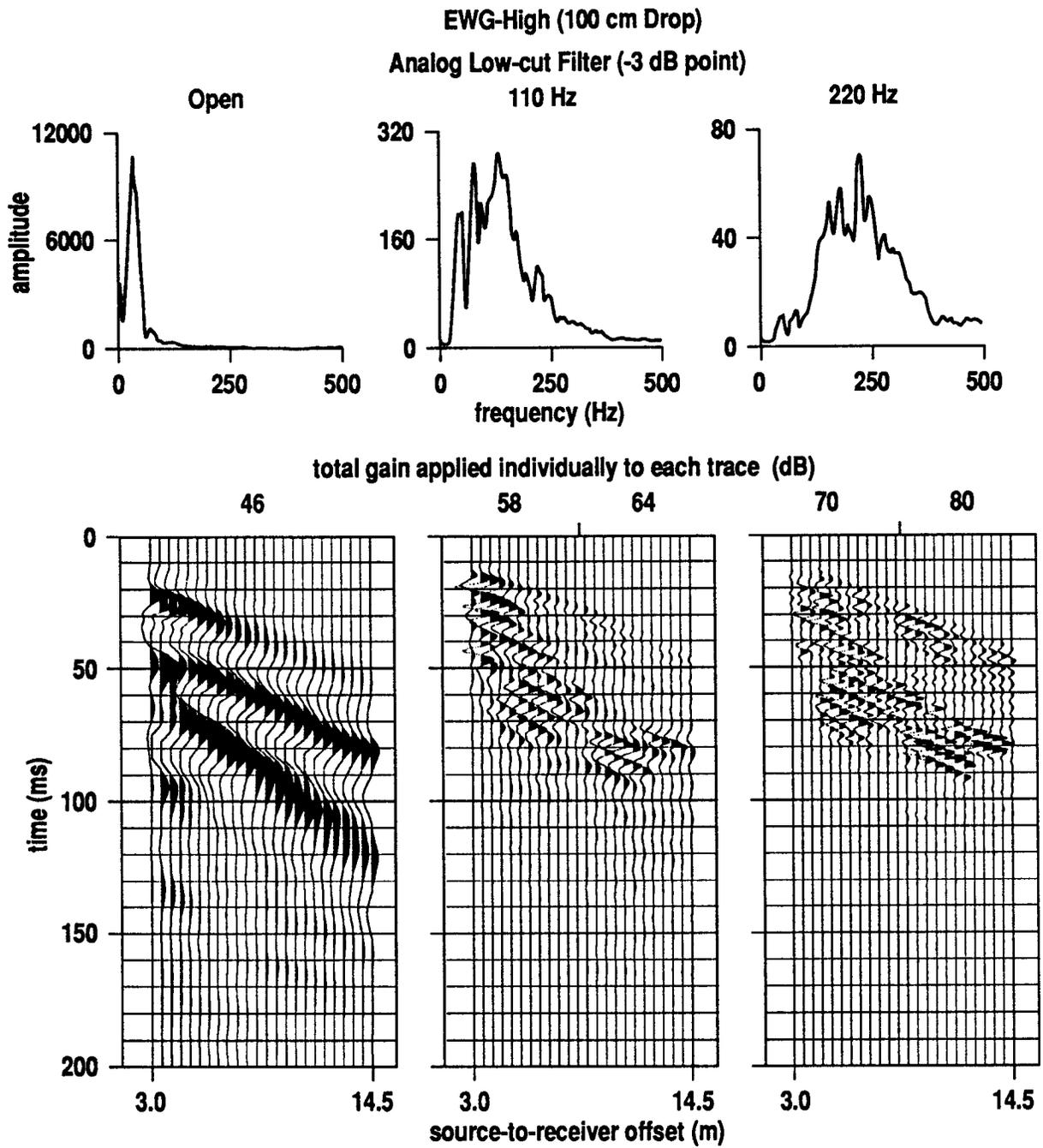


Figure 16 Bison Elastic Wave Generator IV (EWG) with a one meter acceleration onto a seated steel plate. Clipping on the low cut out data set resulted from over-driven amplifiers during acquisition.

