

**KANSAS GEOLOGICAL SURVEY  
OPEN-FILE REPORT 92-33**

Field Comparison of Shallow S-wave Seismic Sources near Houston, Texas

by

Richard D. Miller  
Susan E. Pullan  
Dean A. Keiswetter  
Don W. Steeples  
James A. Hunter

*Disclaimer*

The Kansas Geological Survey does not guarantee this document to be free from errors or inaccuracies and disclaims any responsibility or liability for interpretations based on data used in the production of this document or decisions based thereon. This report is intended to make results of research available at the earliest possible date, but is not intended to constitute final or formal publications.

Kansas Geological Survey  
1930 Constant Avenue  
University of Kansas  
Lawrence, KS 66047-3726

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

by

Richard D. Miller\*  
Susan E. Pullan†  
Dean A. Keiswetter\*  
Don W. Steeples\*  
James A. Hunter†

\*Kansas Geological Survey  
1930 Constant Avenue  
Lawrence, Kansas 66047-3726

†Canadian Geological Survey  
601 Booth Street  
Ottawa, Ontario, Canada K1A 0E8

October 1992

Open-file Report #92-33

## SUMMARY

Choosing a seismic source can be a pivotal decision for a shallow-reflection survey. This paper summarizes preliminary results of a shallow S-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 10 different sources in November, 1991, at a single site near Houston, Texas. Confident identification of reflected S-wave energy on field files is not possible with either analog low cut filters out or at 20 Hz. Good quality P-wave reflections can be obtained at this site. 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 P-wave source comparisons in New Jersey and California in *Geophysics* (Miller et al., 1986; 1992).

Engineering and environmental applications of shallow seismic reflection are increasingly focusing on site characterization and highest possible resolution. Combining shallow P- and S-wave data sets allows for in-situ determinations of some engineering properties. Since some of the physical characteristics measured by S-waves and P-waves are different, geologic situations relatively transparent to a P-wave survey could be attuned to S-waves and vice versa. High frequency P-wave reflection energy seems to be sensitive to moisture content of near-surface materials, but S-waves are for the most part unaffected by moisture content. Therefore in some areas S-wave methods could result in higher quality reflections than P-wave methods. With the low velocity of S-waves, potential resolution is greater if the frequencies are comparable. In some unconsolidated environments, S-wave data with half the dominant reflection frequency of equivalent P-wave data could possess significantly higher bed resolution on stacked data.

During November, 1991, a group of shallow-seismic S-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 attempt a controlled comparison of shallow S-wave sources (Figure 1). This comparison was stimulated by increasing enthusiasm and desire among members of the Engineering and Groundwater Committee of the SEG to have a quantified side-by-side comparison of all available shallow S-wave sources. The preliminary results from those tests are summarized in this paper.

Many factors should be considered in a source evaluation. This experiment was designed to be as consistent as possible with the 1985 New Jersey (Miller et al., 1986), 1988 California (Miller et al., 1992), and 1992 Texas (Miller et al., 1992) P-wave 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.

The polarized nature of S-waves increases potential comparison criteria while complicating display and arrival identification. For these tests the sources and receivers were oriented to maximize the potential of recording the SH component of the wave field. For directional sources, left-to-right and right-to-left oriented impacts/explosions were individually recorded, allowing reversal of one direction and overlay of traces in a format slightly modified from the convention adopted by Hasbrouck (1991).

The geologic conditions at this site near Houston, Texas, were relatively conducive to the propagation of high-frequency P-wave energy. The acoustic properties of the near-surface at this site were unknown prior to initial walkaway tests. 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 upper 1 m of near-surface sand was relatively moist due to recent rains. A thin cover of vegetation covered the entire site. P-wave data from this site have interpretable reflections at 40 and 60 ms. These P-wave reflections are probably from the water table and a deeper clay/sand or sand/clay contact, respectively.

Cultural noise was virtually nonexistent. The only noise source outside of the an occasional gust of wind were spectators and source owners preparing sources in the staging areas. In both cases, data were only recorded when noise levels were low. The site was unobstructed by surface barriers that could 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. The record length was 500 ms with a sample interval of 1/2 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. The nearest geophone to the source area was 15 m and the receiver interval was 1 m. The receivers were single horizontal OYO-Geospace 10 Hz geophones, on 0.07 m spikes with the geophone axis perpendicular to the line of the spread. The geophones were firmly planted and left in place throughout the comparison.

All field parameters were held constant for each source except for analog low-cut (high pass) filters and amplifier gains. Each source was fired four times, recording two impacts or explosions with source oriented left-to-right and right-to-left with no low-cut filtering and 20 Hz low-cut filtering, with a 24 dB per octave roll-off from the selected -3 dB point of 20 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 exceeding the maximum 11 bits (relative amplitude plots in the field were used to verify that no signal was clipped).

Each source was fired on, into, or within previously undisturbed ground. The center of the source area was in-line with the spread and 15 m from the first live geophone. The source area was about a 3-m square in which each source had a spot specifically prepared for its individual needs. 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, 21 were the same for all sources. Only the 21 source-to-receiver offsets inherent to all sources were used for spectral analysis. The total surface area disturbed during testing was less than 9 m<sup>2</sup>.

## RESULTS

The participants brought and tested a total of 11 sources (Table 1). The relative source energy and effects of low-cut filtering are evident from relative whole record amplitudes of the various sources (Figure 2). With the polarized nature of some sources, two shots were recorded with all directional sources and with only one shot with explosive sources.

With the directional nature of most S-wave sources, both directions (left-to-right and right-to-left) were recorded and then displayed with the polarity of the right-to-left impact reversed. Traces from the two opposite polarity shots with the same source-to-receiver offsets are displayed adjacent to each other. The data are plotted in a record normalized format. The final report will contain all the data plotted with true amplitude, frequency spectra, power spectra, photographs, and physical information.

It is difficult to confidently identify reflection energy on raw field data (Figures 3 through 13). The first coherent arrival is the air coupled wave. Strong refracted arrivals with a linear velocity of 230 m/s can be interpreted across all 24 traces. A hint of a coherent higher frequency arrival can be observed cross cutting the refractions at about 150 ms. The calculated NMO velocity of this event is not consistent with the S-wave refraction or the P-wave reflections from this site. With the lack of confidently identifiable reflection energy comparisons will be based primarily on relative recorded amplitudes and spectral properties. 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 of an S-wave source test from an area with a moderate water table depth and slow near-surface velocity.

## REFERENCES

- Hasbrouck, W.P., 1991, Four shallow-depth, shear-wave feasibility studies; *Geophysics*, 56, 1875-1885.
- 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.
- Miller, R.D., Pullan, S.E., Keiswetter, D.A., Steeples, D.W., and Hunter, J.A., 1992, Field comparison of shallow seismic sources near Houston, Texas: Kansas Geological Survey, Open-file report #92-32.
- Pullan, S.E., Hunter, J.A., and Neave, K.G., 1990, Shallow shear-wave reflection tests: Exp. Abstrs. of Technical Program with Biographies, SEG, 60th Annual Meeting, San Francisco, Cal., 380-382.

