# *FIELD COMPARISON OF SHALLOW SOURCES*

# *NEAR CHINO, CALIFORNIA*

by

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## *SUMMARY*

Choosing a seismic source can be the most pivotal decision for a shallow-reflection survey. The intent of this paper is to summarize preliminary results of a shallow seismic-source comparison conducted in an area with a water-table depth in excess of 30 m and near-surface velocities less than 330 m/s. Data were acquired from 13 different sources in November, 1988, at a single site in California. The unique characteristics of each source can be deduced from the data. A possible reflecting event can be interpreted at about 70 ms. The geologic unit responsible for this event is 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*

During November, 1988, a group of shallow-seismic source owners, in cooperation with the Geological Survey of Canada, California Division of Mines and Geology, Kansas Geological Survey, and U.S. Geological Survey, gathered at a site approximately 40 km east of Los Angeles near Chino, California, to compare their sources. The preliminary results from those tests are summarized in this paper. Application of seismic-reflection methods to engineering, ground water, mining, and environmental problems has become increasingly popular over the last 10 years (Jongerius and Helbig, 1988; Steeples and Miller, 1988;

Pullan and MacAulay, 1987; Hunter et al., 1984; Ruskey, 1981; Schepers, 1975). With the extreme site-dependent nature of shallow reflections, any source in a specific geologic setting can generate higher quality and more usable seismic energy than any other. 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.

In an attempt to quantify significant characteristics of some of the more popular shallow-seismic sources, a simple source comparison was conducted in New Jersey during 1985 (Miller et al., 1986). This comparison was orchestrated by the Geologic Survey of Canada, Kansas Geological Survey, New Jersey Geological Survey, and U. S. Geological Survey. Under the geologic conditions at that particular site, the main distinction between the 26 different sources and variations of sources tested was related to the total energy recorded for each source. Very little diversity in recorded seismic characteristics could be deduced from analysis of the data generated during that extensive series of 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 site near Chino, California, were less conducive for the propagation of high-frequency seismic energy than at the New Jersey site. Previous studies in 1985 by the Kansas Geological Survey and the U.S. Geological Survey identified the Chino site as fair-to-poor with respect to recording of shallow-seismic reflections. Some reflection information seems to be present, however, on unprocessed field files around 65 to 85 ms at offsets of between 8 and 15 m (Fig. 2).

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 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 shallow subsurface geology at the site is not well known. The near-surface velocity at the site is unknown. The depth to the water table is more than 30 m. The observed surface and very shallow near-surface material consisted of a thin layer of dust overlying loosely compacted unsorted material with grains ranging in size from clay particles to pebbles. The cultural noise was limited to an occasional car or light plane passing within a predesignated unacceptable distance from live geophones. In cases involving excessive noise, the recording of data was halted until traffic cleared. 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. 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. The nearest geophone to the source area was 8.5 m and the receiver interval was 0.5 m. The receivers were 3-40 Hz L28E Mark Products geophones damped to 0.65 of critical, on 0.14 m spikes, wired in series, and spaced 0.25 m apart perpendicular to the survey line. The geophones were firmly planted and left in place throughout the tests.

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, or 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 plots in the field were used to verify no signal was clipped). The total surface area disturbed during the 2 days of testing was less than 6 $m^2$.

### *RESULTS*

The participants brought and tested a total of 23 sources or variations of sources (Table 1). Thirteen primary types of sources were tested with variations including wet holes, dry holes, types of gun powder, amounts of gun powder, type of projectile, weight of projectile, and drawback on rubber band.

The data are displayed in a true amplitude, variable area wiggle-trace format to allow trace-to-trace and file-to-file comparisons. Indicated on each plotted field file is the total whole trace gain applied individually to each trace. These values take into consideration all gaining from the input port of the seismograph through all processing to the displayed final output. All data can be directly compared, if consideration is given, to the indicated total gain.

Spectral characteristics of each source or source configuration tested is presented in an amplitude-vs-frequency plot. The spectra displayed for each source is a 24-trace average, sampling a time window beginning at 20 ms and ending at the end of the trace (250 ms).

The total amplitude for each source with no low-cut (high pass) filtering will be used to give some indication of relative source energy. The relative amplitude bar-graph display represents the sum of the absolute value of all samples (920 samples) of each trace (24 traces) between 20 to 250 ms of the representative 24-channel seismogram (total samples/amplitude value is 22080). The intent of this graph is to allow relative ordering of the sources according to energy output at this site. The total amplitude value of each source is not necessarily related to the signal-to-noise (S/N) ratio of the recorded data.

Reflections are interpretable on the raw field data at approximately 65 ms (Figs. 3, 4, 5, and 6). The reflection can best be observed on data acquired with 220-Hz analog low-cut filters. The first-arrival information on all the field data at this offset is interpreted as source-generated air coupled wave. This suggests the velocity of the material in the very-near surface is less than the speed of sound in air.

## *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 relatively deep water table and very 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. We hope the final results of this comparison will prove useful to the engineering geophysic community.

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*TABLE 1*

| | Source | Variation | Site Preparation |
|---|---|---|---|
| 1) | 7.3 kg hammer onto steel plate | | Seated steel plate with several impacts. |
| 2) | surface .30-06-cal. rifle silenced | a) shot into undisturbed ground 180-grain bullet.<br>b) shot into water-filled hole 180-grain bullet. | none<br><br>Poured water into bullet hole from previous shot. |
| 3) | downhole .30-06-cal. rifle | shot into wet hole 180 grain projectile. | Poked 1/3 m deep hole with 2.3 cm shaft and poured in water. |
| 4) | 10 kj spark pak | | Dug hole 0.5-m deep and 0.3 m in diameter lined with trash bag and poured in water and salt. |
| 5) | Betsy Seisgun M3 8-ga. | a) undisturbed dry area 3 oz lead slug.<br>b) shot 3 oz into wet hole. | Fired into undisturbed ground.<br>Poured water into hole from dry shot of Betsy. |
| 6) | .50-cal. rifle downhole | a) dry hole<br><br>b) wet hole | Auger drilled 0.05 m hole 0.66 m deep.<br>Poured water in previous dry shot hole; placed condom on end of barrel. |
| 7) | 8-ga. downhole capsules | a) 500-grain high voltage electric detonation.<br>b) 220-grain high voltage electric detonation. | Auger drilled 0.05-m hole 0.66-m deep, loaded capsule, tamped water, and dirt on capsule. |
| 8) | 8-ga. Buffalo Gun /wet hole | a) powder only (blank) 250-grain REM R8BL.<br>b) 3 oz lead slug REM 3 oz Pb.<br>c) powder only (blank) w/PVC liner 250-grain REM R8BL. | Auger drilled 0.05 m hole 0.66 m deep, load gun in hole, pour in water, held in place by ATV*, compression detonation rubber mallet. |
| 9) | 12-ga. Buffalo Gun /wet hole | a) 1 oz lead slug REM SP12-Mag.<br>b) black powder only (blank) WIN VW12BL, 165 grain.<br>c) black powder only (blank) w/PVC liner WIN VW12BL, 165 grain. | Same as source 8, except ATV not used to hold gun down in hole, one-person secured gun. |

| | | | |
|---|---|---|---|
| 10) | .410 Buffalo Gun /wet hole | 1/5-oz lead slug FED F412-RS | Same as source 9. |
| 11) | 8-ga. Betsy Cage Gun downhole | powder only (blank) 250 grain REM R8BL | Same as source 9. |
| 12) | Bison EWG Generator (accelerated weight drop) | a) full extension of rubber band before release.<br>b) extend rubber band 0.5 m before release.<br>c) extend rubber band 0.25 m before release. | Seat 2.6 cm steel plate with several impacts. |
| 13) | Explosives | 1.25 m det. cord 200 grains PETN. | Same as source 7. |

* All terrain vehicle (ATV).

## FIGURE CAPTIONS

FIGURE 1. Location map of Chino, California.

FIGURE 2. Synthetic field file generated using the refraction velocity and depth model generated from the walkaway noise testing. The model used to generate this seismogram is diagramed on the right side of the figure. Each significant body-wave arrival has been identified with a number on the seismogram that correlates to the model diagramed on the right of the figure.

NOTE: All bar graphs used in this paper represent amplitude values (for the indicated source, with the indicated recording parameters) that are the sum of the absolute values of each sample of each of the 24 traces after the 24 traces have been amplitude-corrected to 42 dB of gain and the air-coupled wave has been removed.

FIGURE 3. This bar graph allows comparison of the amplitudes of the recorded seismic energy of each source and configuration of source, with the seismograph's analog low-cut filters out (AP), tested at the Chino site. The values of amplitude are the sum of the absolute value of each sample (1000) of each trace (24) after each trace was gain-corrected to 42 dB and the air-coupled wave was removed.

FIGURE 4. 1) This bar graph allows comparison of the amplitudes of the recorded seismic energy of 10 (Figures 5 through 14) of the more commonly used shallow seismic sources with the seismograph's analog low-cut filters out (AP).

2) Same as figure 4.1 except the seismograph's analog low-cut filters were set at 110 Hz.

3) Same as figure 4.1 except the seismograph's analog low-cut filters were set at 220 Hz.

NOTE: All the seismograms in Figures 5 through 14 have been amplitude corrected. Each of the 24 traces within any particular seismogram has been gained up according to the dB indicated along the top of the seismogram. The gain applied is divided into two parts (partly by coincidence and partly by design) on each seismogram. The first part includes the 17 traces nearest the source and the second part includes the far 7 traces (channel numbers 18 and 24). Two spectra for each seismogram are superimposed on a single amplitude-vs-frequency plot directly above the corresponding seismogram. Both spectra are amplitude corrected to 42 dB of gain. One represents the sum of the 24 individual spectra from a single seismogram; the other is the same sum of 24 spectra except that the air-coupled wave has been removed prior to the spectral determinations. The 10 sources depicted in Figures 2 through 11 were chosen as representative of the majority of actively used types and configurations of shallow-seismic sources. Other sources and configurations will be displayed and compared later in this paper. The time-break system for all sources was a 10-Hz geophone planted within 20 cm of the source. Each source was tested with analog low-cut filters out, 110-Hz analog low-cut filters, and 220-Hz analog low-cut filters. The source-to-nearest-receiver offset was always 8.5 m, with a geophone interval of 0.5 m. A single reflection can be interpreted on some seismograms at approximately 70 ms and 8.5 m offset.

FIGURE 5. Single impact on an approximately 10-lb steel plate with a 20-lb sledge hammer. The steel plate was seated with several impacts with the sledge hammer. The location of the seated steel plate was the same for all shots recorded with the sledge hammer.

FIGURE 6. 10 kJ Sparker immersed in a saltwater solution contained in a dug hole approximately 50 cm deep and 75 cm in diameter. The hole was lined with a plastic bag to contain the salt-water solution. The same hole was used for all the shots recorded with the sparker.

FIGURE 7. Downhole .50-caliber rifle firing a 750-grain projectile into a water-filled hole. Approximately 50 cm of the rifle barrel was submerged in the water-filled hole. A standard condom was used to keep water out of the rifle barrel. A new hole was used for each shot.

FIGURE 8. 8-gauge Betsy Seisgun fired into a 50-cm hole filled with water. The Betsy was firing a 3-oz lead slug. A new hole was used for each shot.

FIGURE 9. Downhole .30-06 rifle firing a 180-grain projectile into a 50-cm deep water-filled hole. Approximately 25 cm of the gun barrel was submerged in the water-filled hole. The water was kept out of the gun barrel with a standard condom covering the end of the barrel. A new hole was used for each shot.

FIGURE 10. 13 grams of PETN with 1.2 m of Det Cord. The charge was placed at the bottom of a 0.8-m hole and stemmed with water and dirt. A new hole was used for each shot. Each shot was fired electrically with a standard seismic blasting box.

FIGURE 11. 14-gram black powder 8-gauge capsule. This 8-gauge electrically detonated blank shotgun shell was incased in a PVC housing, buried, and detonated with a standard seismic blasting box. The stemming material for the 0.8-m holes included water and dirt. A new hole was used for each of the three recorded shots.

FIGURE 12. 8-gauge buffalo gun fired into a water-filled hole at a depth of approximately 0.8 m. The buffalo gun was compression-fired using a rubber mallet to strike the firing rod exposed at the top of the gun approximately 1-m above the ground surface. The 8-gauge shell was a black-powder blank round (i.e., no projectile). A new hole was used for each of the three recorded shots.

FIGURE 13. 8-gauge buffalo gun fired into a water-filled hole at a depth of approximately 0.8 m. The buffalo gun was compression-fired using a rubber mallet to strike the firing rod exposed at the top of the gun approximately 1 m above the ground surface. The 8-gauge shell was a 250-grain load firing a 3-oz projectile. A new hole was used for each of the three recorded shots.

FIGURE 14. 12-gauge buffalo gun fired into a water-filled hole at a depth of approximately 0.8 m. The buffalo gun was compression-fired using a rubber mallet to strike the firing pin at the top of the gun approximately 1 m above the ground surface. The 12-gauge shell was a magnum load of black powder with no projectile (blank). A new hole was used for each of the three recorded shots.

NOTE: All figures from 15 through 23 are gain-adjusted (as Figures 2 through 11) according to the first 17 channels and the last 7 channels. The amount of whole-trace fixed-gain applied is indicated above each trace along the top of the seismograms. These next set of figures compare like or similar sources under a variety of different conditions. The figures are each given a numeric value (sequential) as well as an (1a, 2a, or 3a) or (1b, 2b, or 3b). The (a) part of each figure contains the variable area wiggle-trace display, while the (b) portion is a bar-graph representation of relative whole-trace amplitudes. The relative whole-trace amplitudes are defined (as previously noted)as the sum of the absolute value of each sample within the indicated field file (after the air-coupled wave has been removed). For this data set, the absolute values of 24,000 samples are added to determine the relative whole-trace amplitude. The relative whole-trace amplitude is intended to give some indication of relative seismic energy generated by a particular source. The recording and display of the seismograms have been done in such a way as to allow direct comparison with respect to the indicated parameter(s) changes. The intent of this next set of figures is to highlight particular characteristics of each source and source configuration that may be significant to a shallow-reflection or refraction survey at this site or sites similar to this one.

FIGURE 15. 1a) Comparison of seismograms of the 8-gauge buffalo gun firing black-powder blanks with and without water in the drilled hole.

1b) Graph of relative whole-trace amplitudes comparing the 8-gauge buffalo gun fired with and without water.

FIGURE 16. 1a) All 8-gauge sources tested with analog low-cut filters out (AP): Betsy Seisgun firing 3-oz lead slugs, 14-gram capsules with black-powder loads; Buffalo gun 15-gram black-powder loads; Buffalo gun firing 3-oz lead slugs; Buffalo gun 15-gram black-powder loads with PVC sleeve; and Betsy Seisgun.

1b) Graph of relative whole-trace amplitudes of the 8-gauge sources tested with analog low-cut filters out (AP).

2a) All 8-gauge sources tested with analog low-cut filters set at 110 Hz: Betsy Seisgun firing 3-oz lead slugs, 14 gram capsules with black powder loads; Buffalo gun 15-gram black-powder loads; Buffalo gun firing 3-oz lead slugs; Buffalo gun 15-gram black-powder loads with PVC sleeve; and Betsy Seisgun firing 15-gram black-powder loads.

2b) Graph of relative whole-trace amplitudes of the 8-gauge sources tested with analog low-cut filters set at 110 Hz.

3a) All 8-gauge sources tested with analog low-cut filters set at 220 Hz: Betsy Seisgun firing 3-oz lead slugs, 14-gram capsules with black-powder loads; Buffalo gun 15-gram black-powder loads; Buffalo gun firing 3-oz lead slugs; Buffalo gun 15-gram black-powder loads with PVC sleeve; and Betsy Seisgun firing 15-gram black-powder loads.

3b) Graph of relative whole-trace amplitudes of the 8-gauge sources tested with analog low-cut filters set at 220 Hz.

FIGURE 17. 1a) Both 8-gauge and 12-gauge Buffalo guns comparing black-powder blanks and lead slugs with analog low-cut filters out (AP). The 8-gauge gun source compares a 14-gram black-powder blank load to a 3-oz lead slug with a 15-gram powder charge. The 12-gauge gun source compares an 11-gram black-powder blank load to a 1-oz lead slug with a 12-gram powder charge.

1b) Graph of relative whole trace amplitudes of the 8- and 12-gauge buffalo guns comparing blanks and slugs with analog low-cut filters out (AP).

2a) Both 8-gauge and 12-gauge Buffalo guns comparing black-powder blanks and lead slugs with analog low-cut filters set at 110 Hz. The 8-gauge gun source compares a 14-gram black-powder blank load to a 3-oz lead slug with a 15-gram powder charge. The 12-gauge gun source compares an 11-gram black-powder blank load to a 1-oz lead slug with a 12-gram powder charge.