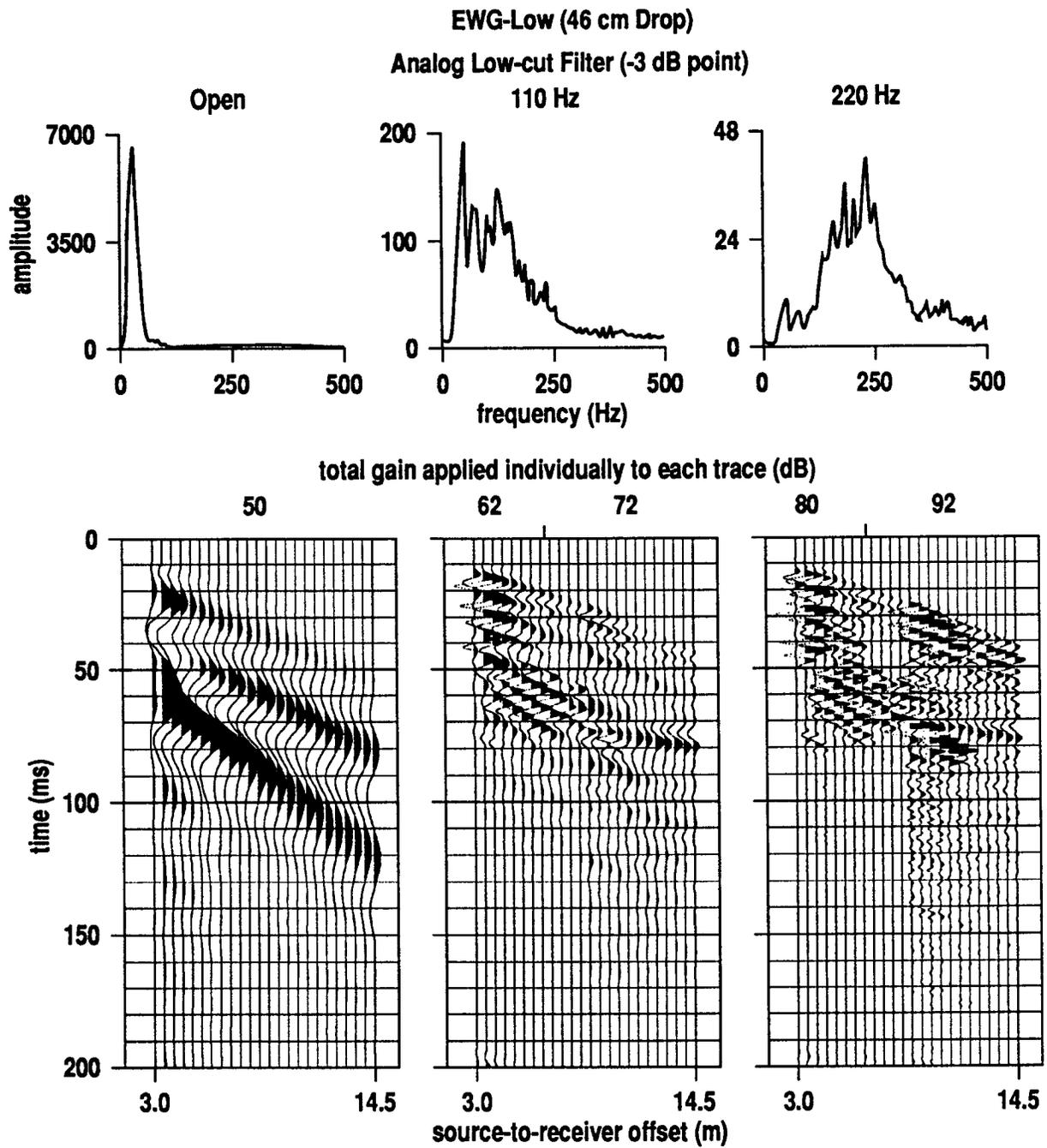


Figure 17 Bison Elastic Wave Generator IV (EWG) with a 0.48 m acceleration onto a seated steel plate.

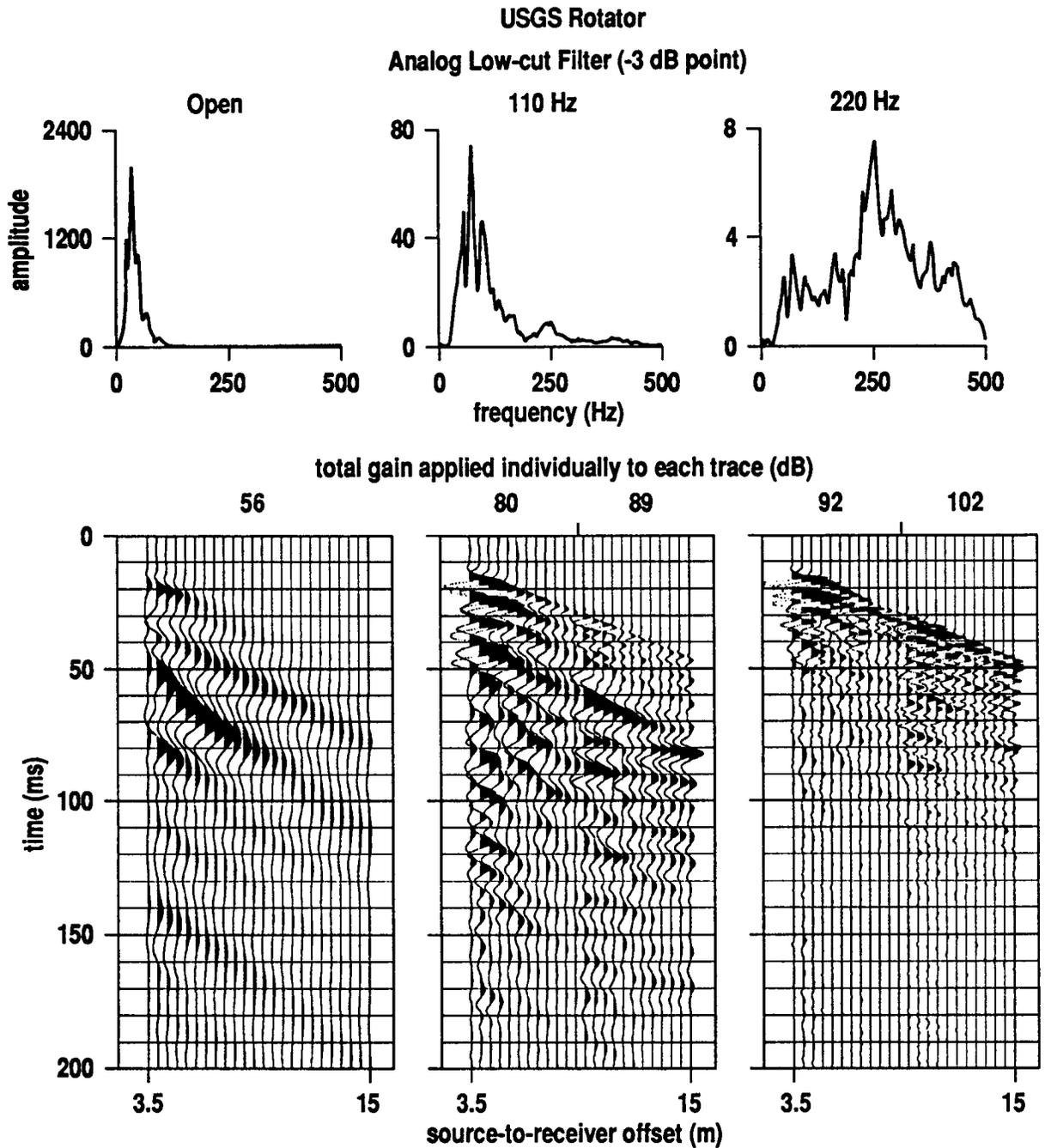


Figure 18 USGS Rotator vertically impacting a seated steel plate following rotational weight acceleration up to 100 rpm.