## ACKNOWLEDGMENTS

The authors appreciate the time, effort, and expense put forth by the owners and operators of the sources and donated equipment as well as those who assisted with both the setting-up and execution of this comparison. We gratefully acknowledge the time, effort, and patience provided by Charles Caldwell, owner of the Caldwell Executive Golf Course, who not only graciously allowed us to use his well kept fairways and clubhouse but also provided refreshments on site. We would especially like to thank Phil Martin of Betsy Seisgun; Finn Michelsen, John Mims, Masaki Osada, and Toshiaki Taheuchi of OYO-Geospace Corp.; Brian Todd of the Geological Survey of Canada; Rob Huggins and Chris Leech of EG&G Geometrics; Brian Herridge of Bison Instruments; Bill Jones of B. R. Jones and Associates Inc.; Will Hasbrouck, Gary Olhoeft, and John West of the U. S. Geological Survey; Aldo Mazzella of the U. S. Environmental Protection Agency; Laura Serpa and Greg Williams of the University of New Orleans; Craig Pearson, Karl Thomason, and Chris Hayward of Southern Methodist University; Harry Jol of the University of Calgary; Jason Culp of Rutter and Wilbanks Corp; James Hasbrouck of Chem-Nuclear Geotech; Todd Peterson of Minnesota Dept. of Natural Resources; and Bob Selfridge of Hazwrap/ASG. We also appreciate the efforts of Pat Acker for her graphic design and manuscript preparation and Mary Brohammer's efforts to edit and compile this document.

**TABLE 1**  
**Description and variation of sources and site preparation requirements**

<u>Source</u>	<u>Variation</u>	<u>Site Preparation</u>
1) Wood plank*	impact each end to get reverse polarity	Vehicle weight applied to maximize couple
2) Hasbrouck golf shoe*	operator stands in shoe and impacts from each side	place golf shoe on ground seated by operator's weight
3) GSC metal covered triangular wood block*	operator stands on top of block , impacts on each of the two exposed faces	person weight applied to block to maintain couple
4) Betsy Seisgun M3 8-gauge side discharge	shot 3 oz slug into pipe with side discharge, water filled	Auger hole, drove 0.1 m pipe with side discharge 0.6 m with hammer
5) KGS Geronimo's arrow*	impact wing clockwise then reset, impact counter-clockwise	Press steel arrow on shaft into ground 0.3 m with hydraulic cylinder
6) GSC sideways downhole 12 gauge shooter	12-gauge black powder in wet hole, side discharge	Auger 0.05 m hole, 0.6 m deep fill with water.
7) Betsy 8-gauge Cage Firing Rod	8-gauge 300 grain black powder blank wet hole	Same as source #6
8) KGS steel capped wood block*	impact each end with vehicle weight on block	Vehicle weight on top to seat/couple
9) USGS Rotator	100 rpm setting	Hydraulically place truck weight on device
10) SMU Shear Wave Impulse Generator (SWIG)	internal pneumatic hammers impact each end of metal plank	vehicle weight on plank to seat/couple
11) 30 Grams High Explosive	explosive source with no polarity	Same as source #6

\* 9.1 kg hammer impact: each source requiring a hammer impact had three impacts vertically stacked to make up the stored record.

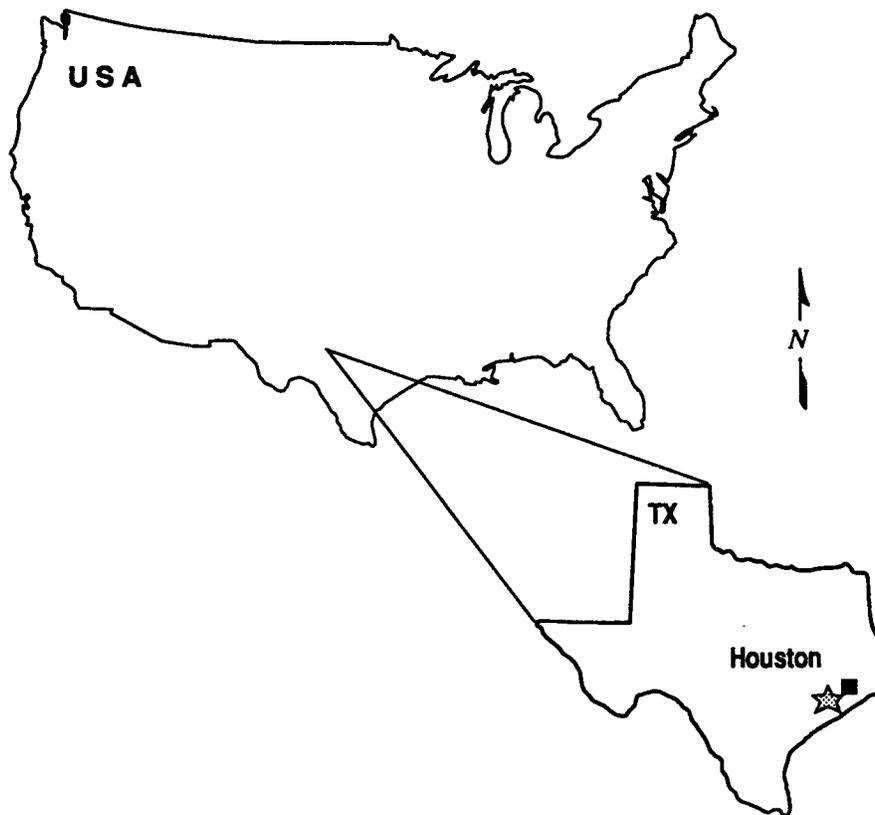


Figure 1 Site map, indicating approximate location of Richmond, Texas.

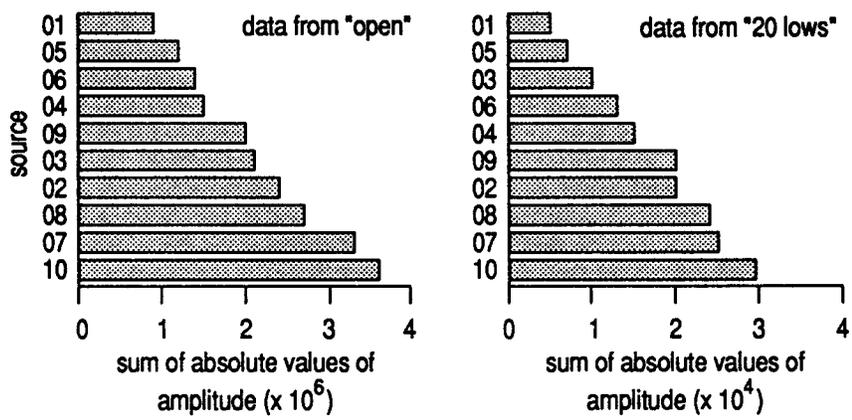


Figure 2 Relative amplitude ranking of sources and variations of sources. Source numbers on the y-axis correlate to numeric listing on table 1.