2b) Graph of relative whole-trace amplitudes of the 8- and 12-gauge buffalo guns comparing blanks and slugs with analog low-cut filters set at 110 Hz.

3a) Both 8-gauge and 12-gauge Buffalo guns comparing black-powder blanks and lead slugs with analog low-cut filters set at 220 Hz. The 8-gauge gun source compares a 14-gram black-powder blank load to a 3-oz lead slug with a 15-gram powder charge. The 12-gauge gun source compares an 11-gram black-powder blank load to a 1-oz lead slug with a 12-gram powder charge.

3b) Graph of relative whole-trace amplitudes of the 8- and 12-gauge buffalo guns comparing blanks and slugs with analog low-cut filters set at 220 Hz.

FIGURE 18 1a) Seismograms of 8-gauge Buffalo gun firing 14-gram black-powder blanks into a water-filled hole recorded with the analog low-cut filters out (AP). The same source was fired once with the gun held down with an ATV the other time the source was fired unheld.

1b) Graph of relative whole-trace amplitudes of the 8-gauge Buffalo gun held by an ATV and unheld with analog low-cut filters out.

FIGURE 19 1a) Comparison of seismograms of the two surface projectile sources tested (Betsy Seisgun and silenced .30-06) fired into a 50 cm deep-drilled hole, once filled with water and once dry. The analog low-cut filters were out (AP).

1b) Graph of relative whole-trace amplitudes of the the two surface projectile sources tested comparing water-filled to dry holes with the low-cut filters out (AP).

2a) same as 19.1a except recorded with 110-Hz analog low-cut filters

2b) same as 19.1b except recorded with 110-Hz analog low-cut filters

3a) same as 19.1a except recorded with 220-Hz analog low-cut filters

3b) same as 19.1b except recorded with 220-Hz analog low-cut filters

FIGURE 20 1a) Comparison between of down hole .50-caliber rifle seismograms with water in a 80-cm-deep bore hole and a dry 80-cm hole with the analog low-cut filters out (AP).

1b) Graph of relative whole-trace amplitudes of the seismograms recorded with the .50-caliber downhole gun with and without water in the hole. The analog low-cut filters were out (AP)

2a) same as 20.1a except recorded with 110-Hz analog low-cut filters.

2b) same as 20.1b except recorded with 110-Hz analog low-cut filters.

3a) same as 20.1a except recorded with 220-Hz analog low-cut filters.

3b) same as 20.1b except recorded with 220-Hz analog low-cut filters.

FIGURE 21 1a) Comparison of seismograms of 14-gram 8-gauge capsules to 13-gram high explosives with a water/mud stem recorded with analog low-cut filters out (AP).

1b) Graph of relative whole-trace amplitudes of the seismograms comparing the 14-gram capsules and the 13-gram high explosive with analog low-cut filters out (AP).

2a) same as 21.1a except recorded with 110-Hz analog low-cut filters.

2b) same as 21.1b except recorded with 110-Hz analog low-cut filters.

3a) same as 21.1a except recorded with 220-Hz analog low-cut filters.

3b) same as 21.1b except recorded with 220-Hz analog low-cut filters.

FIGURE 22 1a) Comparison of seismograms of the .30-06 rifle fired on the surface (silencer) and downhole (both into water-filled 80 cm holes) with the analog low-cut filters out (AP).

1b) Graph of relative whole-trace amplitudes of the seismograms comparing the downhole and the surface fired .30-06 rifle with the analog low-cut filters out (AP).

2a) same as 22.1a except recorded with 110-Hz analog low-cut filters.

2b) same as 22.1b except recorded with 110-Hz analog low-cut filters.

3a) same as 22.1a except recorded with 220-Hz analog low-cut filters.

3b) same as 22.1b except recorded with 220-Hz analog low-cut filters.

FIGURE 23 1a) Comparison of the EWG (Elastic Wave Generator) and the 20 lb sledge hammer with the low-cut filters out. The EWG generated a measurable amount of engine noise. This should be kept in mind when comparing frequency spectra.

1b) Graph of relative whole trace amplitudes of the seismograms comparing the EWG to the 20-lb sledge hammer with the analog low-cut filters out (AP). A portion of the total amplitude of the EWG was from the gasoline engine that was necessary to run in order to fire this source.

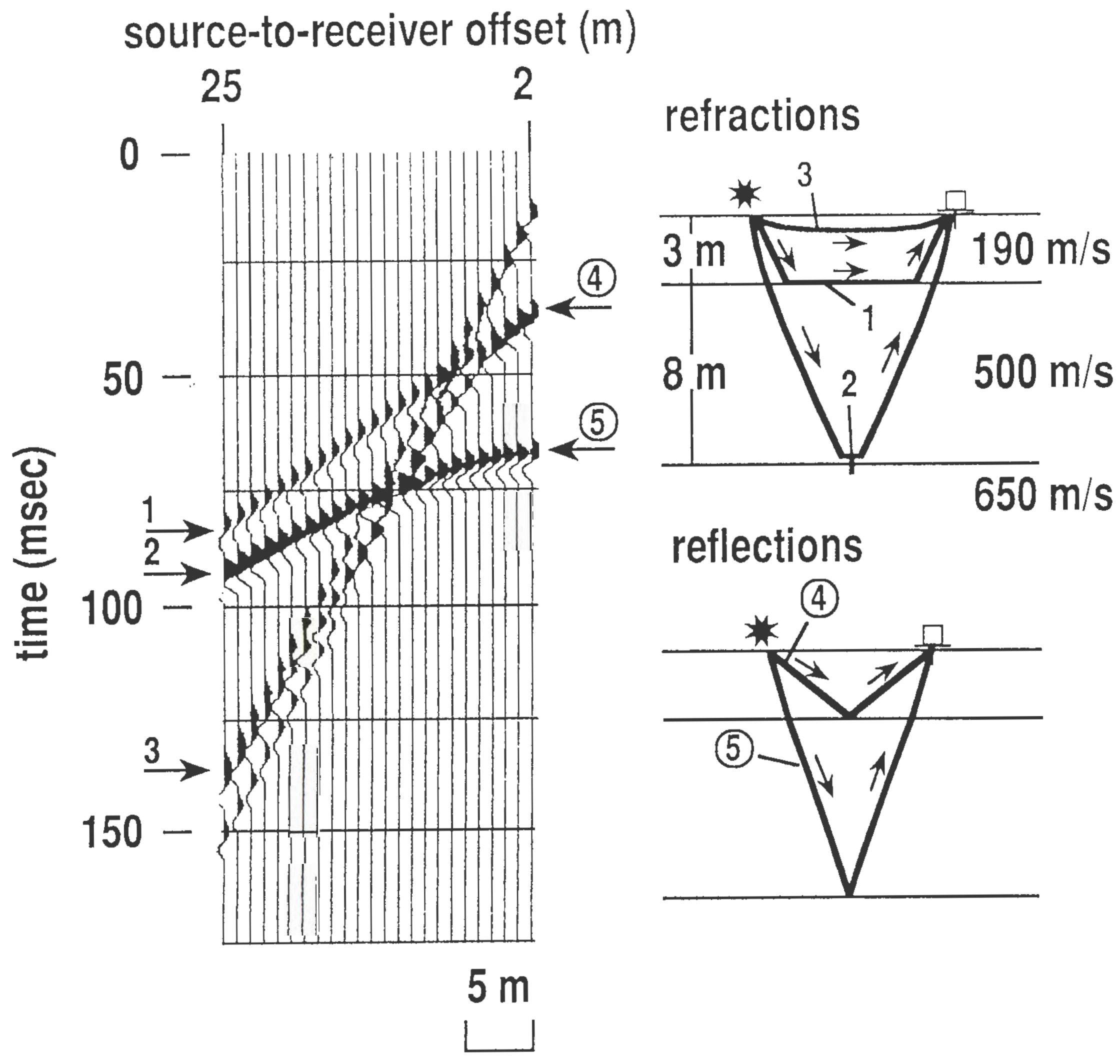
2a) same as 23.1a except recorded with 110-Hz analog low-cut filters.

2b) same as 23.1b except recorded with 110-Hz analog low-cut filters.

3a) same as 23.1a except recorded with 220-Hz analog low-cut filters.

3b) same as 23.1b except recorded with 220-Hz analog low-cut filters.

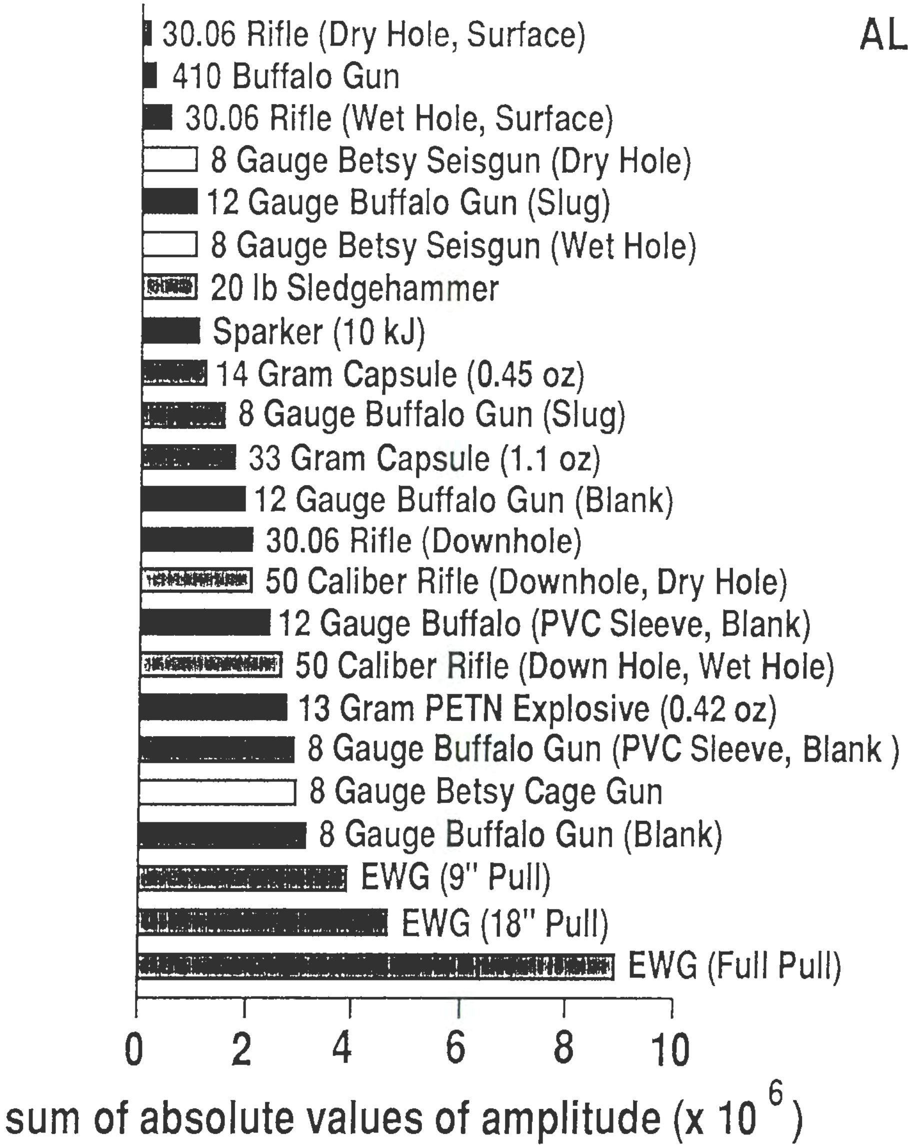

San Francisco
PACIFIC
OCEAN
Los Angeles
CHINO
San Diego
N
80 km



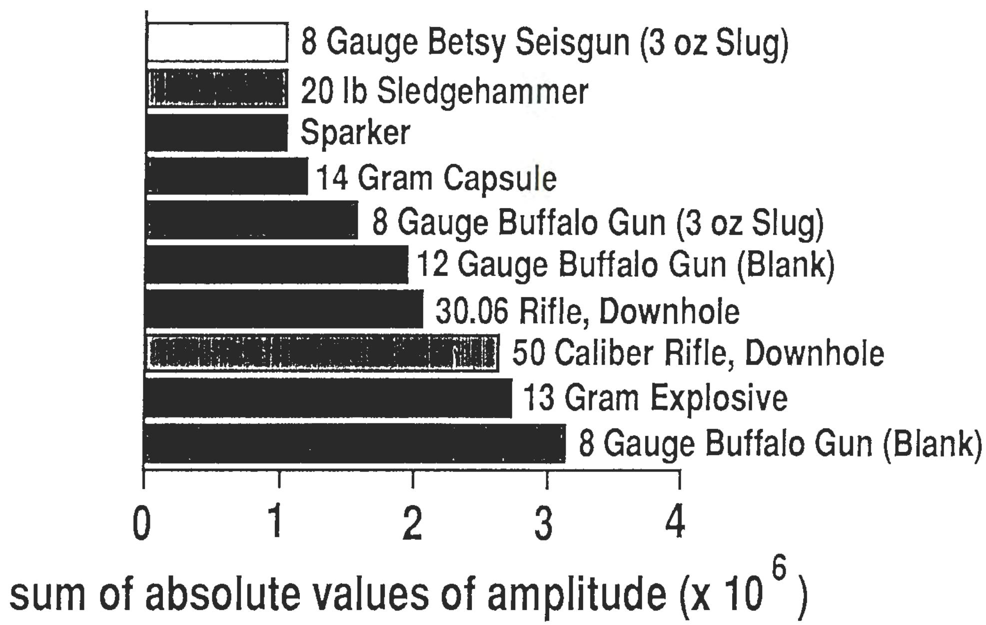
source-to-receiver offset (m)
25
2
0
50
100
150
time (msec)
1
2
3
④
⑤
5 m
refractions
3
3 m
190 m/s
1
8 m
2
500 m/s
650 m/s
reflections
④
⑤


FIGURE 2

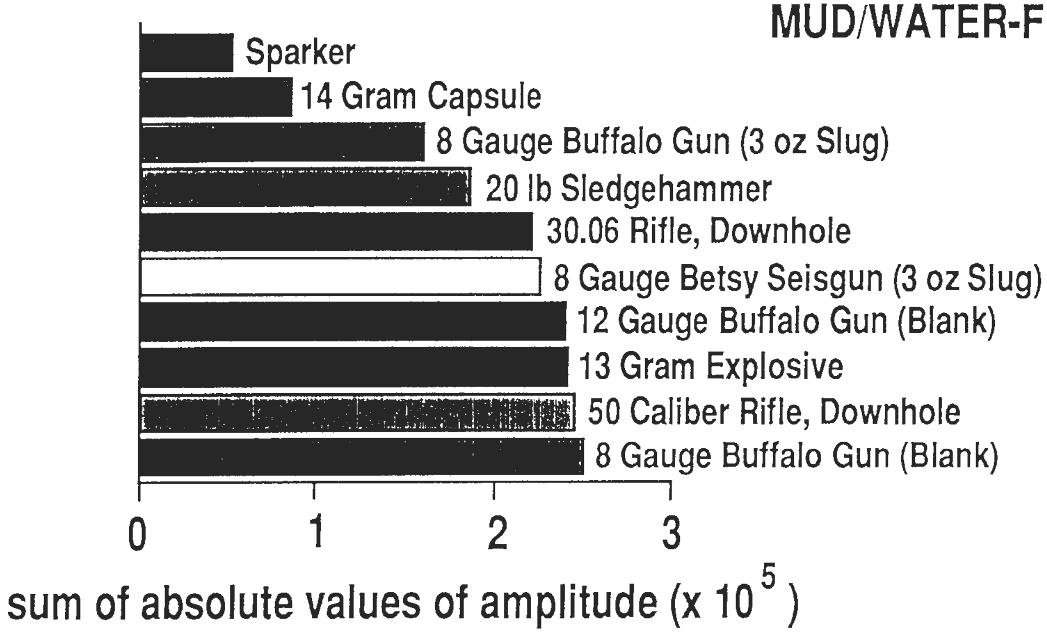
ALL SOURCES & CONFIGURATIONS
TESTED AT
CHINO AIRPORT, CALIFORNIA
LOW CUT FILTERS OUT