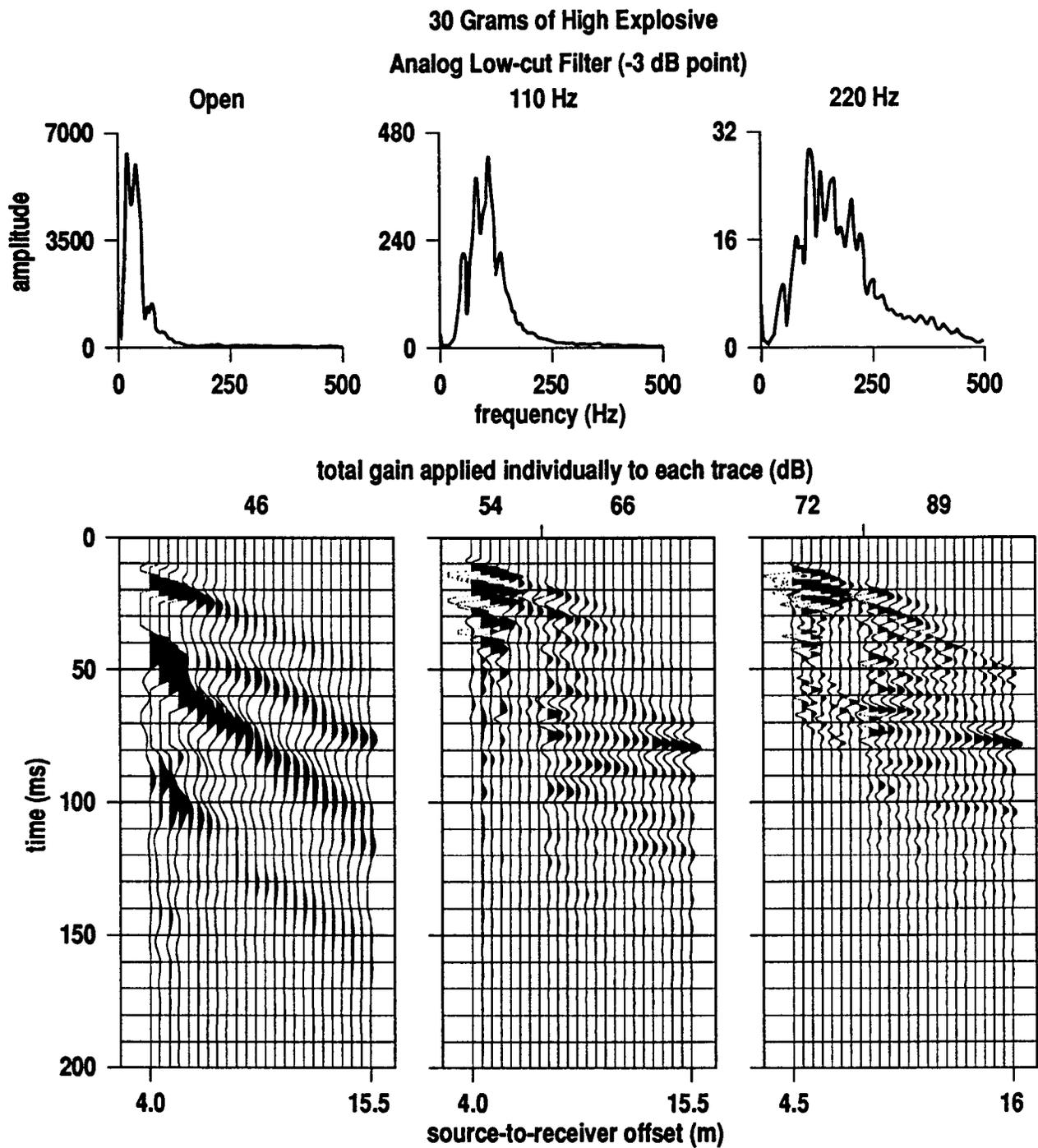


Figure 19 30 grams of high explosives detonated at the base of a 0.6 m deep water filled hole. Clipping on the low cut out data set resulted from over-driven amplifiers during acquisition.