9.1 kg Hammer/Wood Block

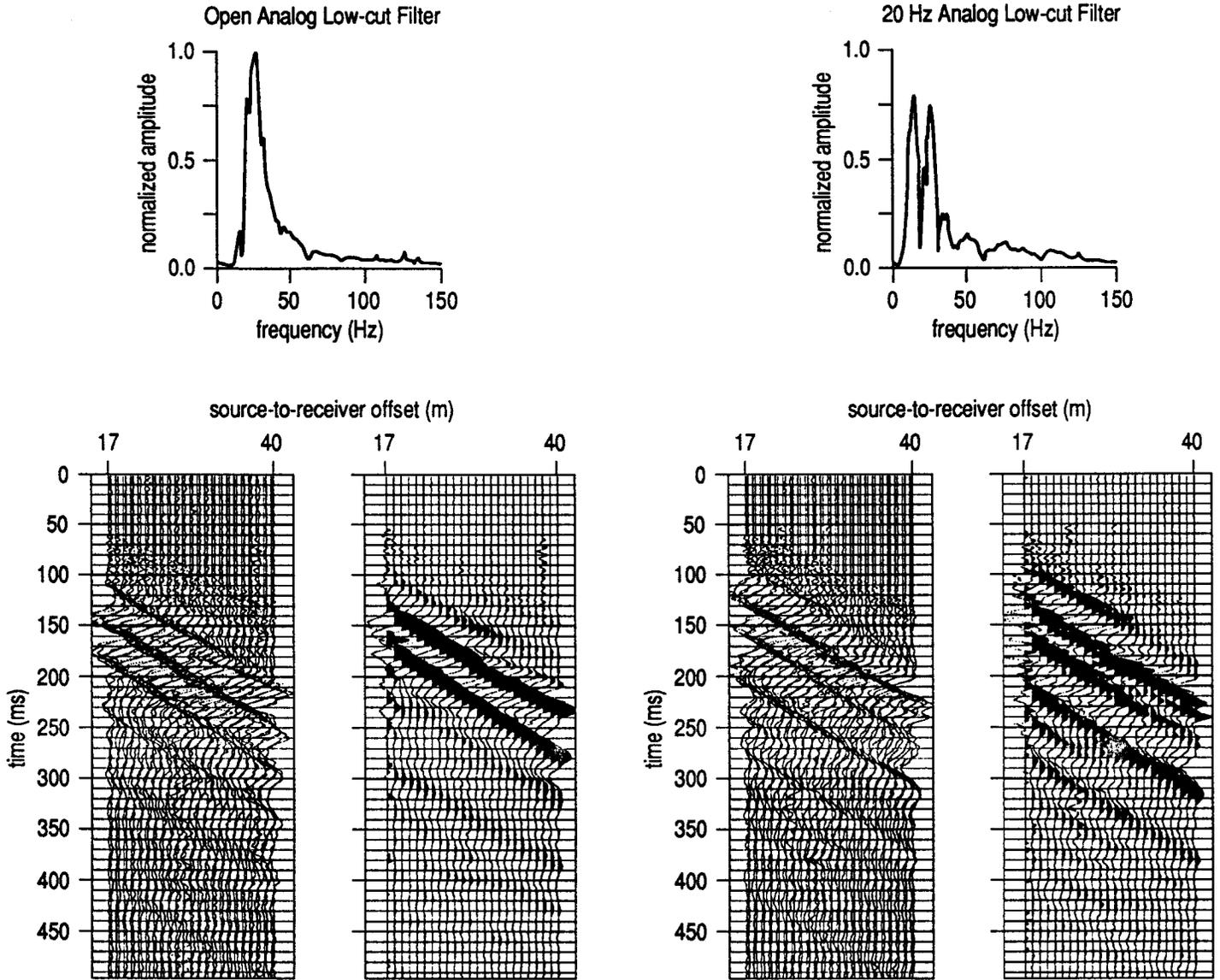


Figure 3 The wood block (6x6 post 6 ft long) was held down with a four wheel loader and both ends of the block were hit three times.

9.1 kg Hammer/Hasbrouck Golf Shoe

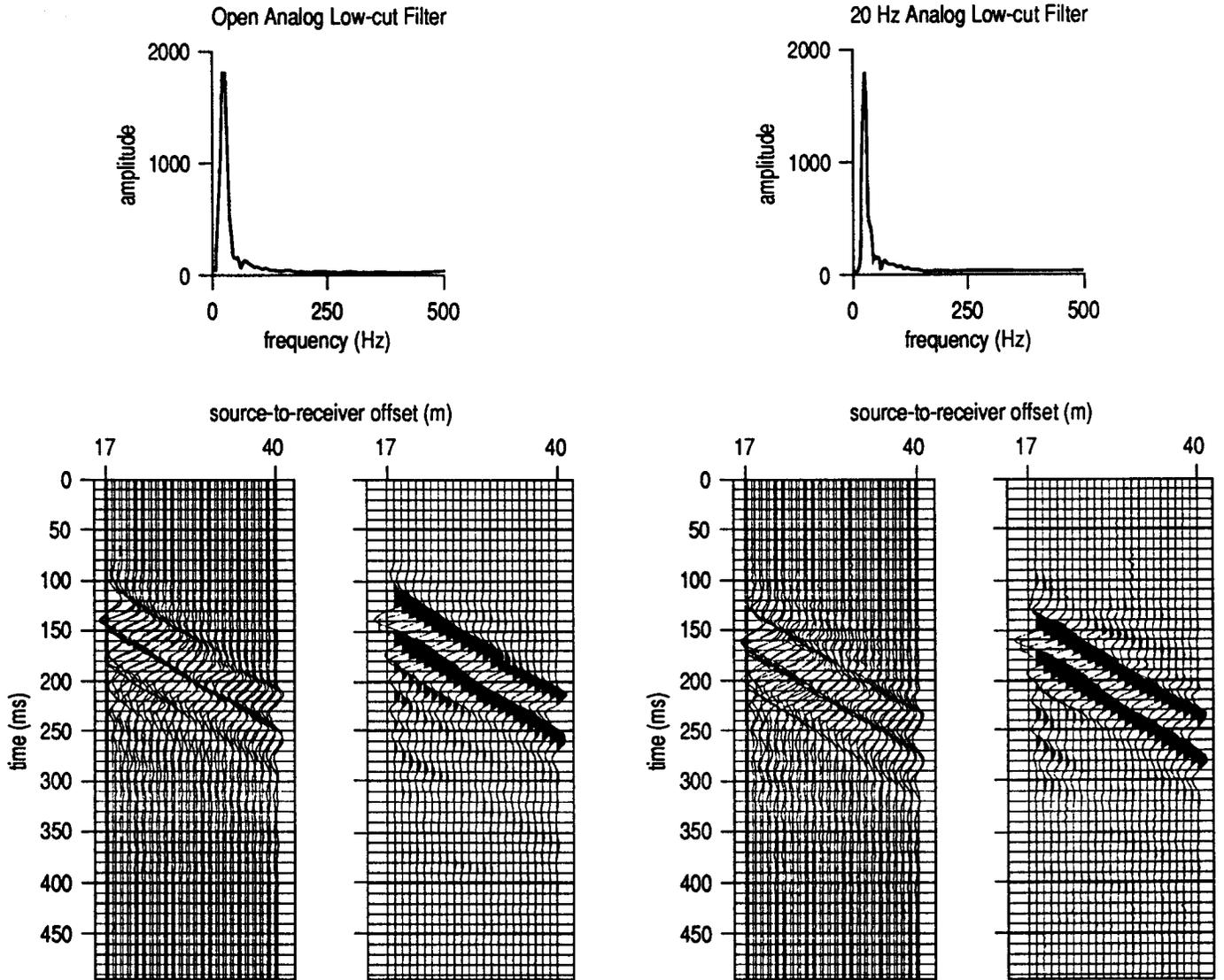


Figure 4 Will Hasbrouck's golf shoe source, a metal framed device with spikes protruding from the base, was held down by a person's weight and then hit on both ends.