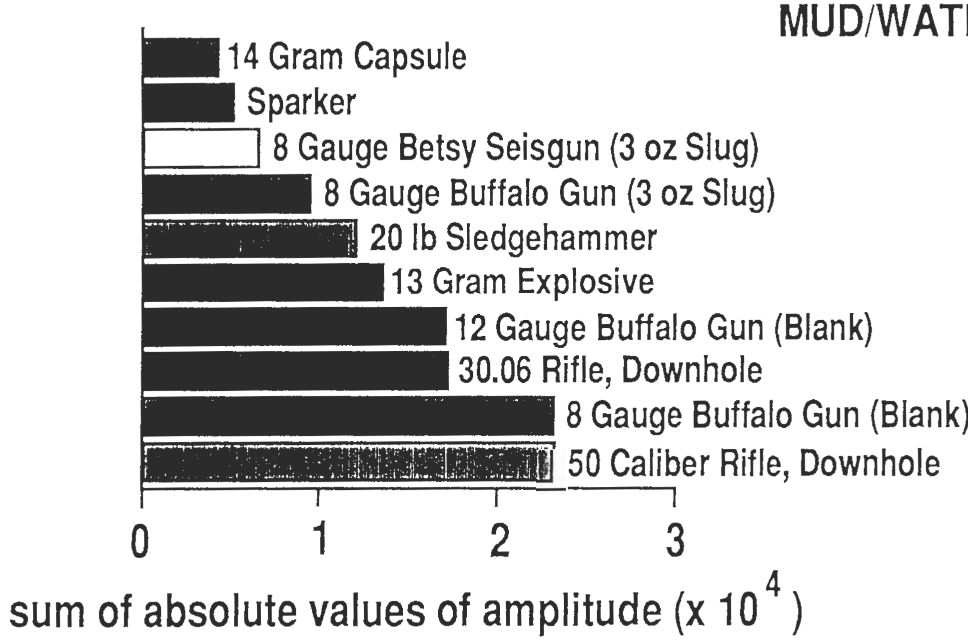
RELATIVE SOURCE AMPLITUDES
LOW CUT FILTER OUT
(ALL RIFLE, SHOTGUN AND EXPLOSIVE
SOURCES WERE SHOT IN WATER- OR
MUD/WATER-FILLED HOLES)

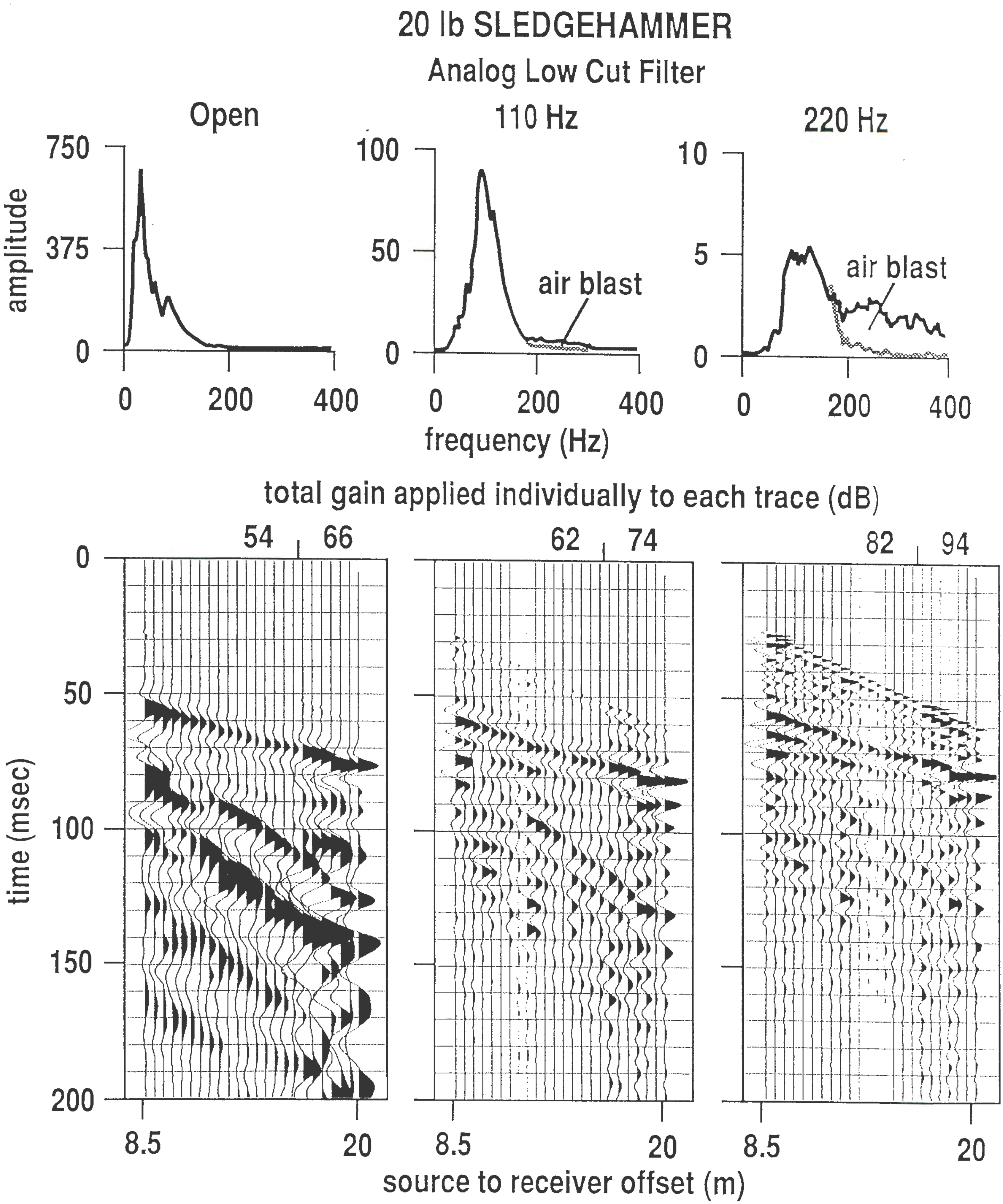


RELATIVE SOURCE AMPLITUDES
110 Hz LOW CUT FILTER
(ALL RIFLE, SHOTGUN AND EXPLOSIVE SOURCES WERE SHOT IN WATER- OR MUD/WATER-FILLED HOLES)



RELATIVE SOURCE AMPLITUDES
220 Hz LOW CUT FILTER
(ALL RIFLE, SHOTGUN AND EXPLOSIVE SOURCES WERE SHOT IN WATER- OR MUD/WATER-FILLED HOLES)




20 lb SLEDGEHAMMER
Analog Low Cut Filter
Open
110 Hz
220 Hz
amplitude
750
375
0
100
50
10
5
air blast
air blast
0
200
400
frequency (Hz)
total gain applied individually to each trace (dB)
54
66
62
74
82
94
time (msec)
50
100
150
200
8.5
20
source to receiver offset (m)
FIGURE 5

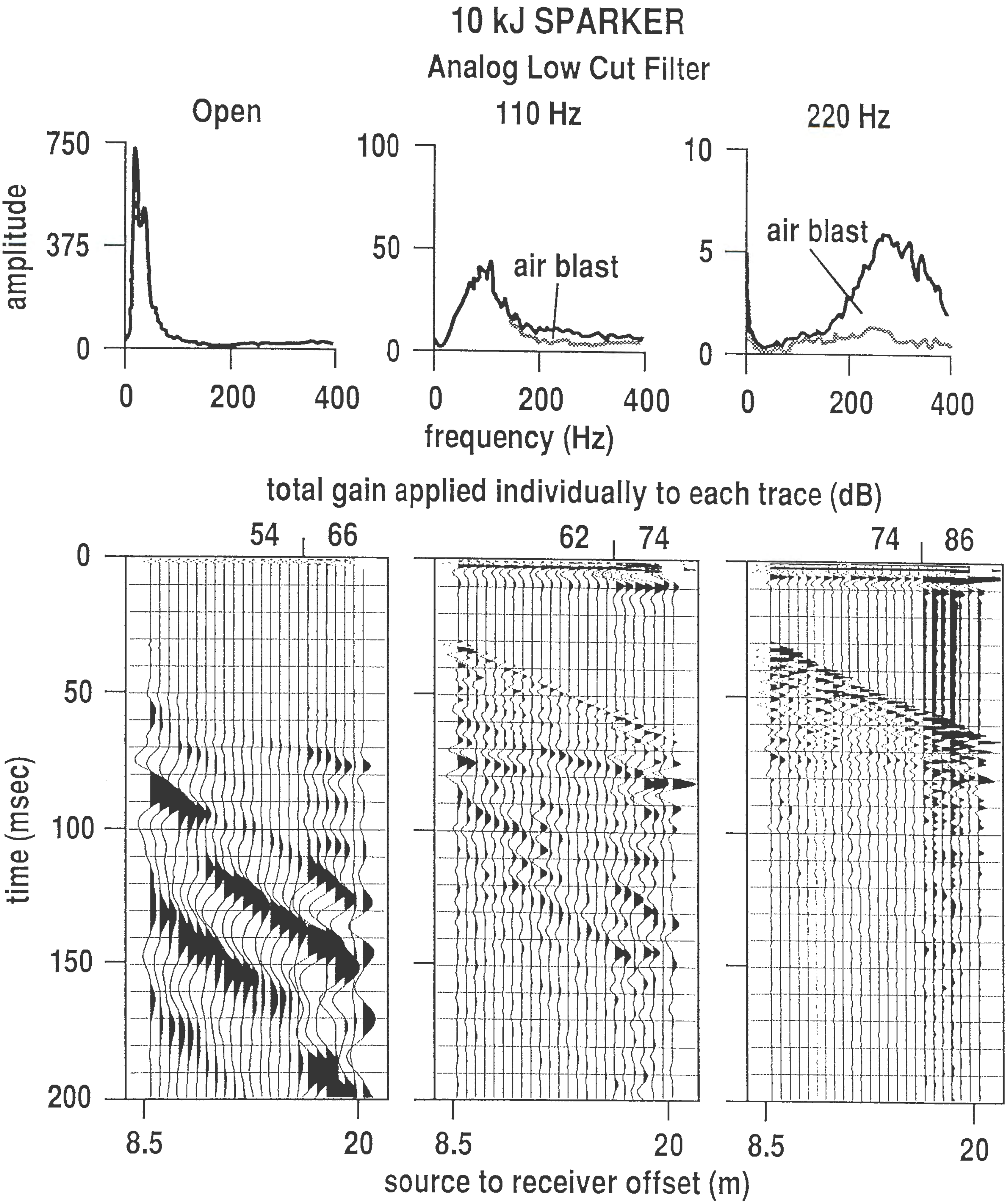

10 kJ SPARKER
Analog Low Cut Filter
Open
110 Hz
220 Hz
amplitude
750
375
0
100
50
10
5
air blast
air blast
0
200
400
frequency (Hz)
total gain applied individually to each trace (dB)
54
66
62
74
74
86
time (msec)
0
50
100
150
200
8.5
20
source to receiver offset (m)

FIGURE 6

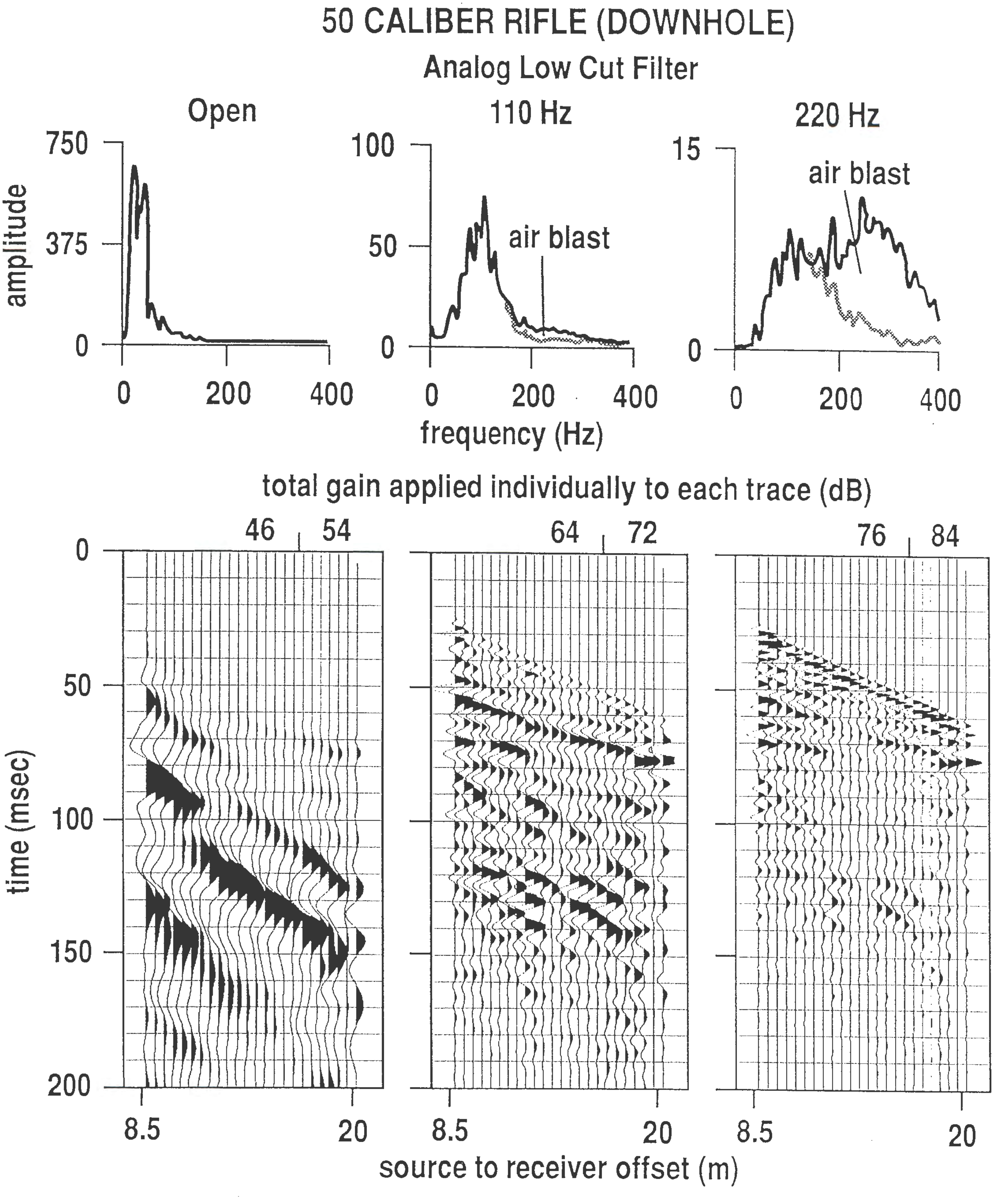

50 CALIBER RIFLE (DOWNHOLE)
Analog Low Cut Filter
Open
110 Hz
220 Hz
amplitude
750
375
0
100
50
15
air blast
0
200
400
frequency (Hz)
total gain applied individually to each trace (dB)
46
54
64
72
76
84
time (msec)
50
100
150
200
8.5
20
source to receiver offset (m)

FIGURE 7

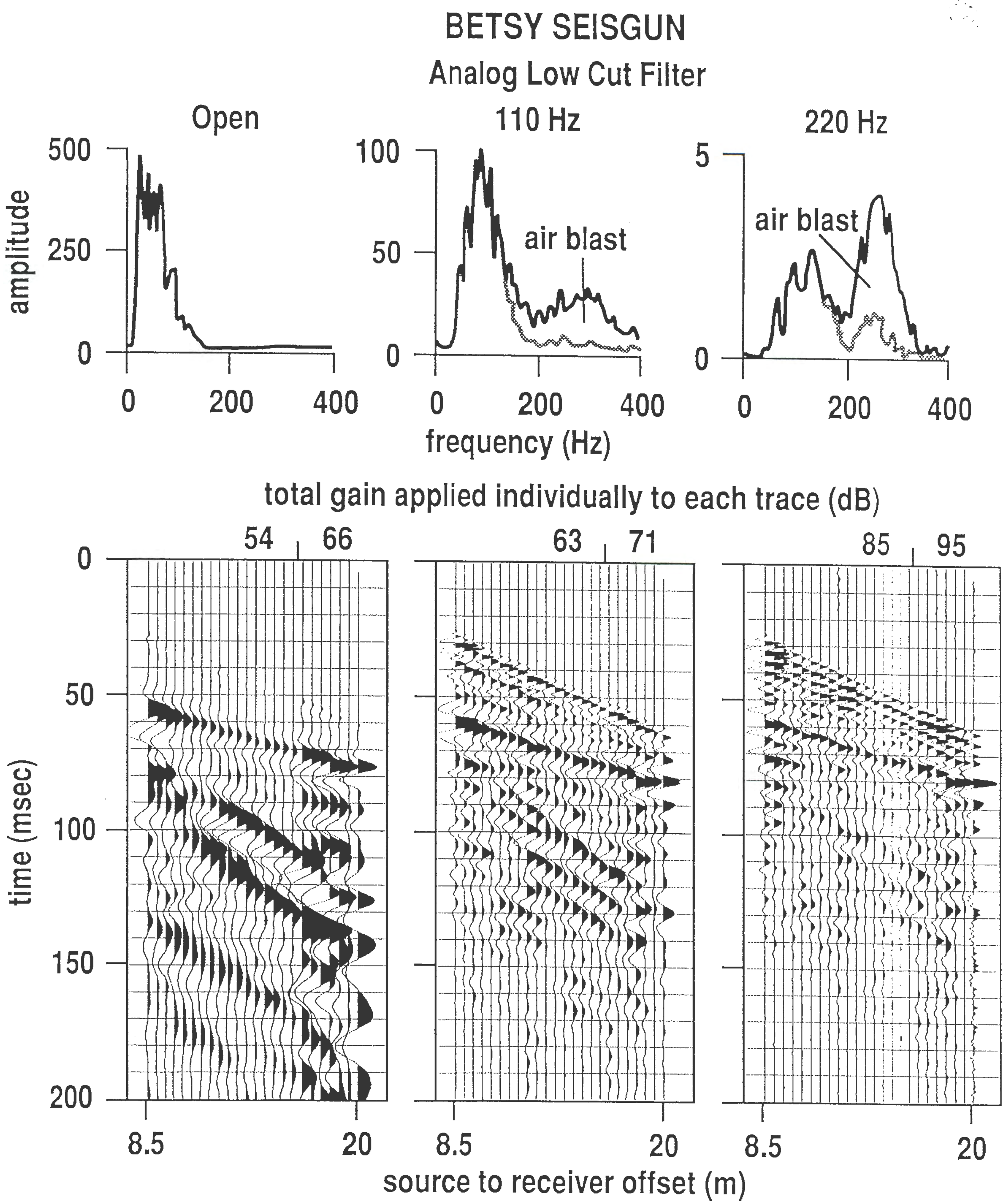

BETSY SEISGUN
Analog Low Cut Filter
Open
110 Hz
220 Hz
amplitude
500
250
0
100
50
0
5
0
air blast
air blast
0
200
400
frequency (Hz)
total gain applied individually to each trace (dB)
54
66
63
71
85
95
time (msec)
0
50
100
150
200
8.5
20
source to receiver offset (m)