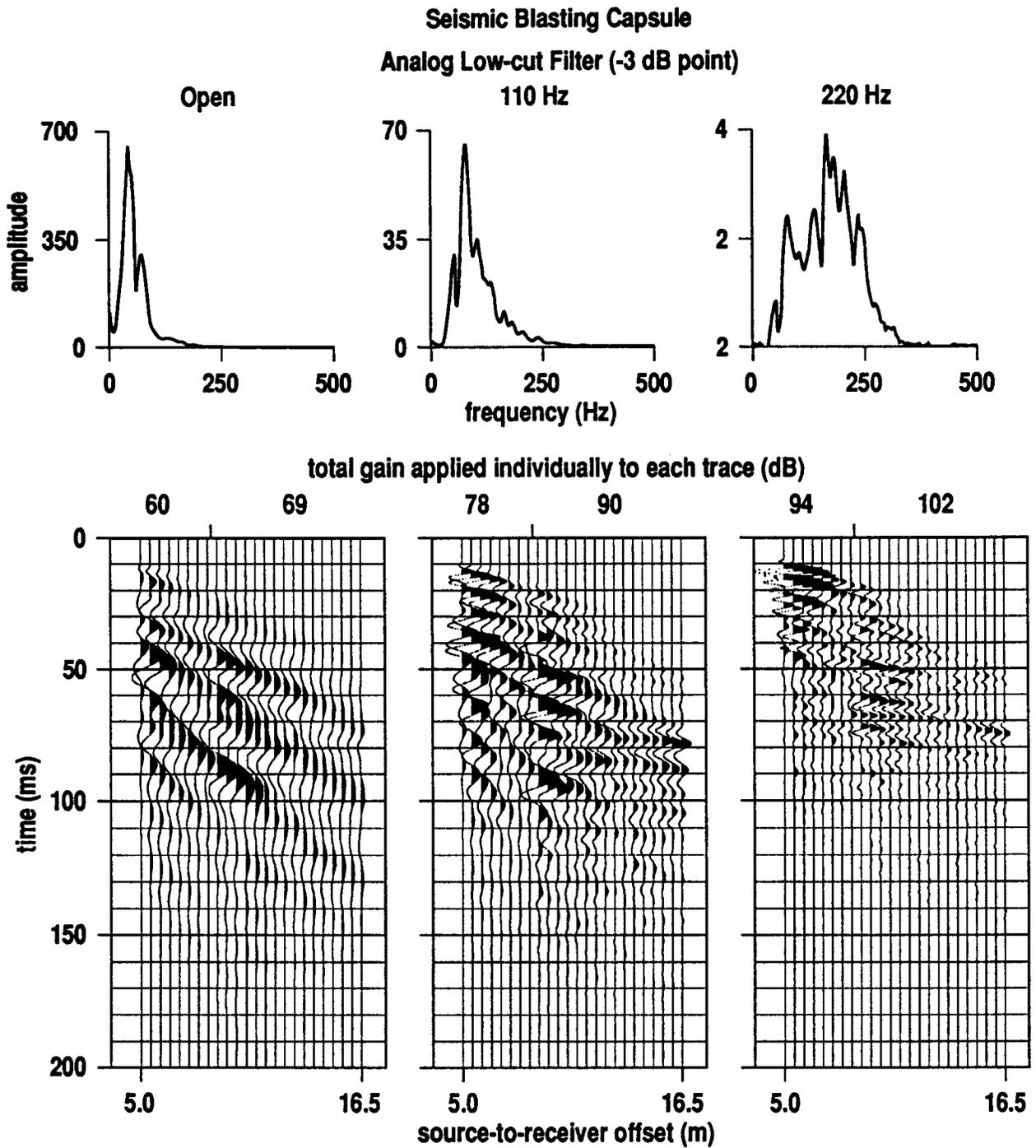


Figure 20 Seismic blasting cap detonated at the base of a 0.6 m deep water filled hole.

High Explosives

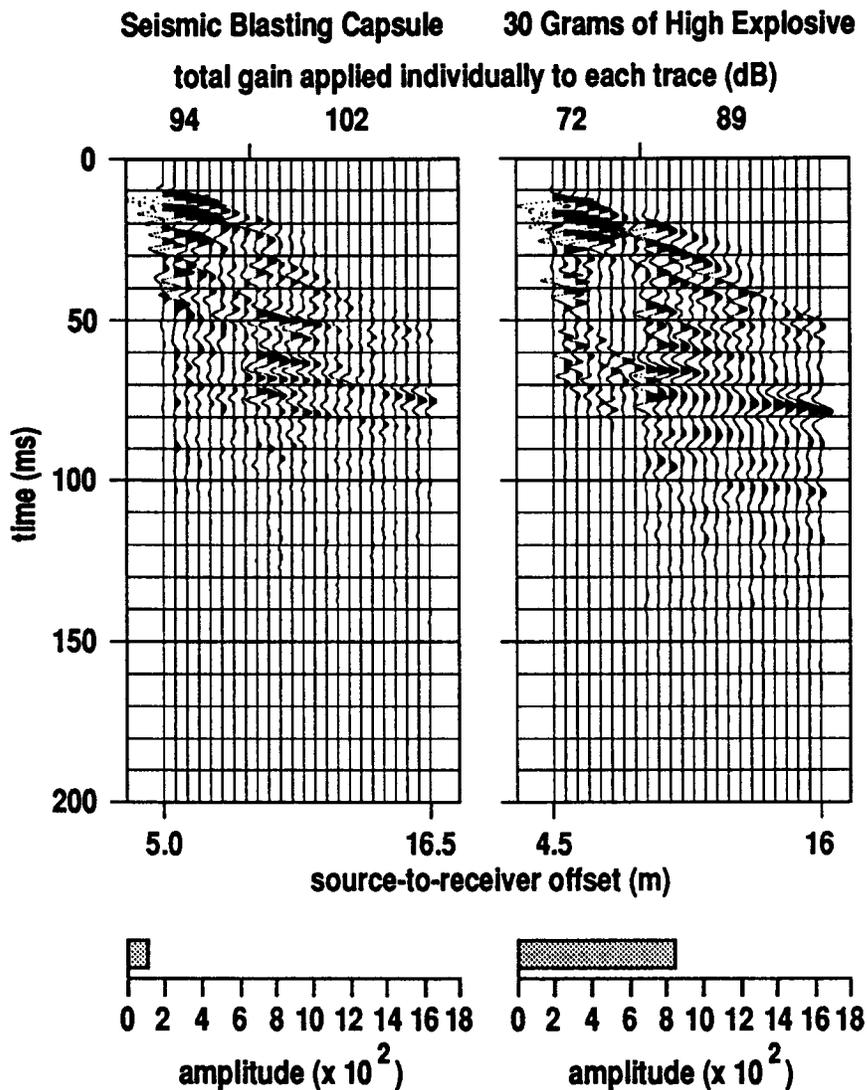


Figure 21 Comparison of the high explosive sources. It is no surprise the cap produced the highest dominant frequency reflection of any source tested.