5.4 kg Hammer/Triangular Wood Block

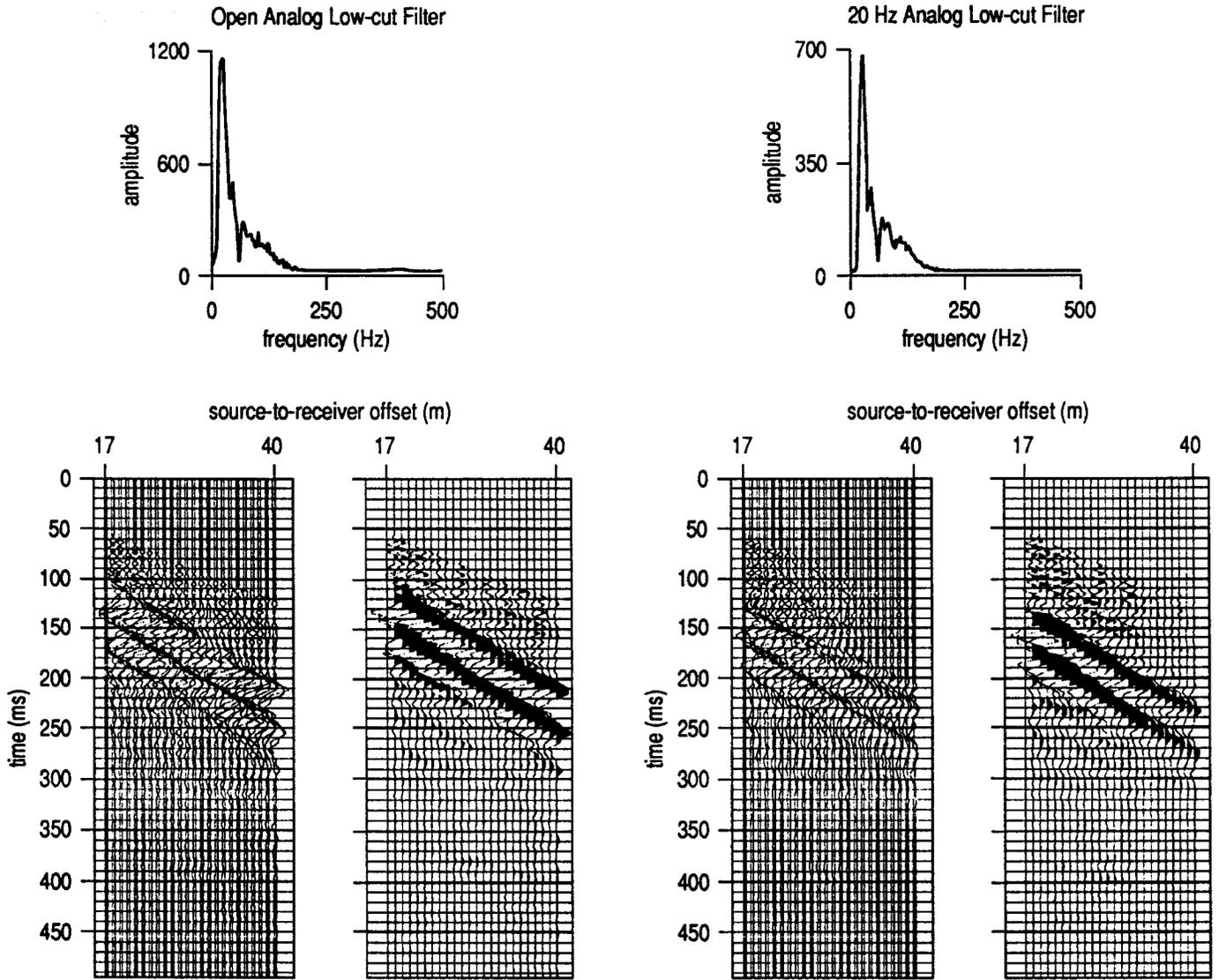


Figure 5 Geological Survey of Canada's triangular wood block with metallic skin. Hammer impacts were at 45 degrees to the ground surface.