FIGURE 8

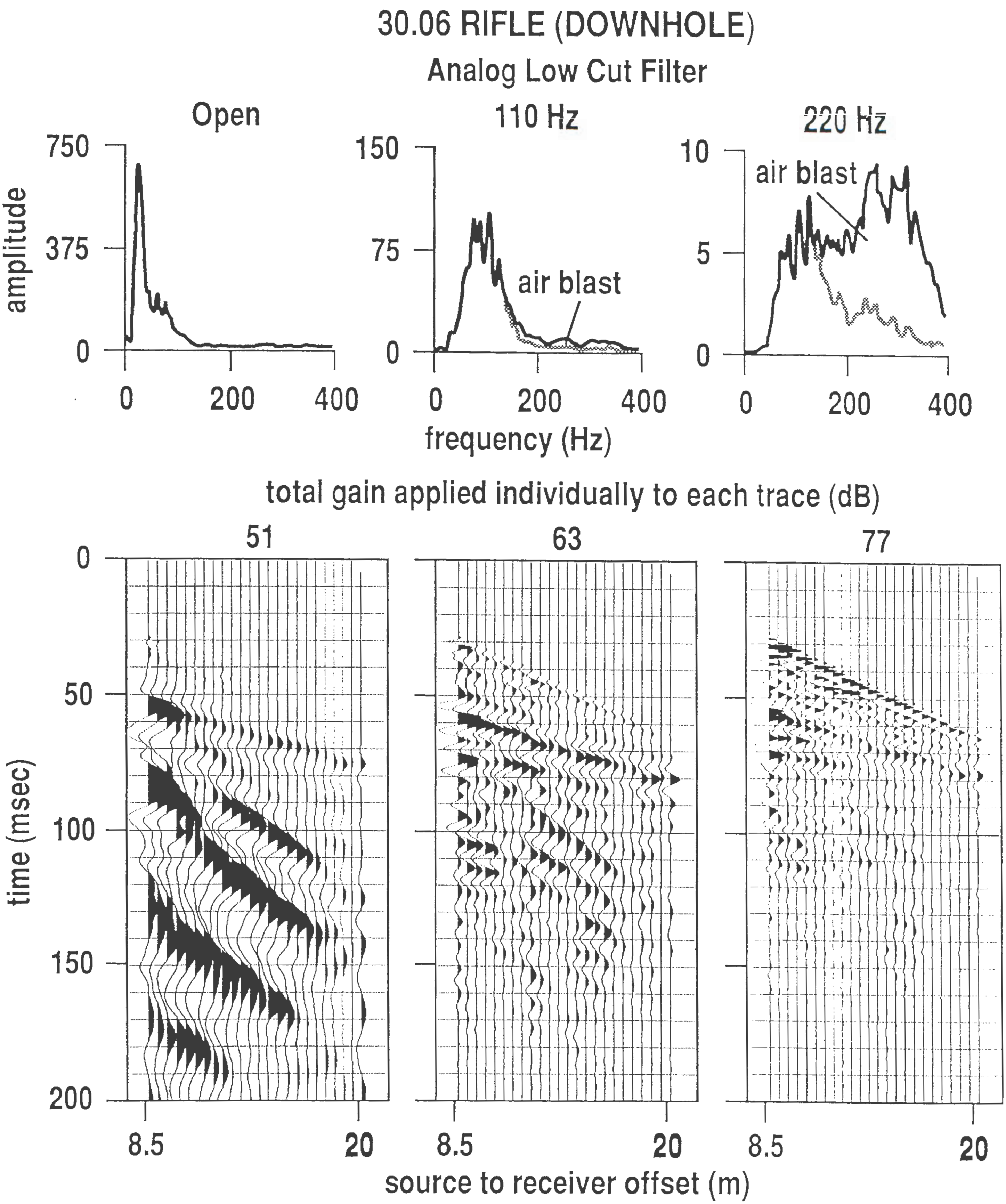

30.06 RIFLE (DOWNHOLE)
Analog Low Cut Filter
Open
110 Hz
220 Hz
amplitude
750
375
0
150
75
10
5
air blast
air blast
0
200
400
frequency (Hz)
total gain applied individually to each trace (dB)
51
63
77
time (msec)
0
50
100
150
200
8.5
20
source to receiver offset (m)

FIGURE 9

# 13 GRAM HIGH EXPLOSIVE

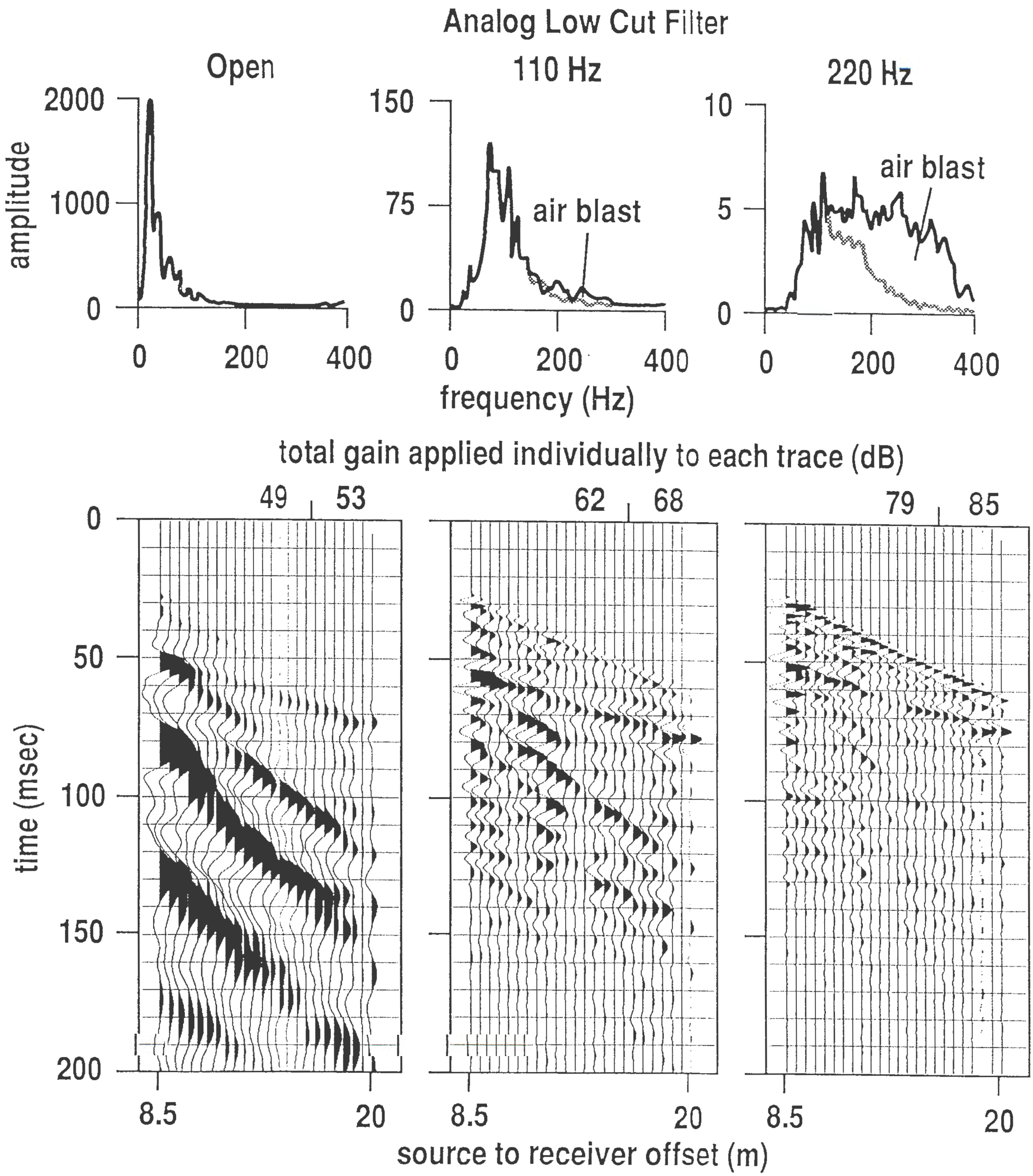



Figure 10

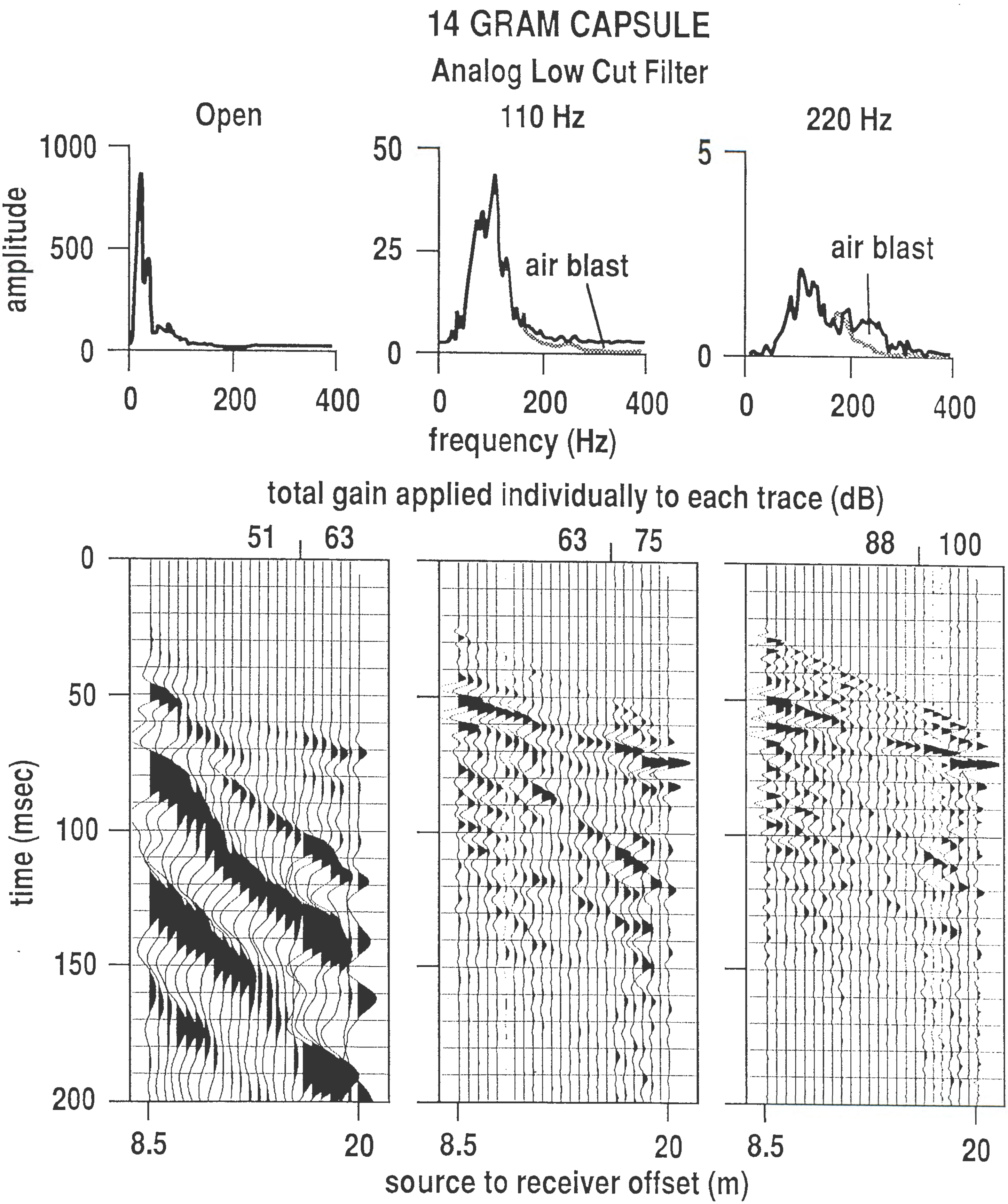

14 GRAM CAPSULE
Analog Low Cut Filter
Open
110 Hz
220 Hz
amplitude
1000
500
0
50
25
5
air blast
air blast
0
200
400
frequency (Hz)
total gain applied individually to each trace (dB)
51
63
63
75
88
100
time (msec)
0
50
100
150
200
8.5
20
source to receiver offset (m)