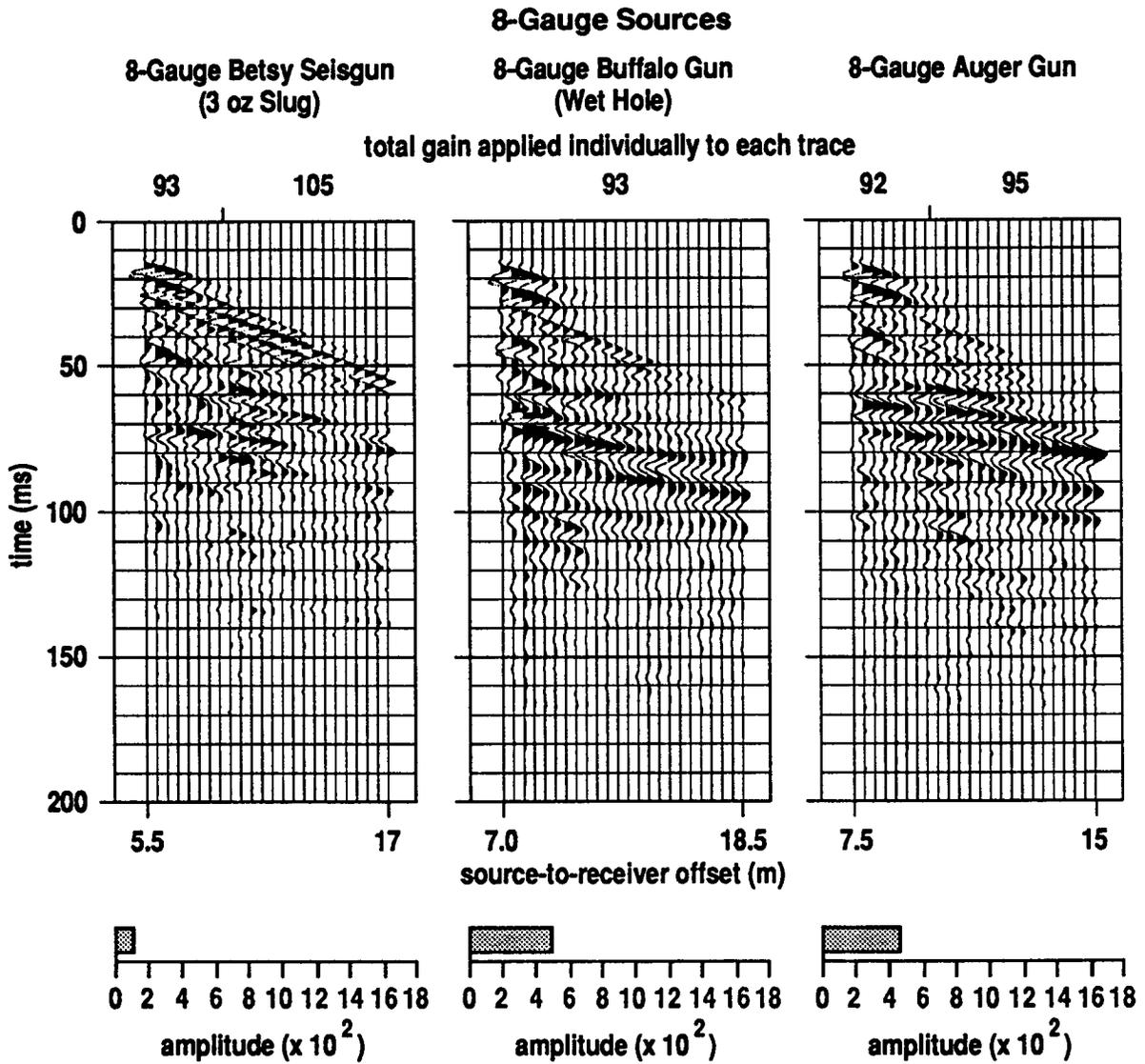


Figure 22 Comparison of the 8-gauge sources tested. The Betsy Seis Gun produced a surprisingly high frequency reflection record but lacked in recorded amplitude and possessed an increased amount of air coupled wave. The 8-gauge firing rod (in previous test identified as the Buffalo Gun) produced a very high amplitude reflection record with reflection events interpretable back to trace 1. The Auger Gun seemed to produce a reflection record with a slightly higher signal-to-noise ratio than the firing rod.

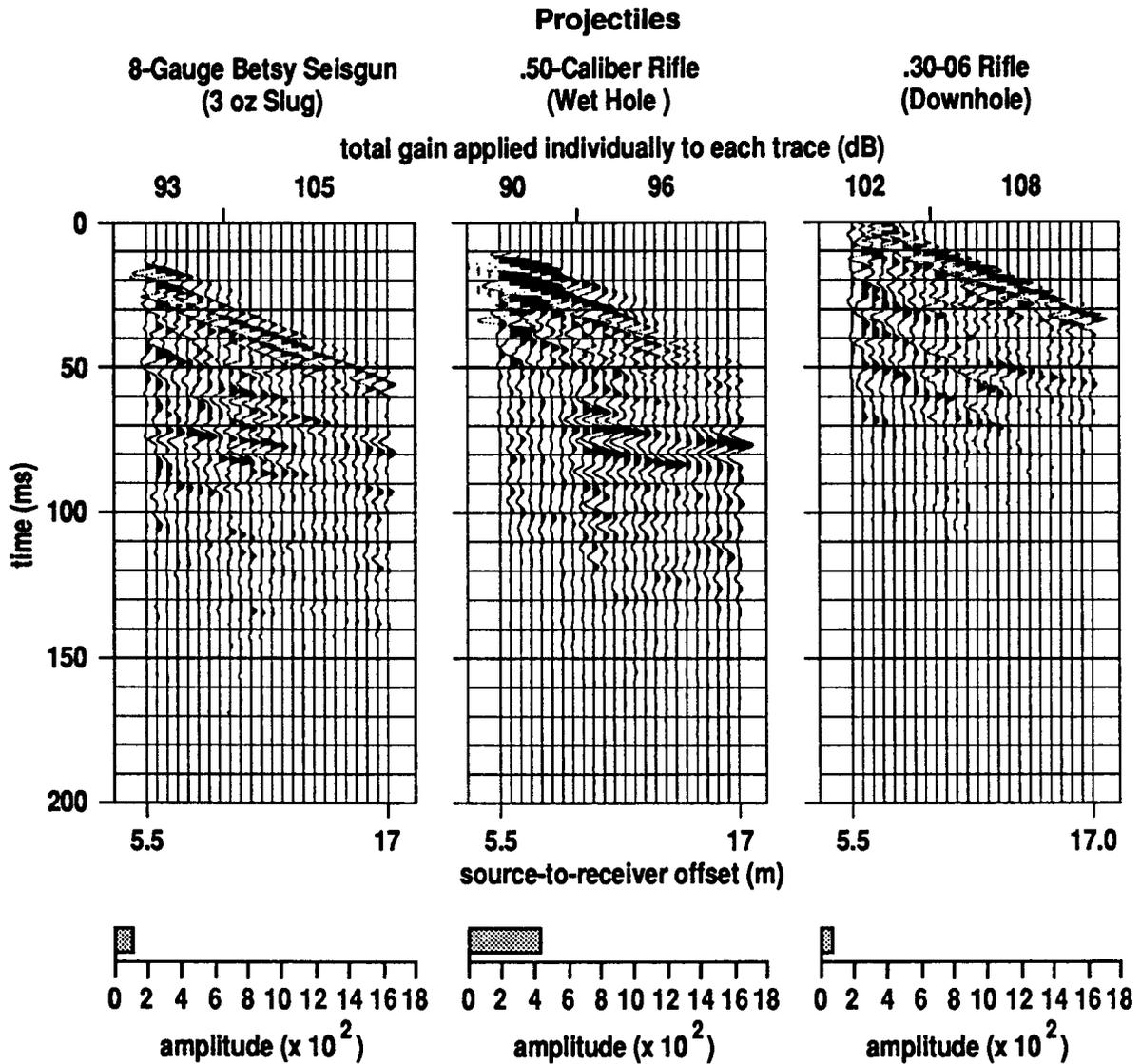


Figure 23 Comparison of projectile sources. The Betsy Seis Gun possess the higher dominant frequency and relatively good coherency on most events across several traces. The 50 caliber downhole has a much higher amplitude signal with reflection energy with high frequency components similar to the Betsy, the signal-to-noise ratio and reflection coherency are significantly higher and less air-coupled wave was recorded. In spite of the time break delay resulting in the time shift observed on the downhole .30-06 data a reflection event can be interpreted on the long offset traces.