8-Gauge Betsy Seisgun/ S-wave Tube

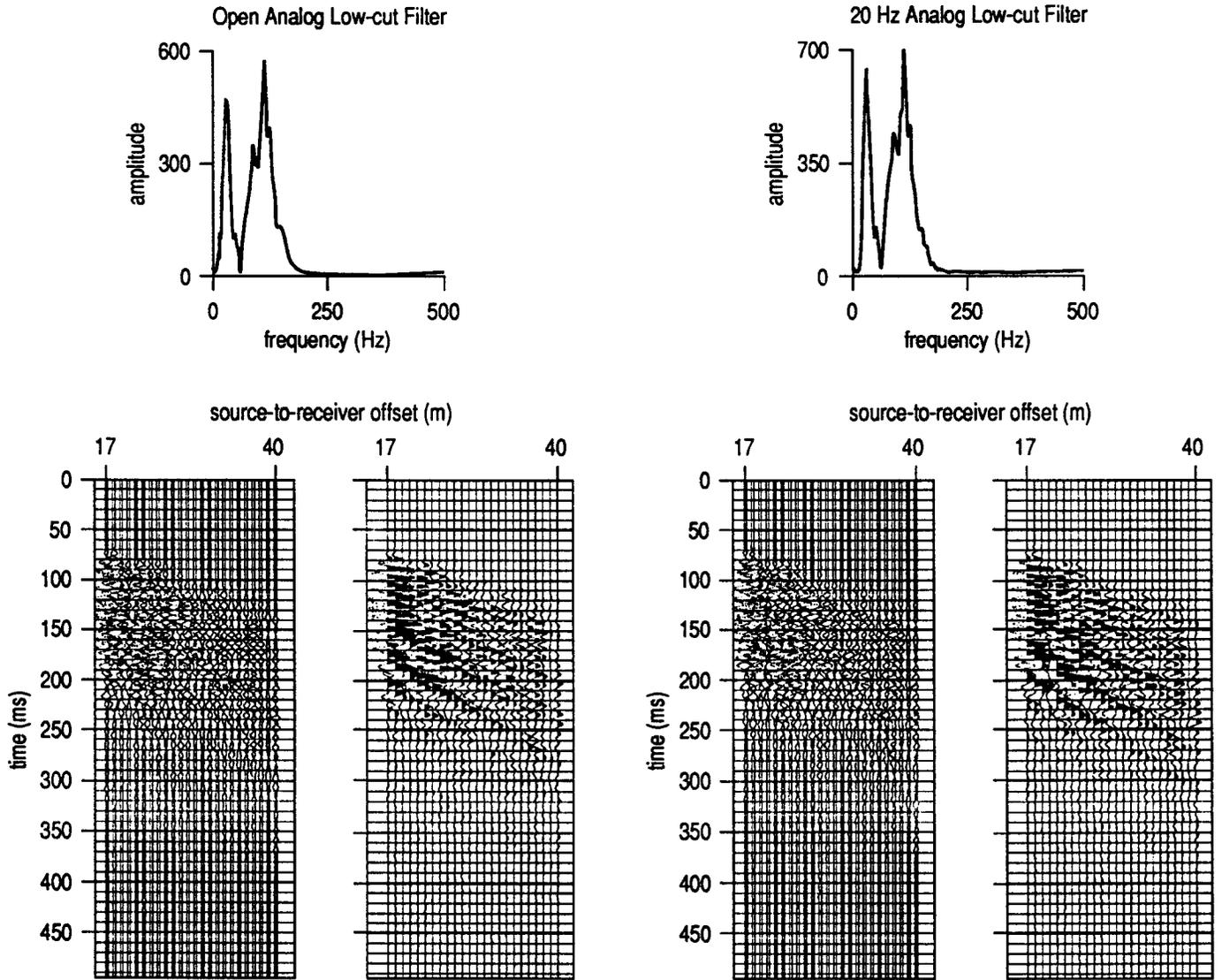


Figure 6 Betsy Seisgun fired into a metal tube with a curved chute at the base forcing the 3 oz lead slug to leave the tube at a right angle.

9.1 kg Hammer/KGS Geronimo's Arrow

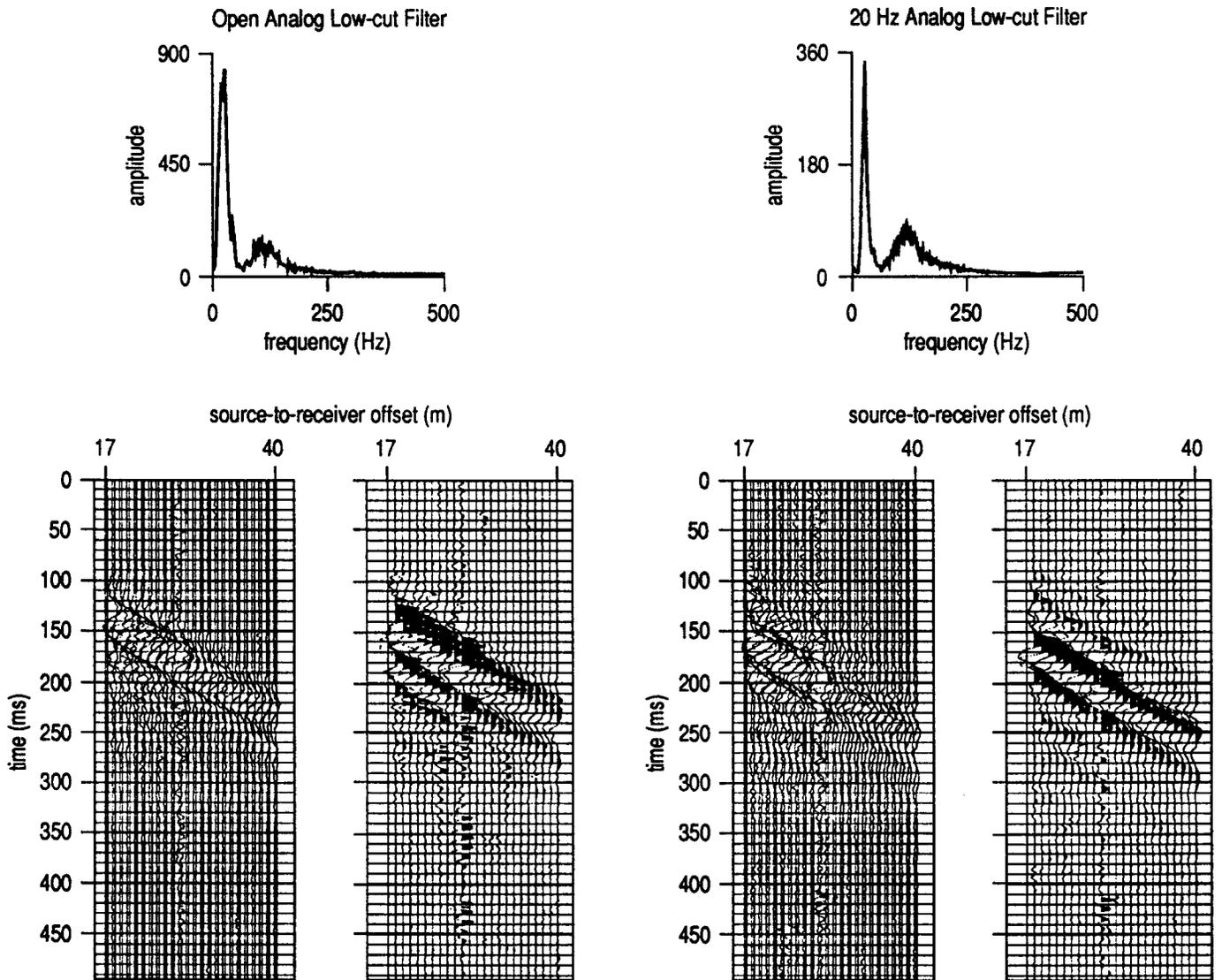


Figure 7 Kansas Geological Survey's Geronimo's arrow is a rotation source with an arrow tip driven about 1 to 1.5 ft into the ground and then rotated with a hammer blow.