FIGURE 11

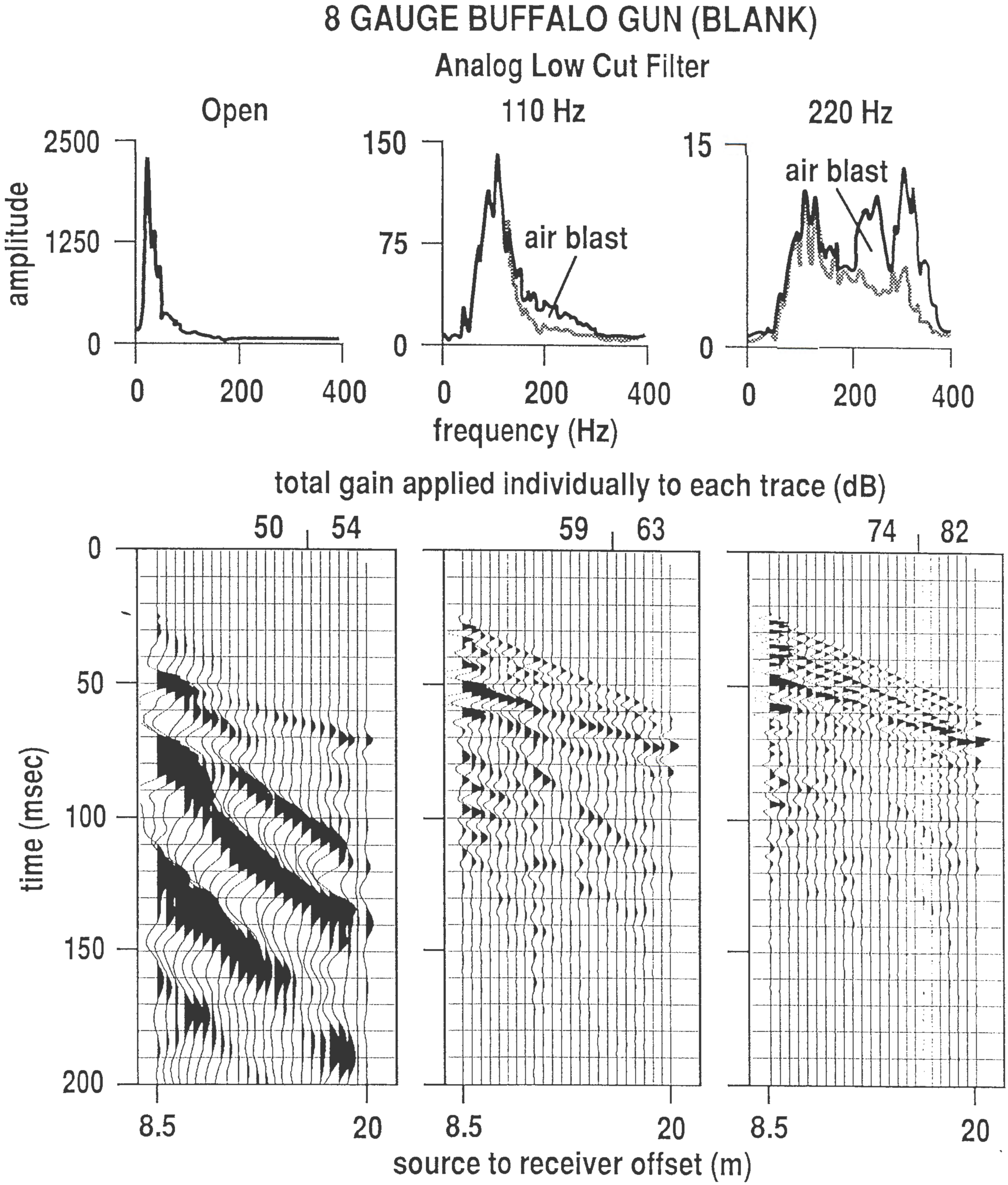
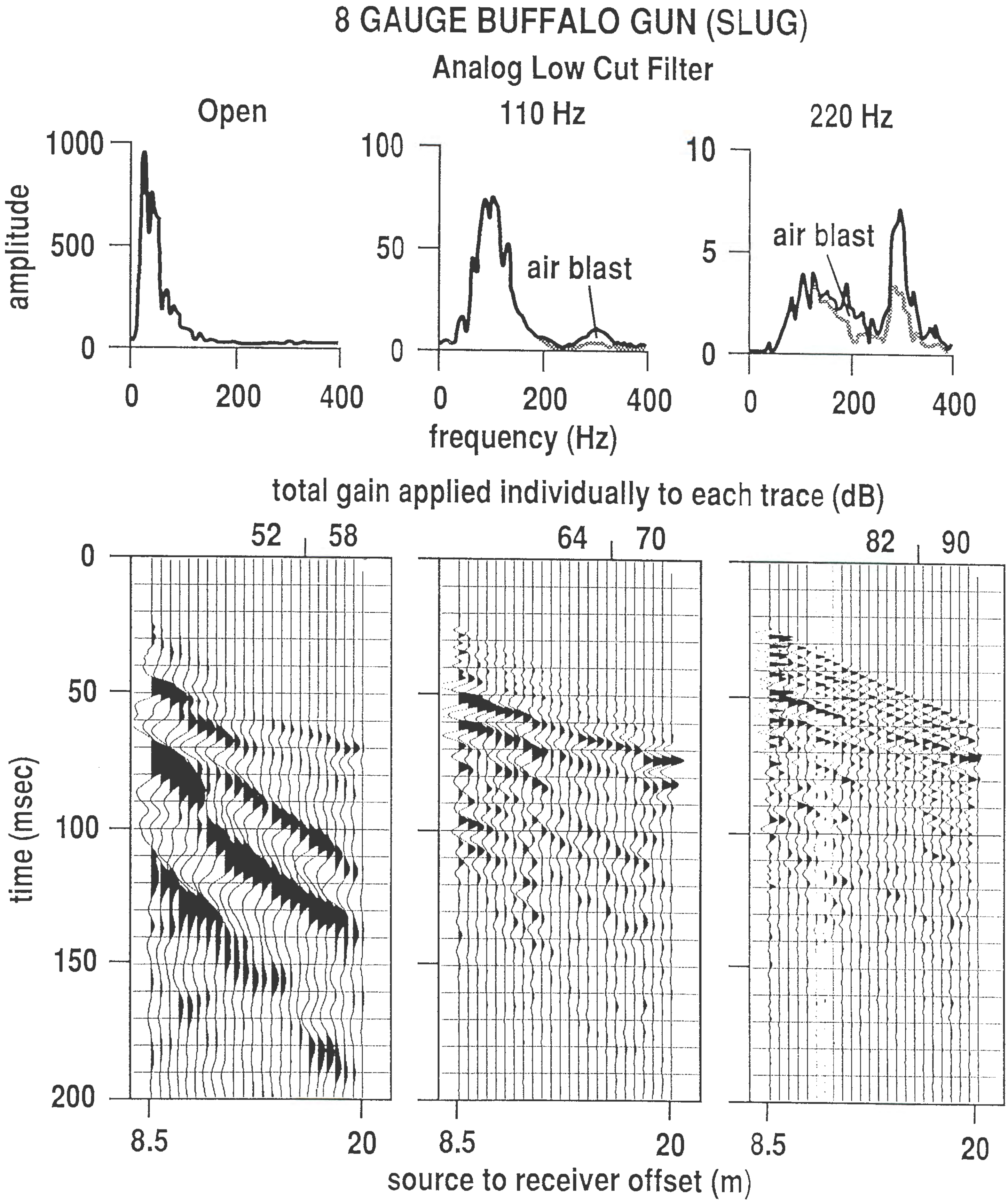
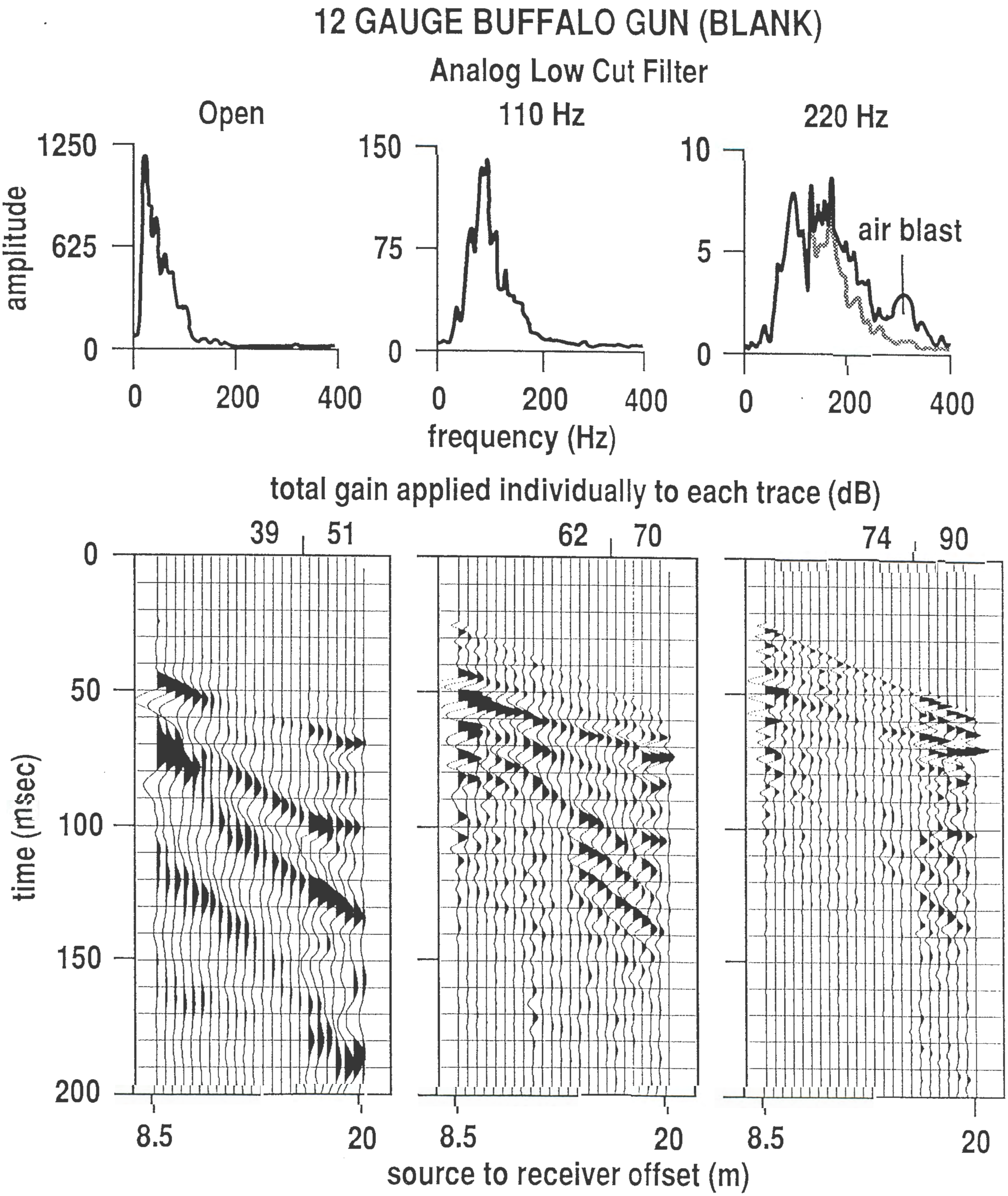

8 GAUGE BUFFALO GUN (BLANK)
Analog Low Cut Filter
Open
110 Hz
220 Hz
2500
1250
0
150
75
15
amplitude
air blast
air blast
0
200
400
frequency (Hz)
total gain applied individually to each trace (dB)
50
54
59
63
74
82
time (msec)
100
150
200
8.5
20
source to receiver offset (m)

FIGURE 12



8 GAUGE BUFFALO GUN (SLUG)
Analog Low Cut Filter
Open
110 Hz
220 Hz
amplitude
1000
500
0
100
50
10
5
air blast
air blast
0
200
400
frequency (Hz)
total gain applied individually to each trace (dB)
52
58
64
70
82
90
time (msec)
0
50
100
150
200
8.5
20
source to receiver offset (m)


FIGURE 13



12 GAUGE BUFFALO GUN (BLANK)
Analog Low Cut Filter
Open
110 Hz
220 Hz
amplitude
1250
625
0
150
75
10
5
air blast
200
400
frequency (Hz)
total gain applied individually to each trace (dB)
39
51
62
70
74
90
time (msec)
50
100
150
8.5
20
source to receiver offset (m)


FIGURE 14

8 GAUGE BUFFALO GUN (BLANK)
WATER STEM VS OPEN DRY HOLE
ANALOG LOW CUT FILTER OUT
Total Gain Applied Individually To Each Trace (dB)

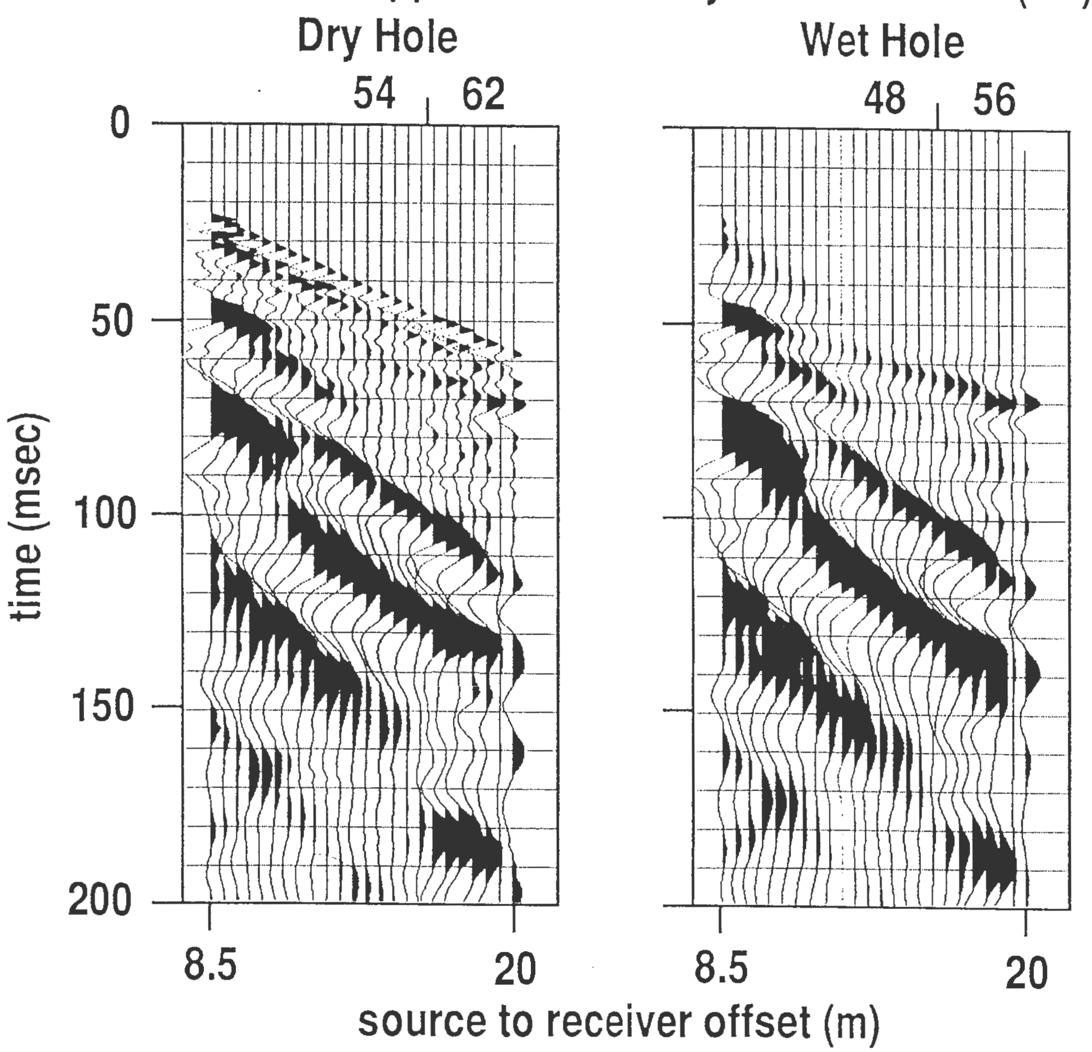



FIGURE 15.1a

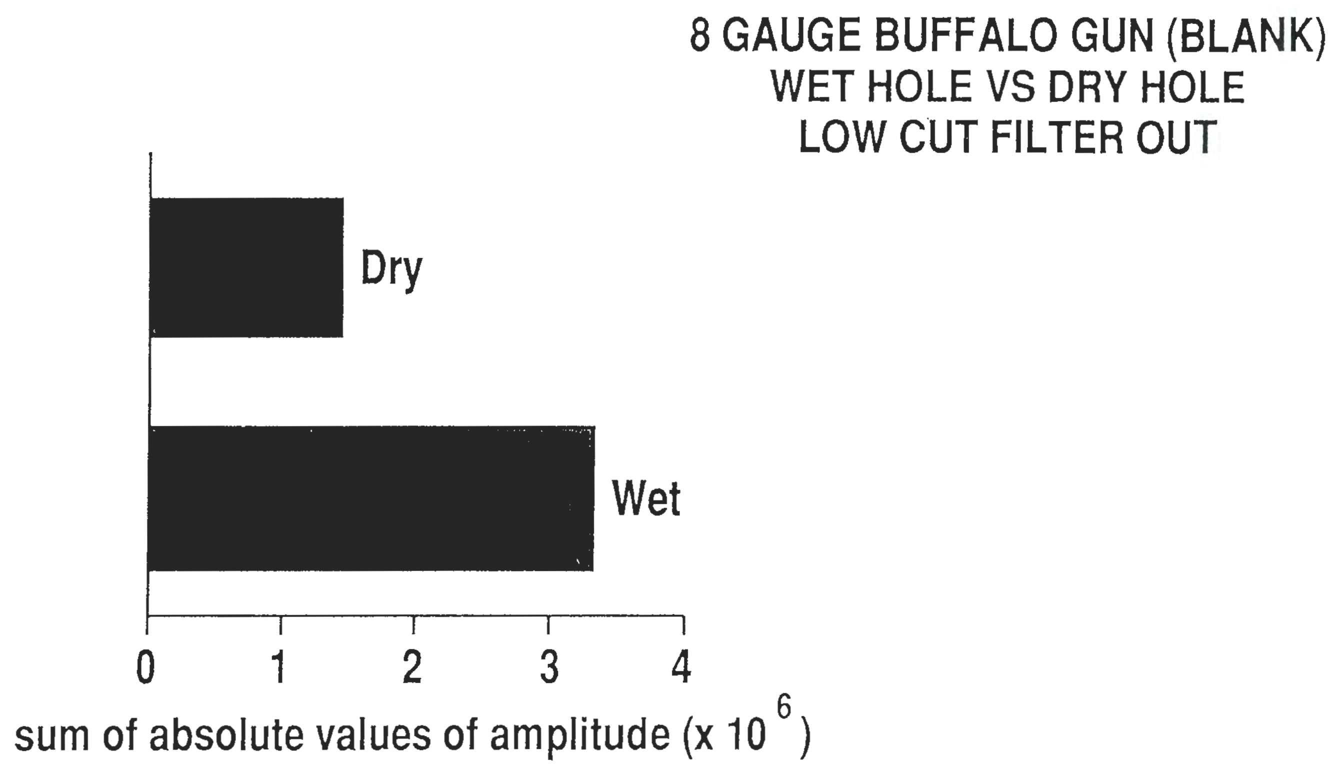

8 GAUGE BUFFALO GUN (BLANK)
WET HOLE VS DRY HOLE
LOW CUT FILTER OUT
Dry
Wet
0
1
2
3
4
sum of absolute values of amplitude (x 10 6 )