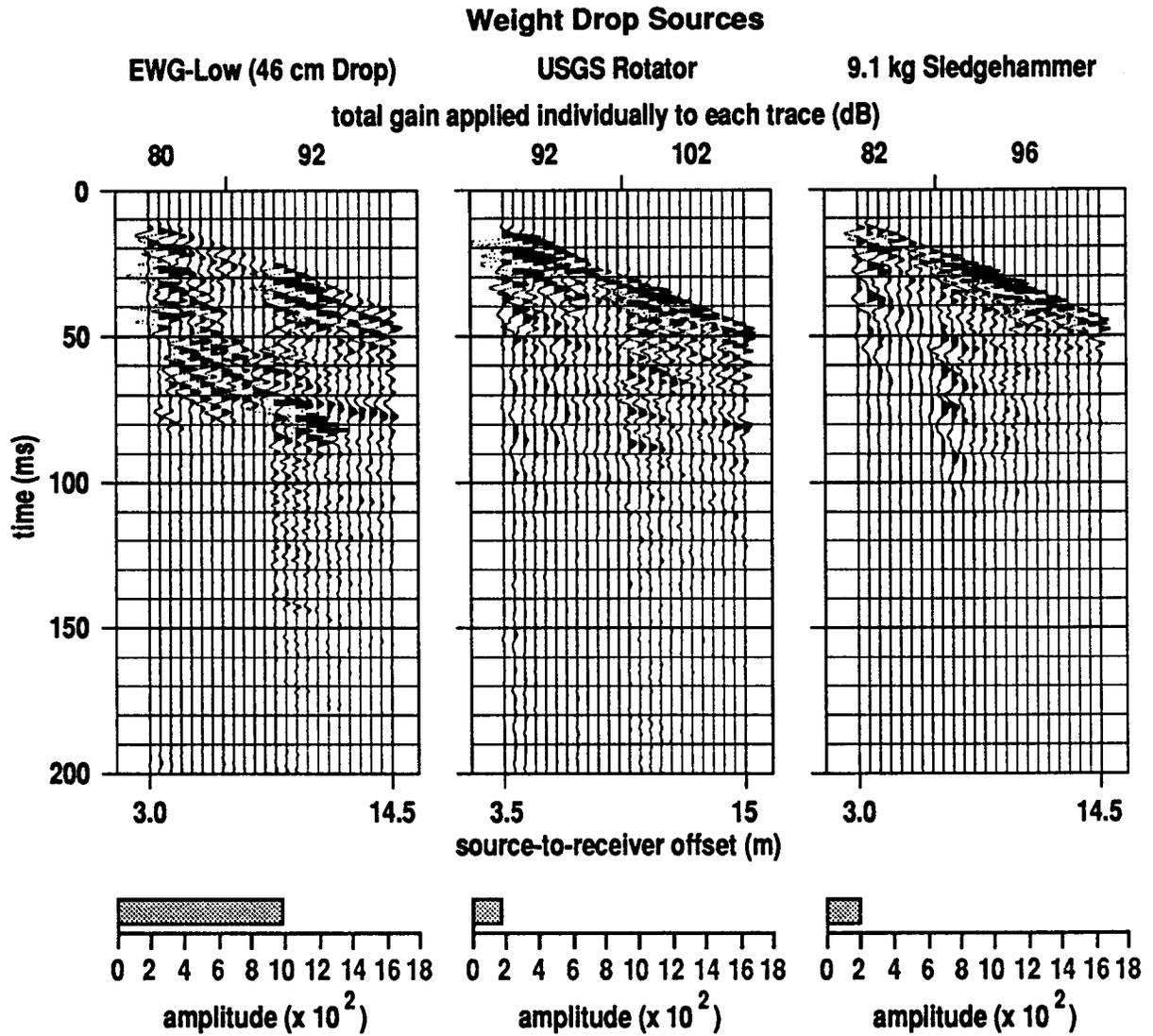


Figure 24 Comparison of weight drop sources. The low energy EWG possess the highest quality reflection at offset greater than 9 meters. The high energy noise after the first breaks on the inside 12 traces of the EWG are most likely the effects of overdriving the analog portion of the seismograph. The outside 12 traces seem to have been recorded with no artifacts. Comparing the three weight drop sources at the longer offsets, the EWG possesses highest signal-to-noise ratio.