12-Gauge GSC Shooter (Wet Hole)

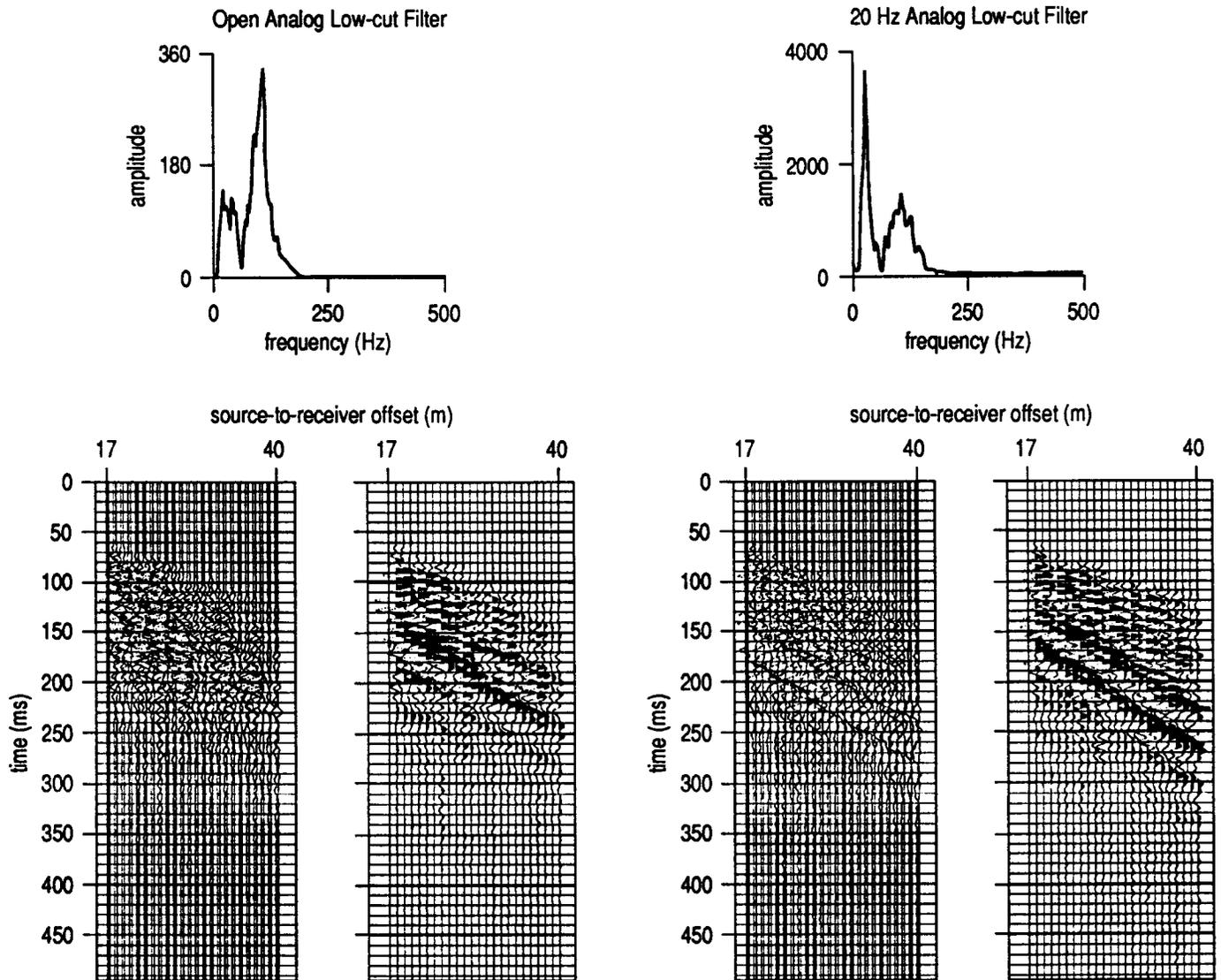


Figure 8 Geological Survey of Canada's sideways shooting 12-gauge gun has a T at the base of a 3 ft pipe where the 12-gauge shell is detonated at the base of the hole and the blast is directed at right angles away from the pipe.

8-Gauge Betsy Cage Gun (Wet Hole)

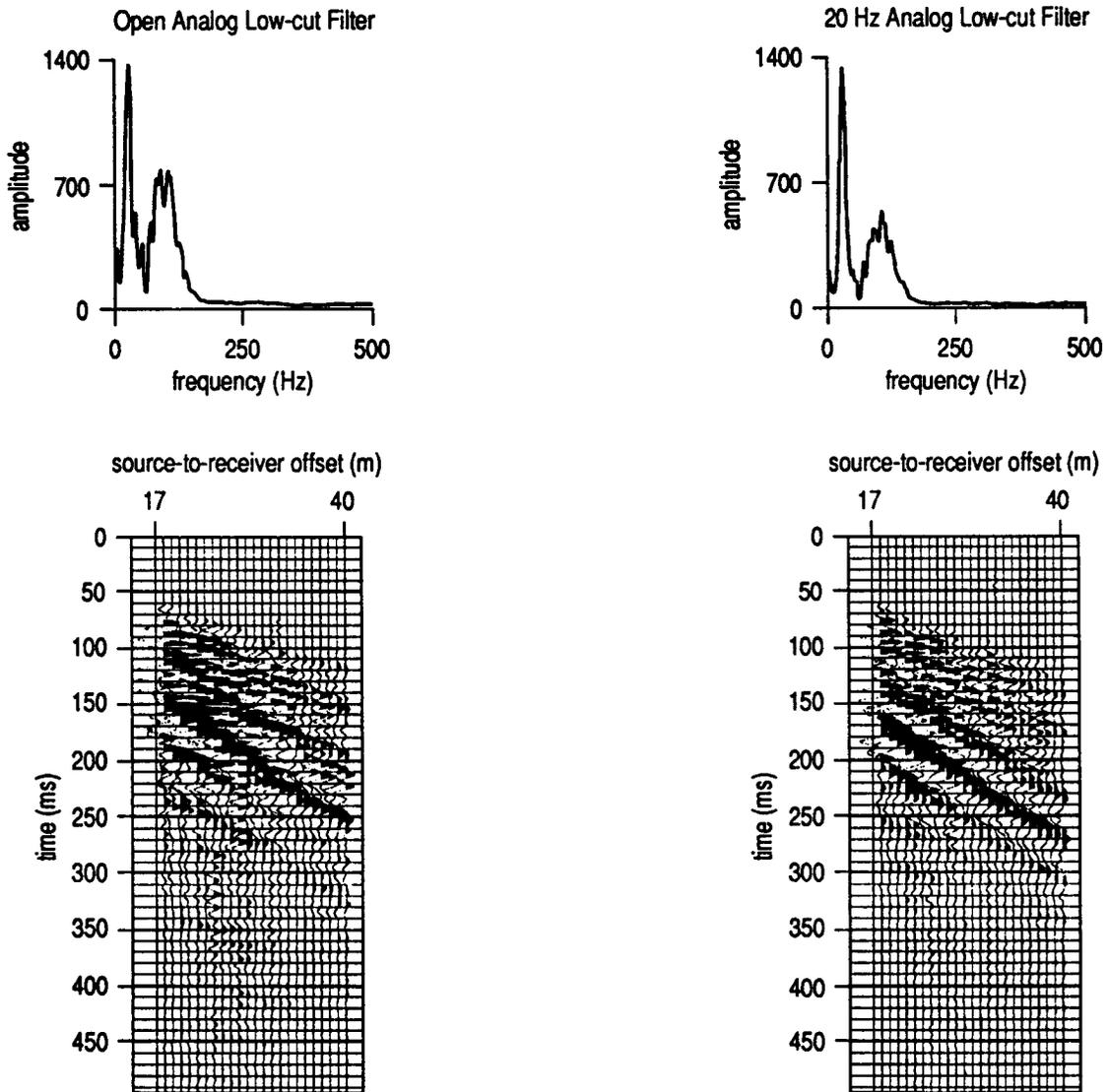


Figure 9 Betsy 8-gauge cage gun detonates an 8-gauge shell in a cage 3 ft below the ground surface, directing the blast in a horizontal direction to the ground surface. This source is not polarized.