FIGURE 15.1b

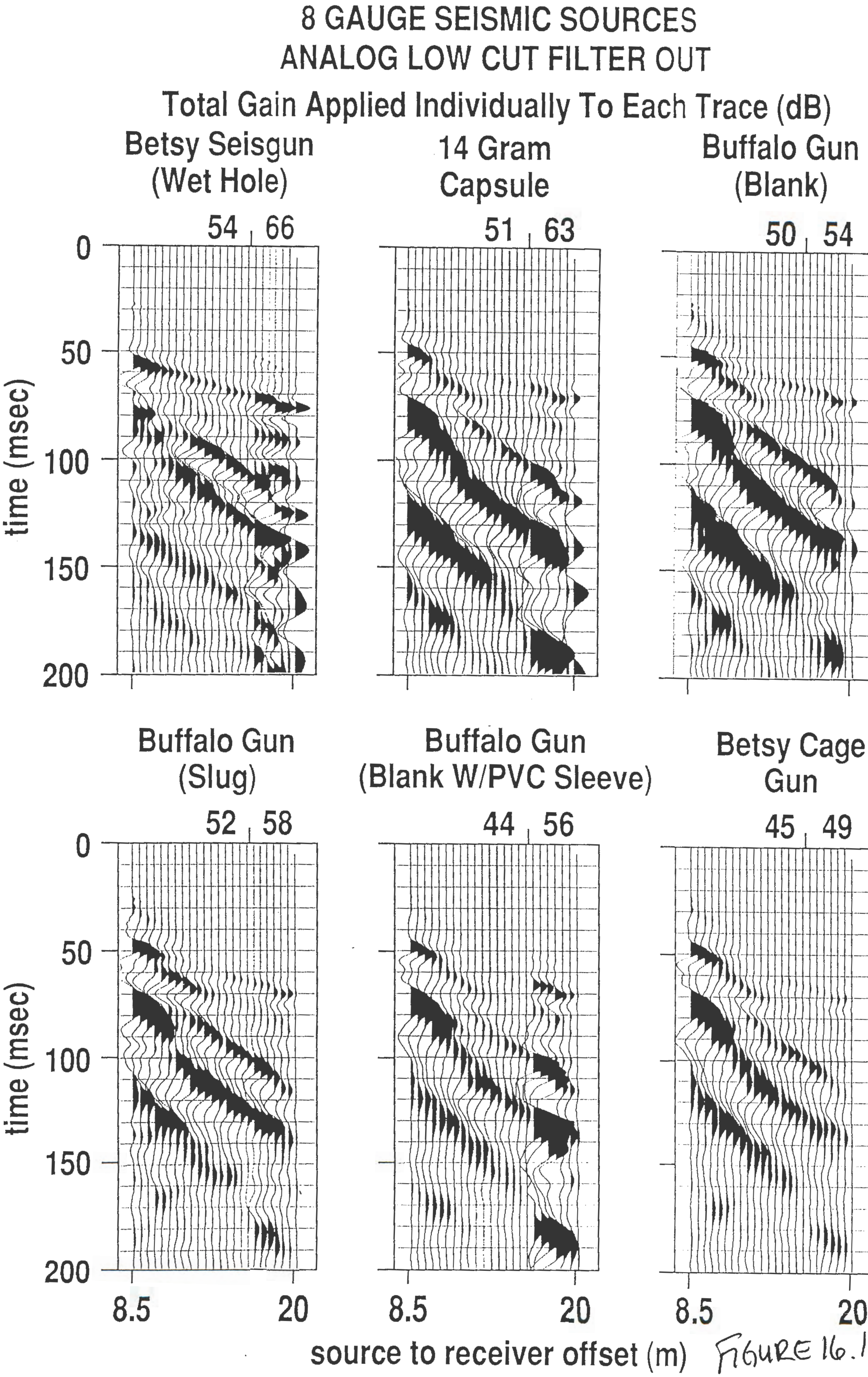

8 GAUGE SEISMIC SOURCES
ANALOG LOW CUT FILTER OUT
Total Gain Applied Individually To Each Trace (dB)
Betsy Seisgun (Wet Hole)
54 66
14 Gram Capsule
51 63
Buffalo Gun (Blank)
50 54
Buffalo Gun (Slug)
52 58
Buffalo Gun (Blank W/PVC Sleeve)
44 56
Betsy Cage Gun
45 49
time (msec)
0
50
100
150
200
8.5
20
source to receiver offset (m)

FIGURE 16.1a

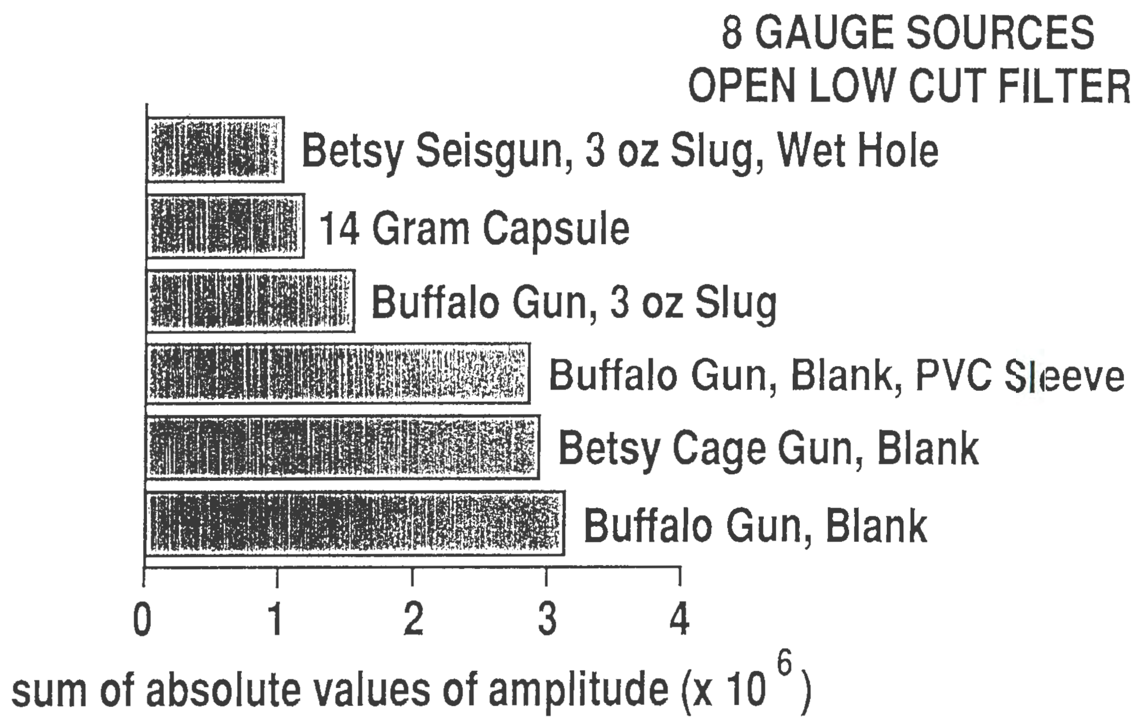

8 GAUGE SOURCES
OPEN LOW CUT FILTER
Betsy Seisgun, 3 oz Slug, Wet Hole
14 Gram Capsule
Buffalo Gun, 3 oz Slug
Buffalo Gun, Blank, PVC Sleeve
Betsy Cage Gun, Blank
Buffalo Gun, Blank
0
1
2
3
4
sum of absolute values of amplitude (x 10 6)

FIGURE 16.16

8 GAUGE SEISMIC SOURCES
110 Hz ANALOG LOW CUT FILTER
Total Gain Applied Individually To Each Trace (dB)

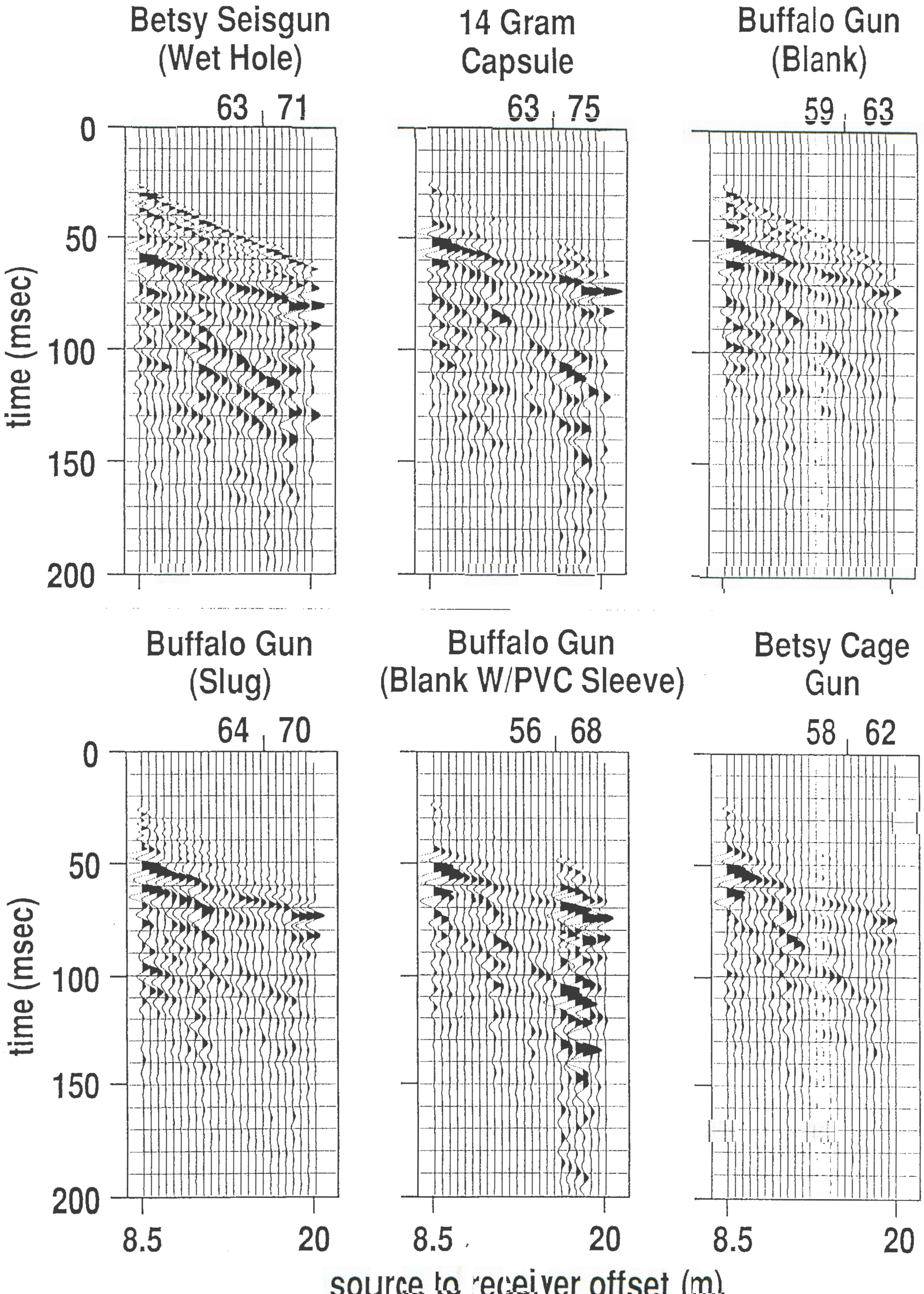



FIGURE 16.2a

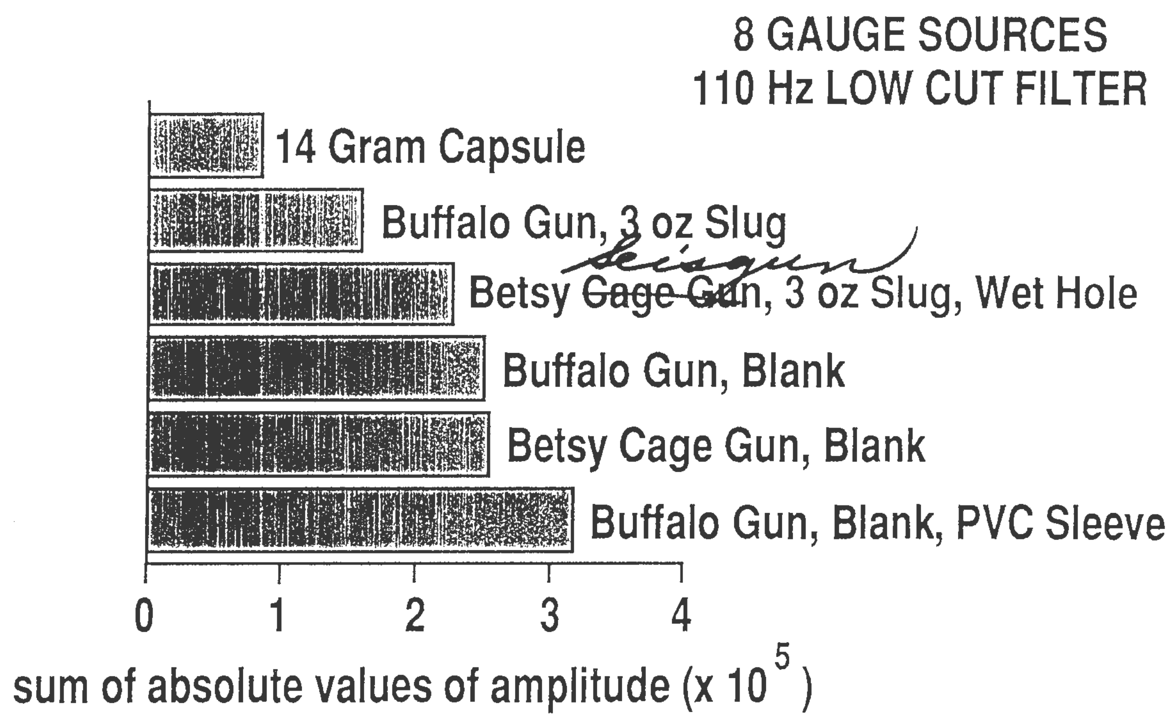

8 GAUGE SOURCES
110 Hz LOW CUT FILTER
14 Gram Capsule
Buffalo Gun, 3 oz Slug
Seisgun
Betsy ~~Cage Gun~~, 3 oz Slug, Wet Hole
Buffalo Gun, Blank
Betsy Cage Gun, Blank
Buffalo Gun, Blank, PVC Sleeve
0
1
2
3
4
sum of absolute values of amplitude (x 10^5)