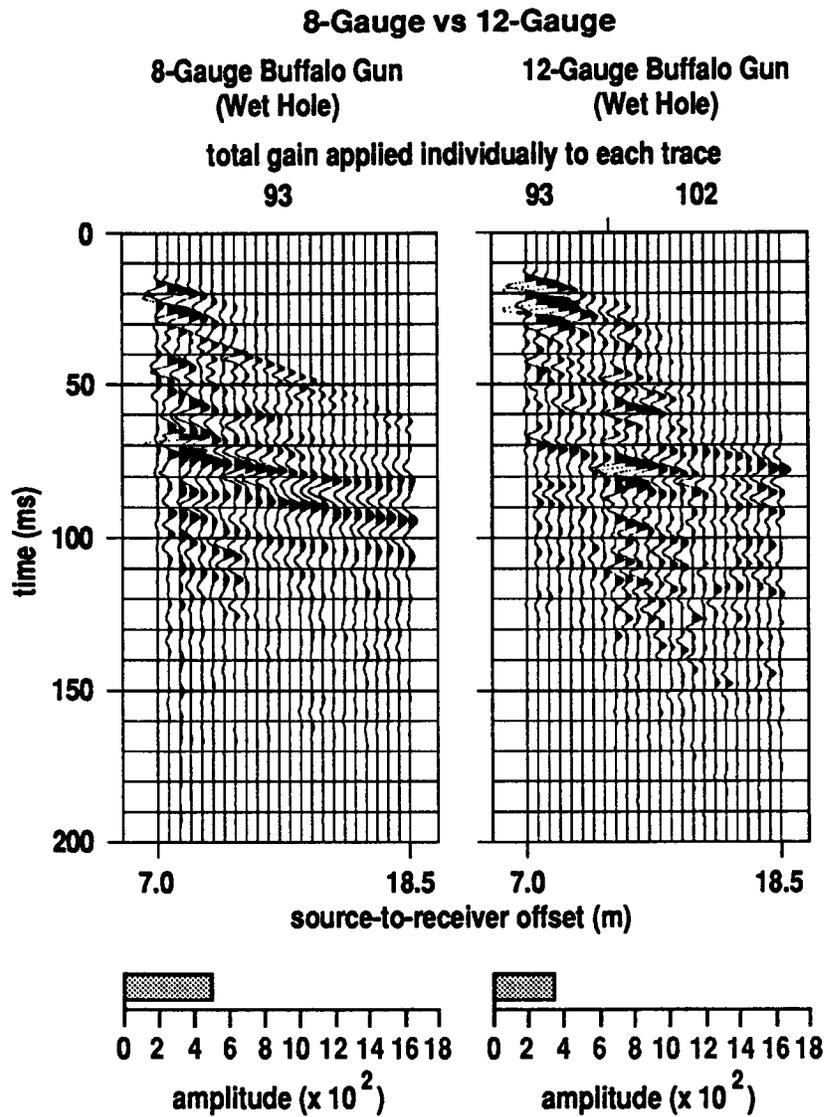


Figure 25 Comparison of 8 and 12-gauge firing rods (300 vs 165 grains of black powder). No air-coupled wave is observable on the 12-gauge and the dominant frequency slightly higher. The 8-gauge possess a stronger, more coherent signal with more trace-to-trace coherency.

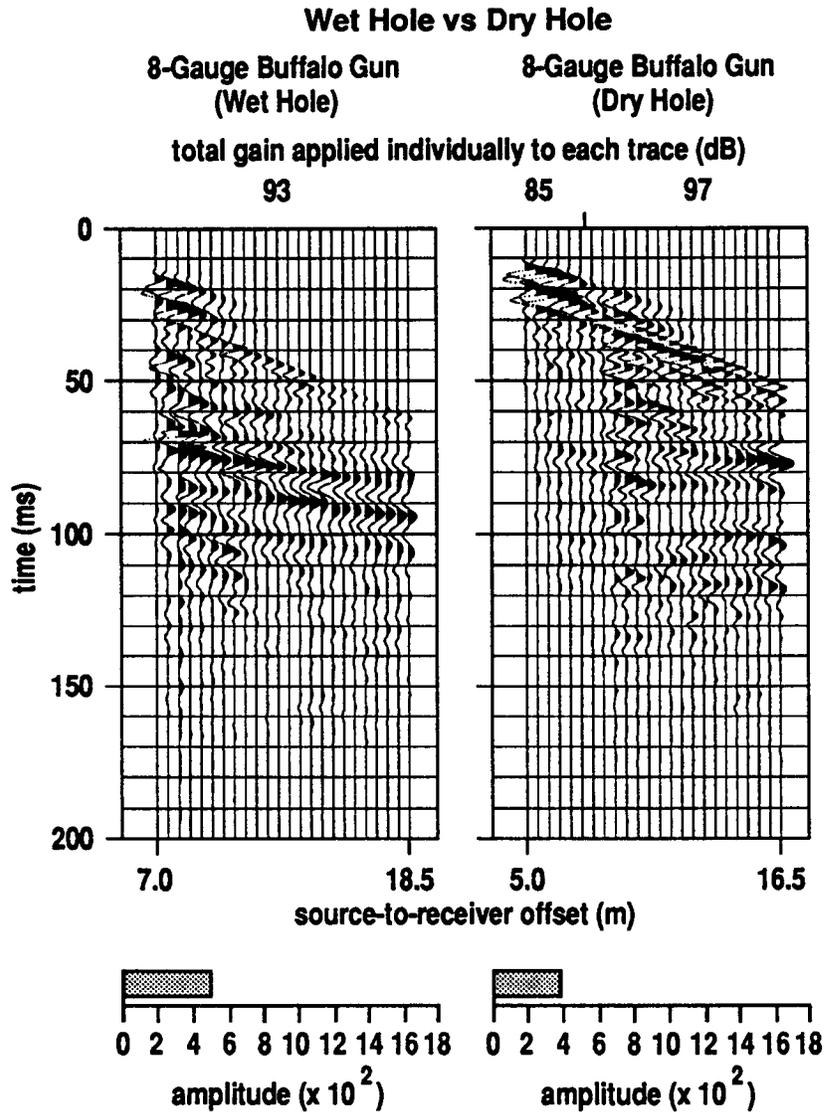


Figure 26 Comparison of wet versus dry hole. The air-coupled wave is much lower amplitude and the signal-to-noise ratio is much higher when the source is detonated in a water filled hole.