9.1 kg Hammer/KGS Mini Wood Block

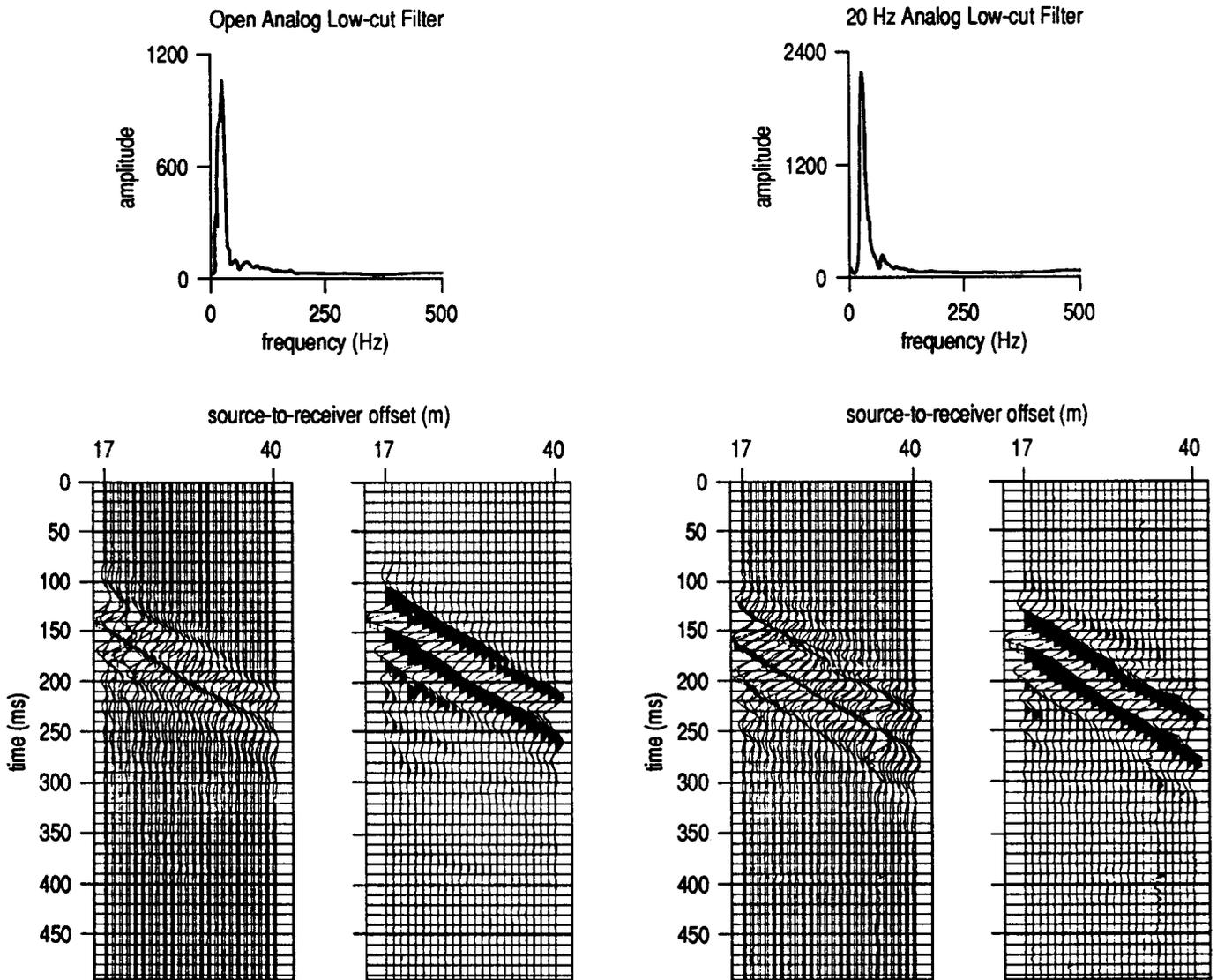


Figure 10 Kansas Geological Survey's mini block is a 4 ft long wood post with steel end caps and triangular shark-style teeth at the base of the steel plates. Impacts on both ends produce the polarized signal.