FIGURE No. 26

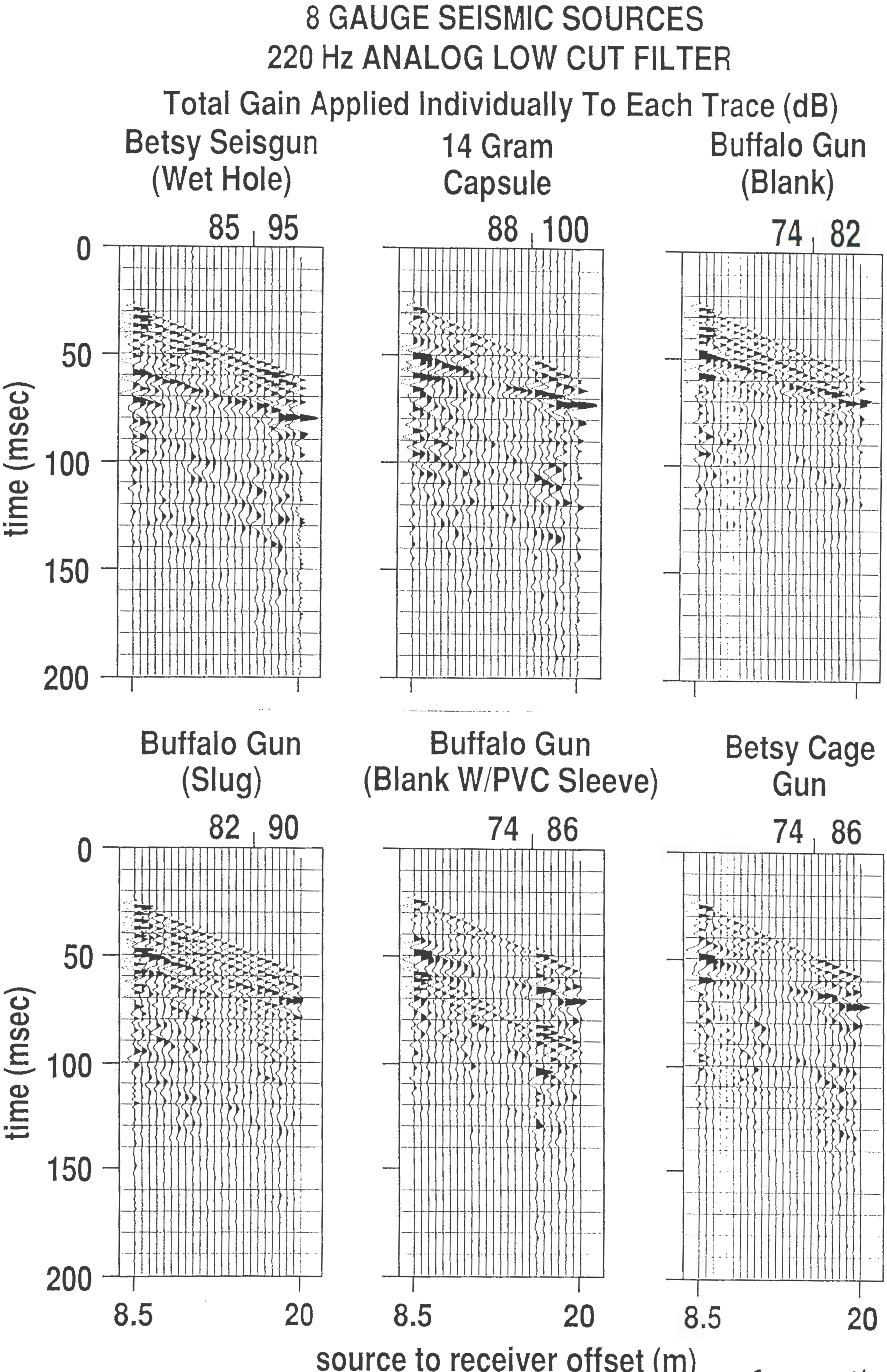

8 GAUGE SEISMIC SOURCES
220 Hz ANALOG LOW CUT FILTER
Total Gain Applied Individually To Each Trace (dB)
Betsy Seisgun (Wet Hole)
85 95
14 Gram Capsule
88 100
Buffalo Gun (Blank)
74 82
Buffalo Gun (Slug)
82 90
Buffalo Gun (Blank W/PVC Sleeve)
74 86
Betsy Cage Gun
74 86
time (msec)
0
50
100
150
200
8.5
20
source to receiver offset (m)

FIGURE 16.3a

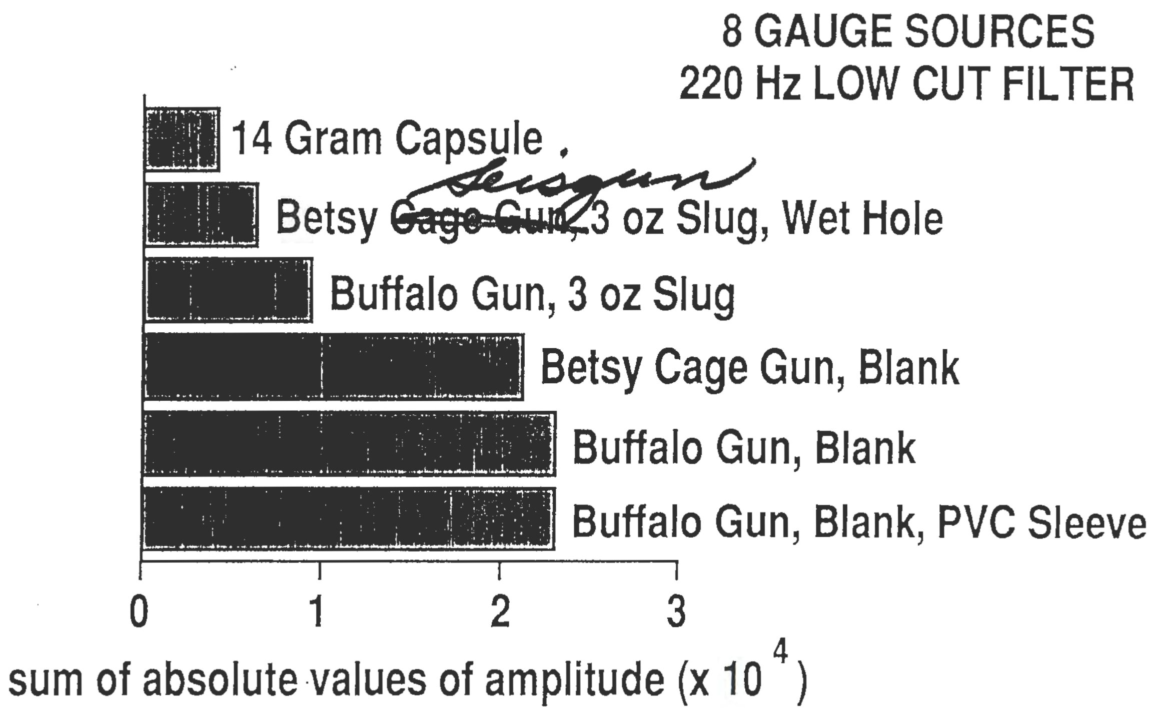
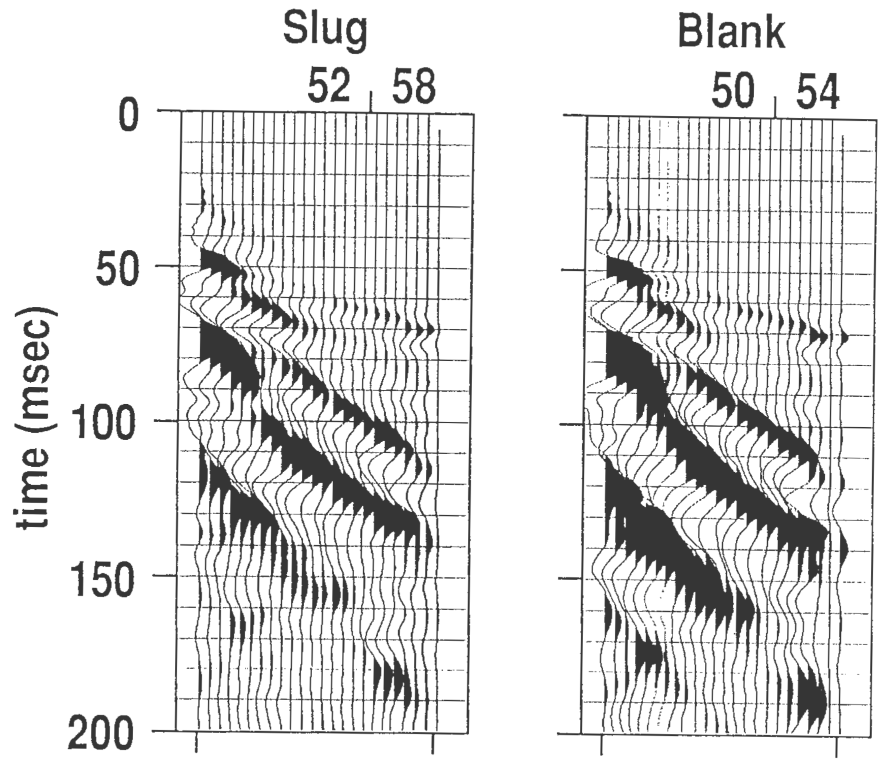

8 GAUGE SOURCES
220 Hz LOW CUT FILTER
14 Gram Capsule
Betsy ~~Cage Gun~~ Seisgun, 3 oz Slug, Wet Hole
Buffalo Gun, 3 oz Slug
Betsy Cage Gun, Blank
Buffalo Gun, Blank
Buffalo Gun, Blank, PVC Sleeve
0
1
2
3
sum of absolute values of amplitude (x 10^4)

Figure 16.3b

## SLUG VS BLANK
## ANALOG LOW CUT FILTER OUT
### Total Gain Applied Individually To Each Trace (dB)

8 Gauge Buffalo Gun




12 Gauge Buffalo Gun

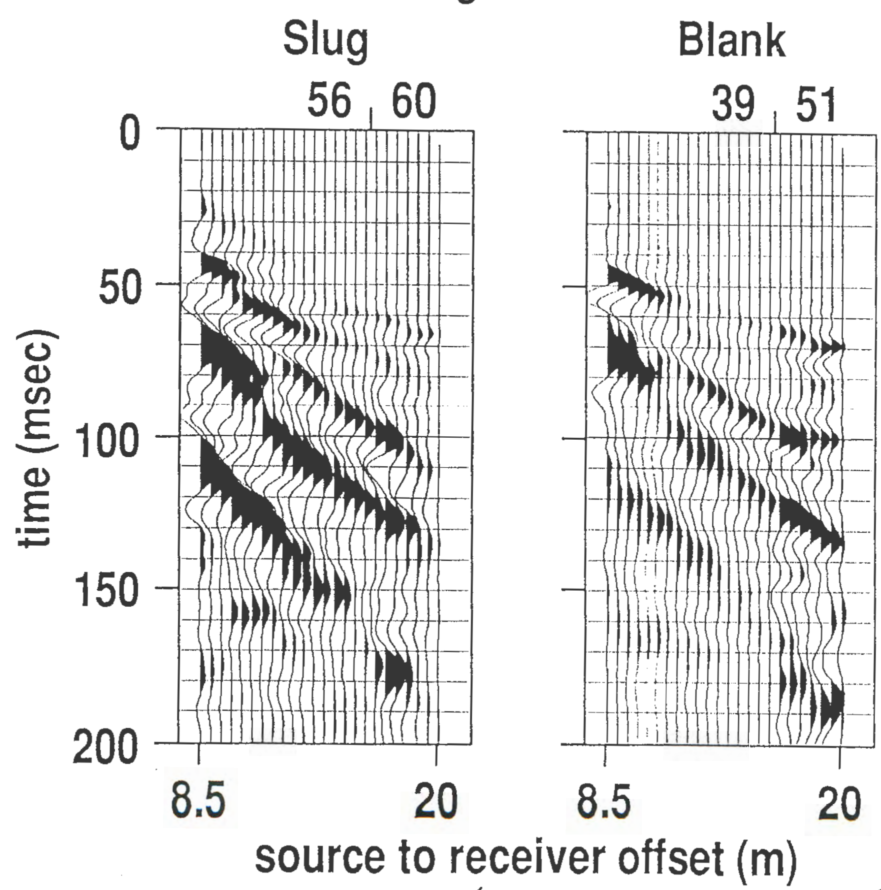
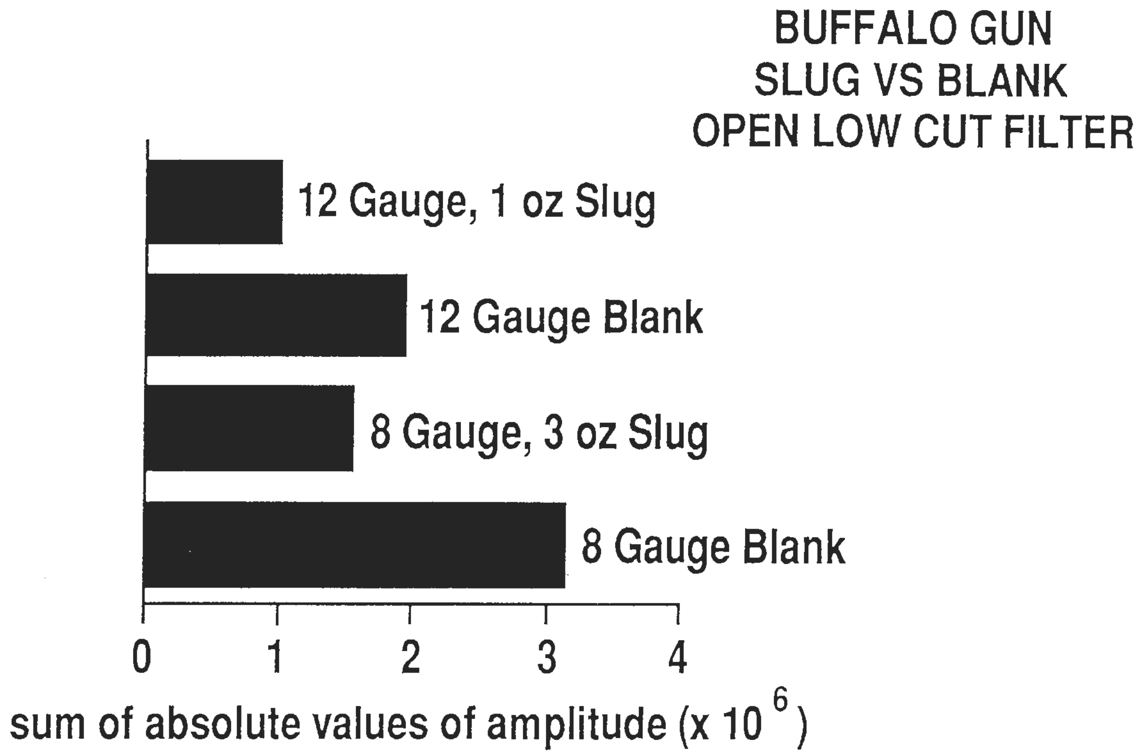



FIGURE 17.1a



BUFFALO GUN
SLUG VS BLANK
OPEN LOW CUT FILTER
12 Gauge, 1 oz Slug
12 Gauge Blank
8 Gauge, 3 oz Slug
8 Gauge Blank
0
1
2
3
4
sum of absolute values of amplitude (x 10^6)

SLUG VS BLANK
110 Hz ANALOG LOW CUT FILTER
Total Gain Applied Individually To Each Trace (dB)