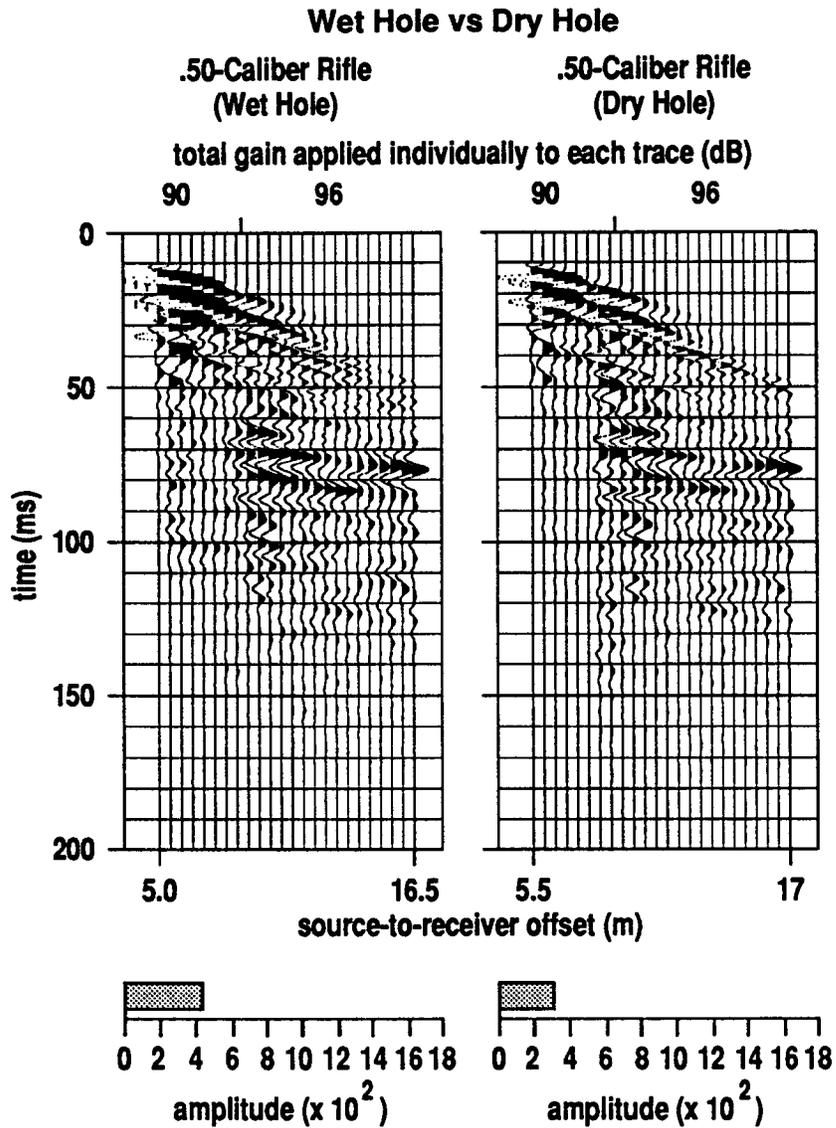


Figure 27 Comparison of wet versus dry hole for the 50-caliber downhole . The difference in signal quality noticeable with the fire rod is not as prevalent with the downhole 50-caliber. The recorded reflection amplitudes are slightly higher but little difference is noticeable in the dominant frequency.

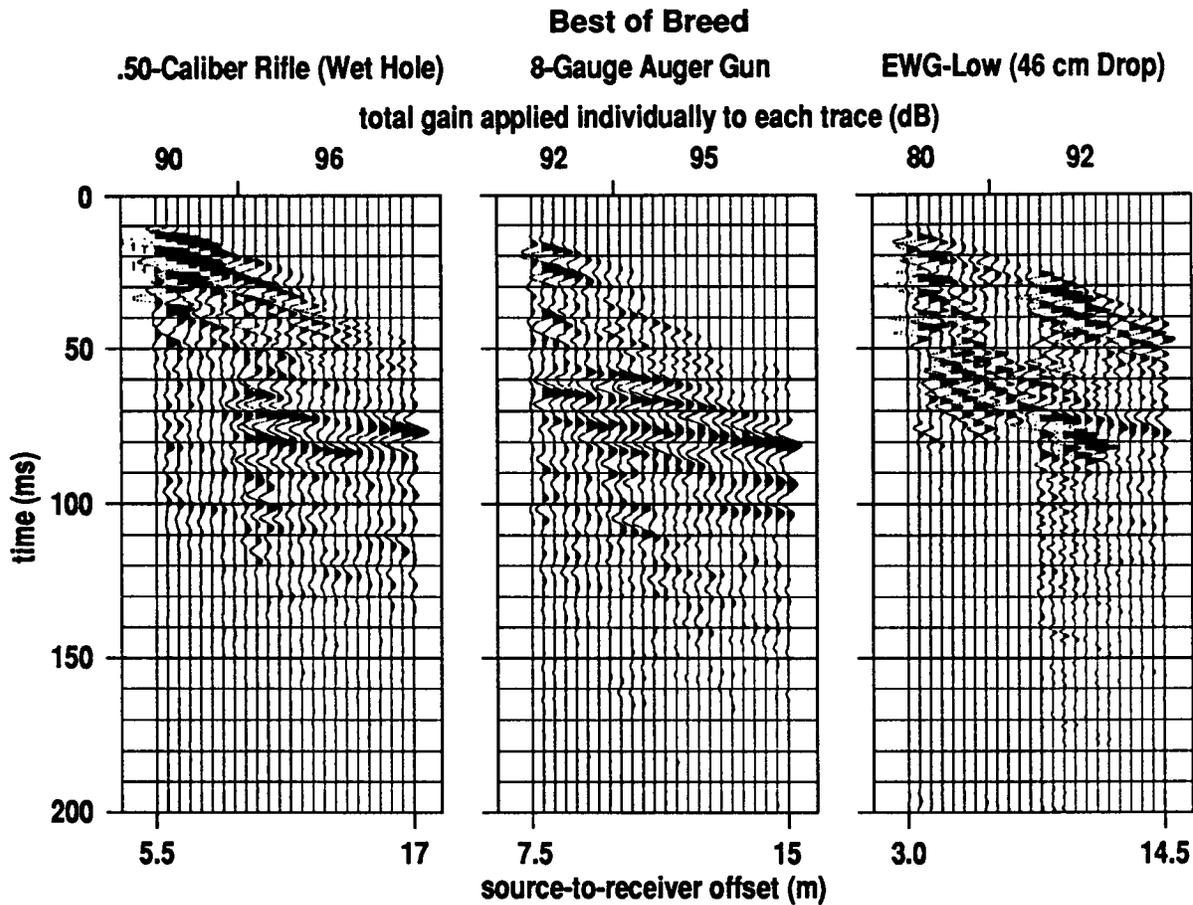


Figure 28 Best of Breed represents a collection of sources that appear to possess the highest number of good qualities for each of the source types tested (excluding high explosives). This group was determined based on data only, many other factors must be considered when choosing a source including: cost, site, conditions, portability, availability, and many others.