### USGS Rotator

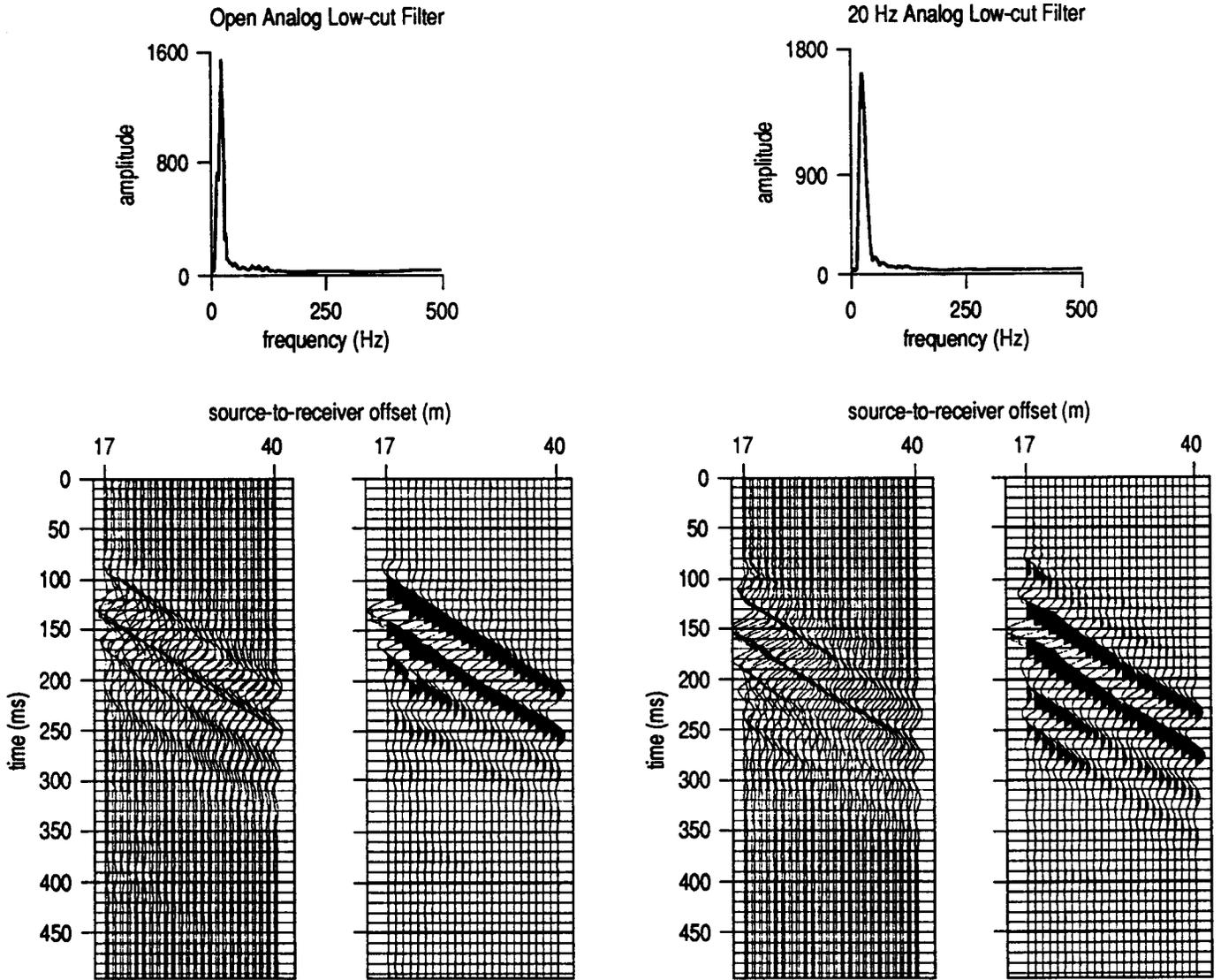


Figure 11 USGS rotator is a truck mounted device with a hammer that is hydraulically swung at a selectable rpm. After a pre-set rpm value is obtained, the source releases and impacts a seated plate with ground coupling ribbing.

SMU (SWIG)

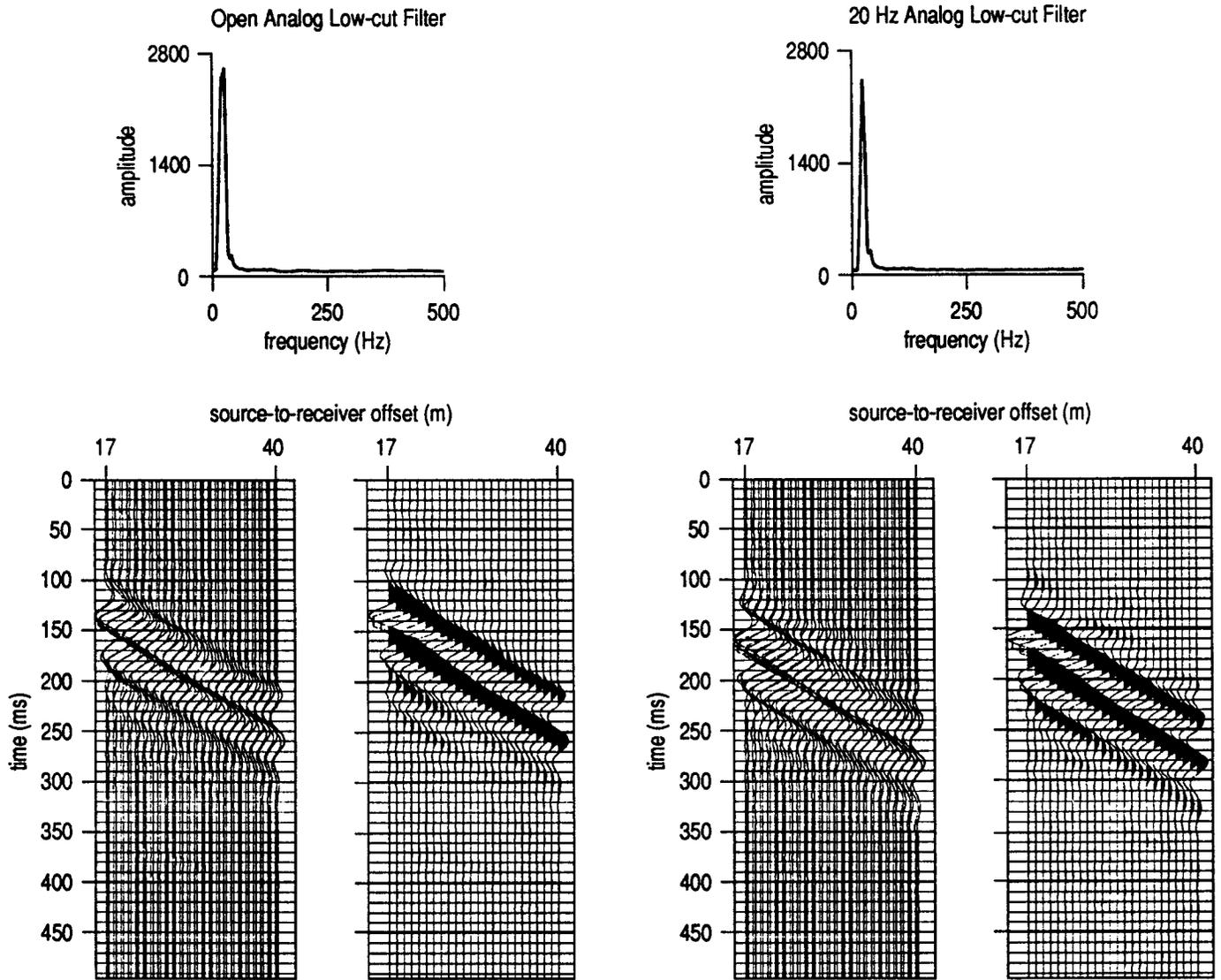


Figure 12 Southern Methodist University's Shear Wave Impulse Generator is a pneumatic hammer device mounted inside a 9 ft long aluminum tube held down by a truck. Compressed air is released into the system and the hammers can impact either end of the tube.

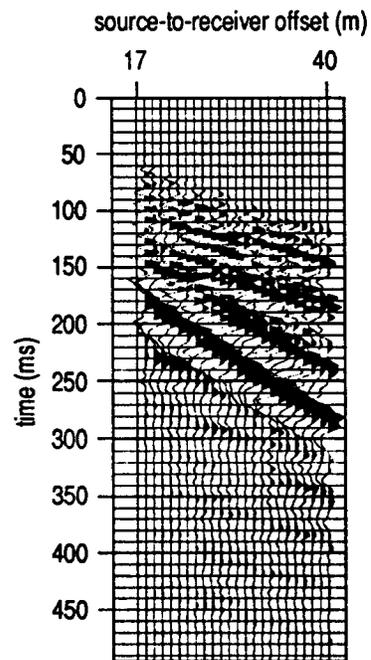
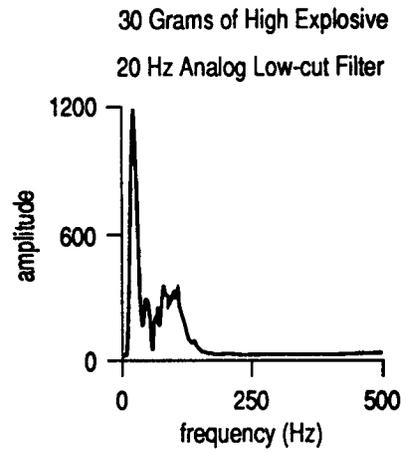


Figure 13 30 grams of high explosive detonated in a 3 ft water filled hole.