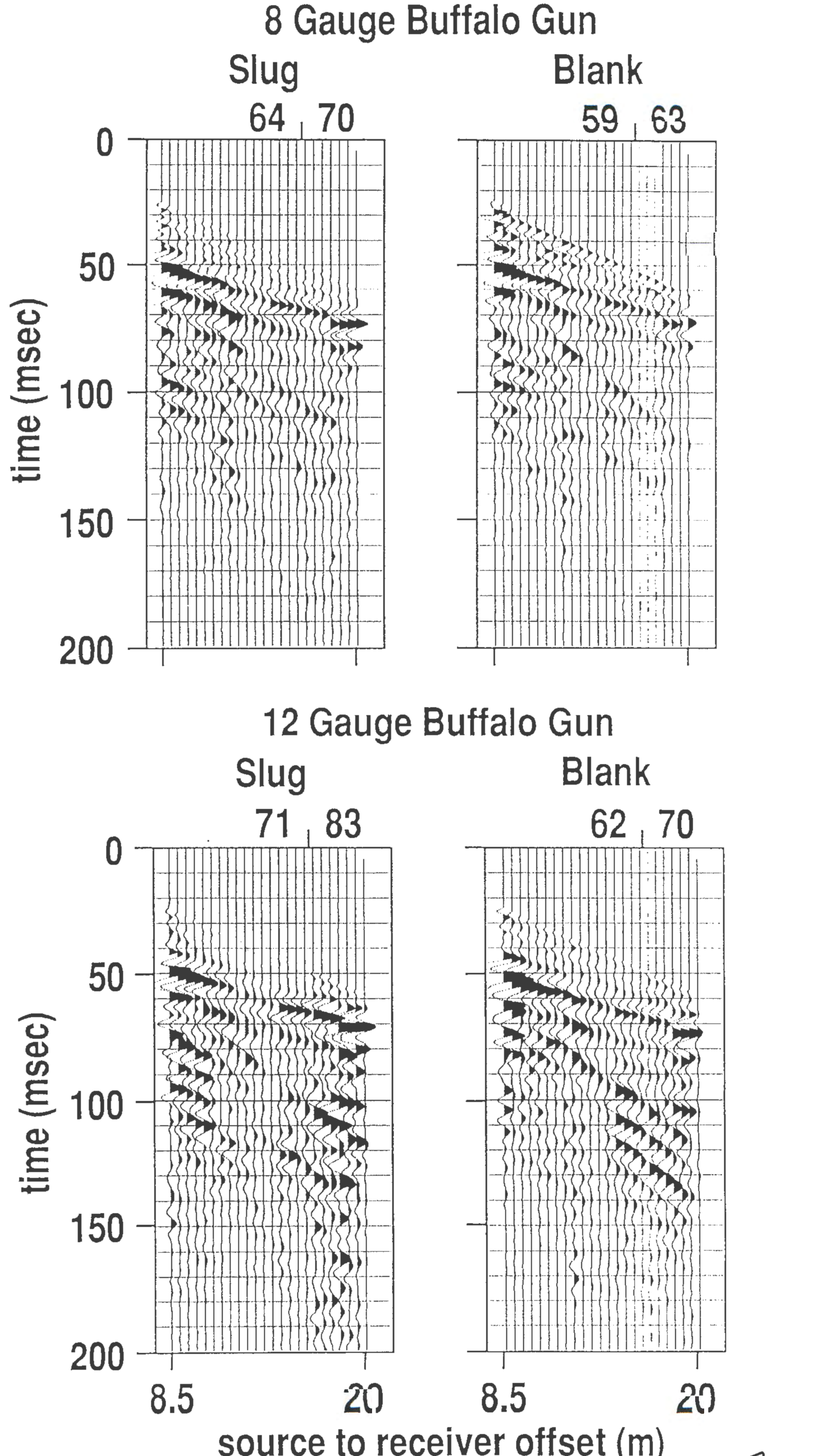



Figure 17 2a

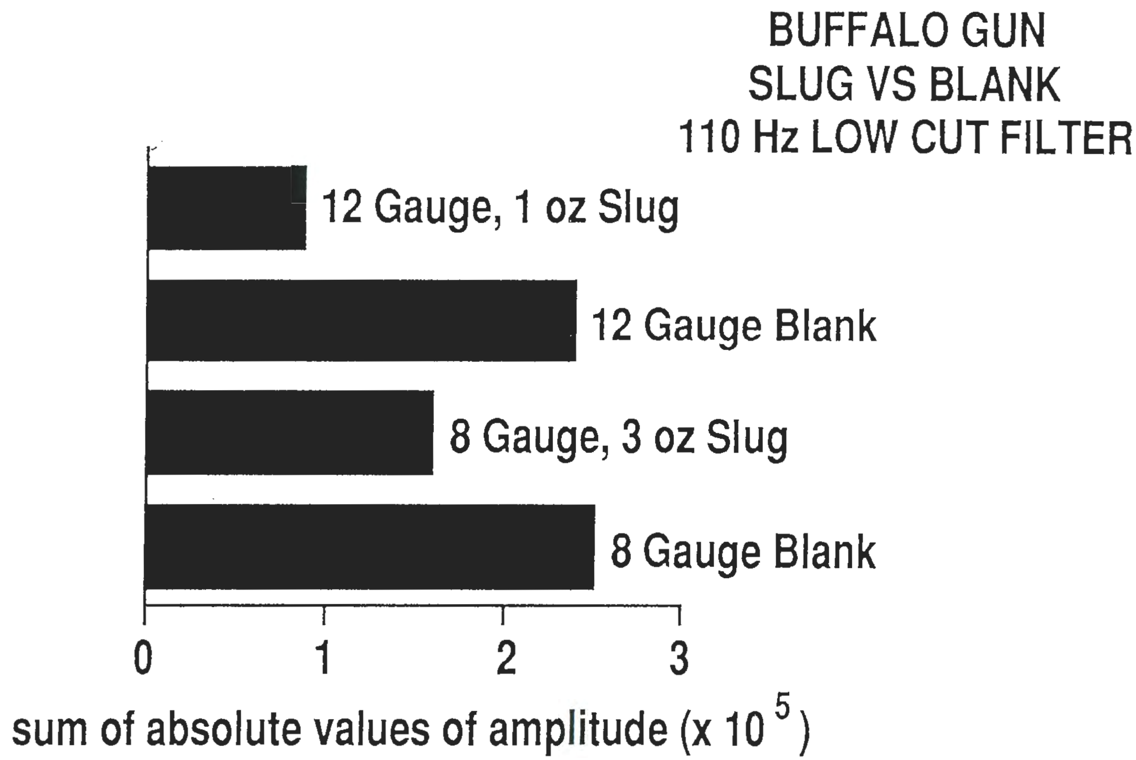
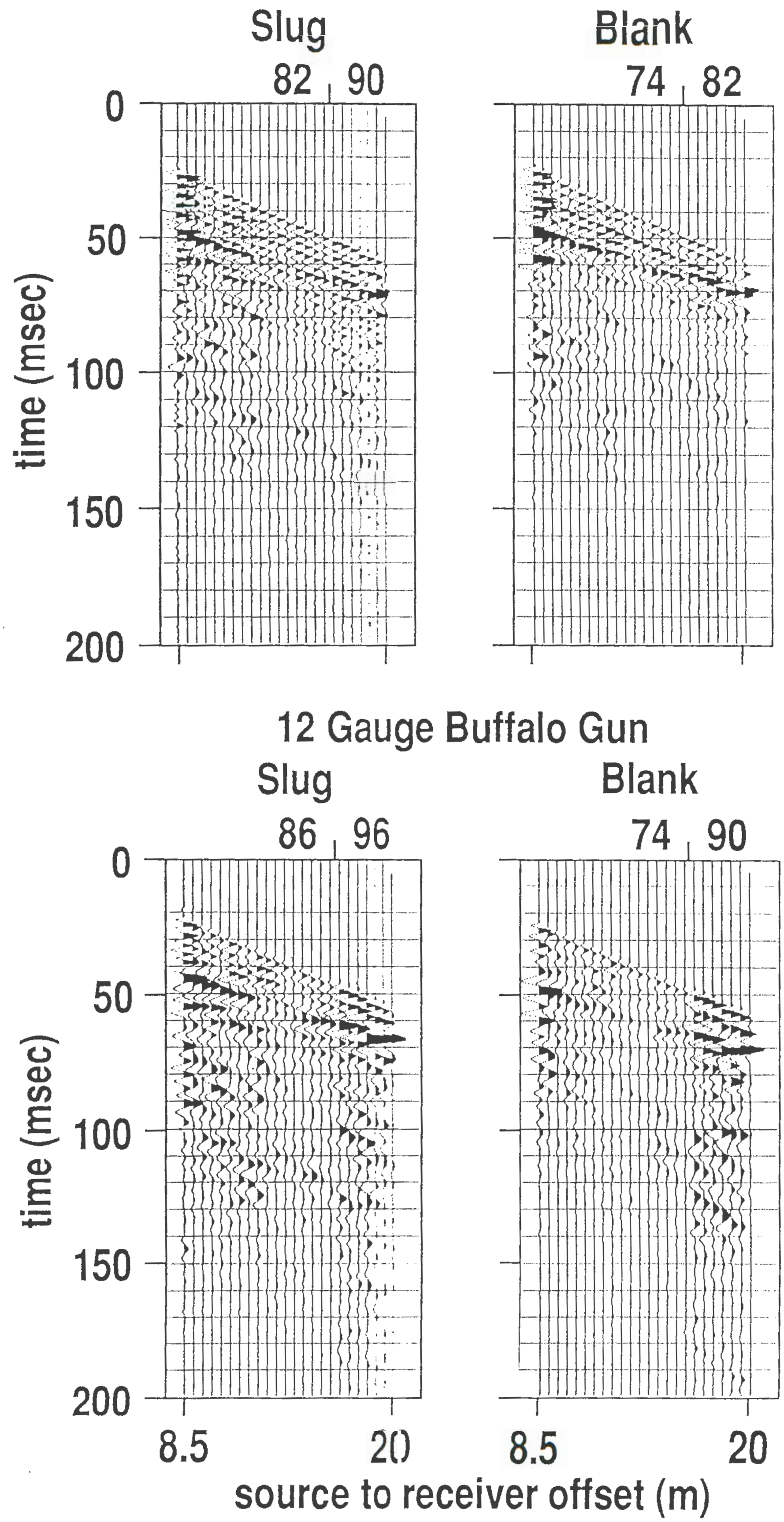
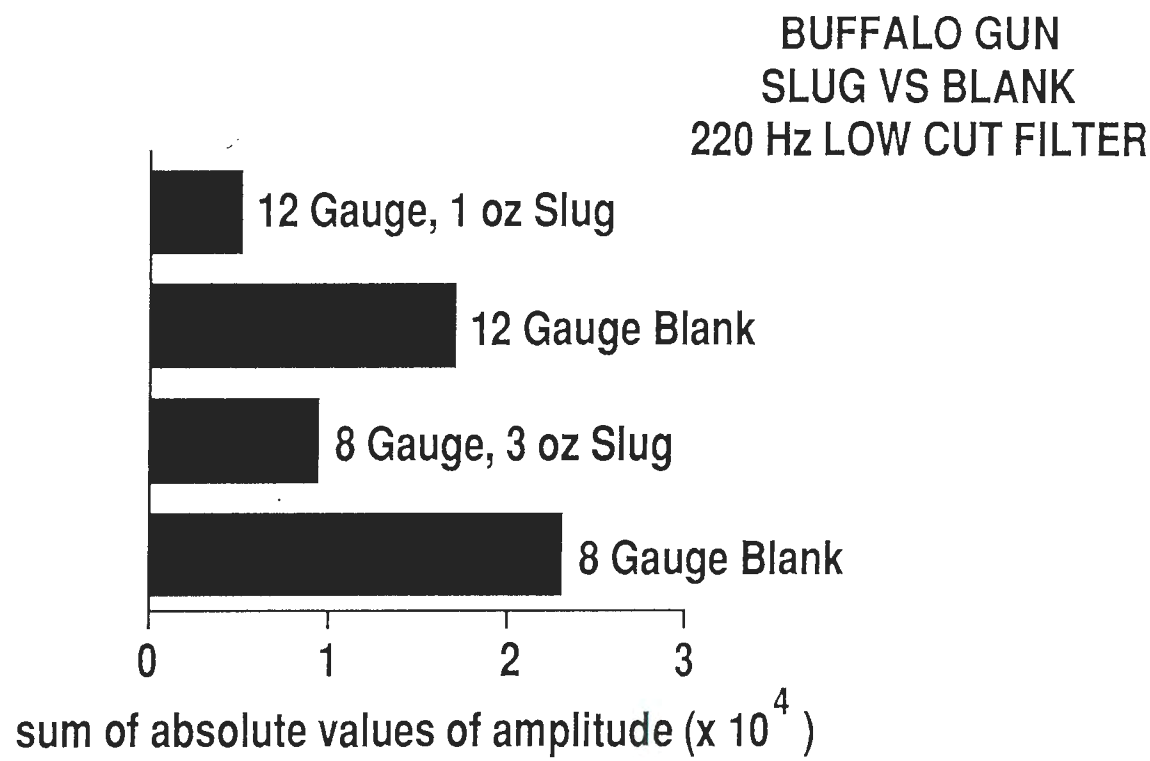

BUFFALO GUN
SLUG VS BLANK
110 Hz LOW CUT FILTER
12 Gauge, 1 oz Slug
12 Gauge Blank
8 Gauge, 3 oz Slug
8 Gauge Blank
0
1
2
3
sum of absolute values of amplitude (x 10 5 )

FIGURE 17.2b

SLUG VS BLANK
220 Hz ANALOG LOW CUT FILTER
Total Gain Applied Individually To Each Trace (dB)
8 Gauge Buffalo Gun




BUFFALO GUN
SLUG VS BLANK
220 Hz LOW CUT FILTER
12 Gauge, 1 oz Slug
12 Gauge Blank
8 Gauge, 3 oz Slug
8 Gauge Blank
0
1
2
3
sum of absolute values of amplitude (x 10^4 )

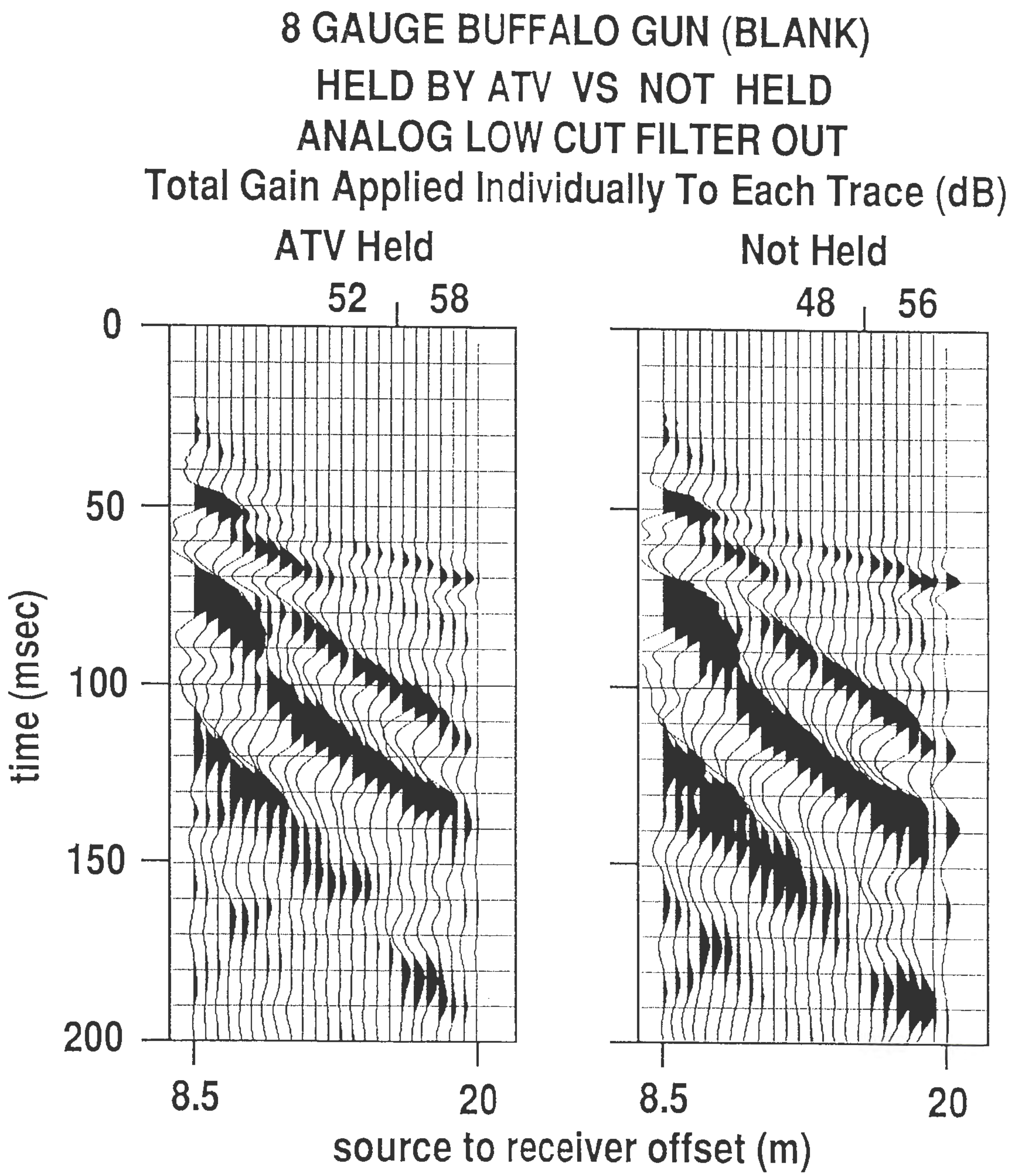

8 GAUGE BUFFALO GUN (BLANK)
HELD BY ATV VS NOT HELD
ANALOG LOW CUT FILTER OUT
Total Gain Applied Individually To Each Trace (dB)
ATV Held
52
58
Not Held
48
56
0
50
100
150
200
time (msec)
8.5
20
8.5
20
source to receiver offset (m)

FIGURE 18.1a

8 GAUGE BUFFALO GUN (BLANK)
HELD BY ATV VS NOT HELD
LOW CUT FILTER OUT

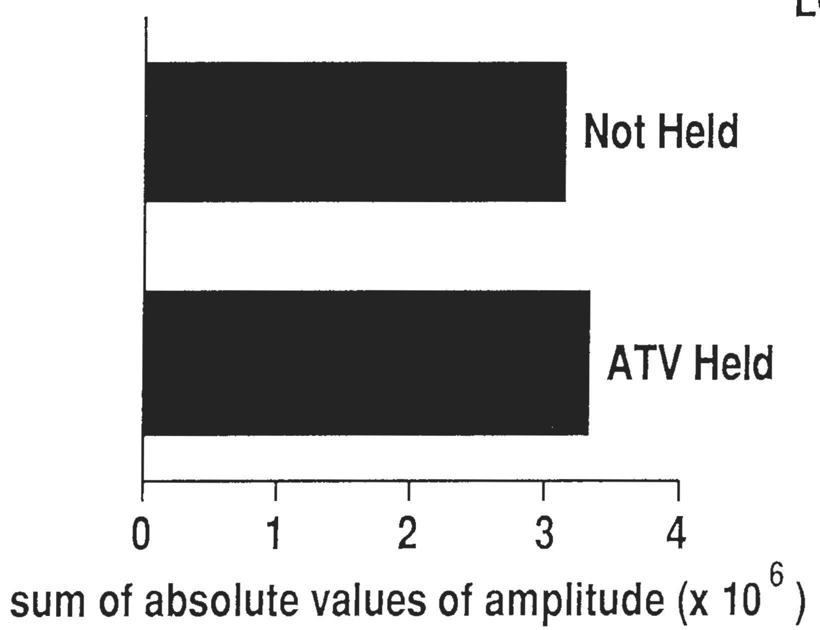
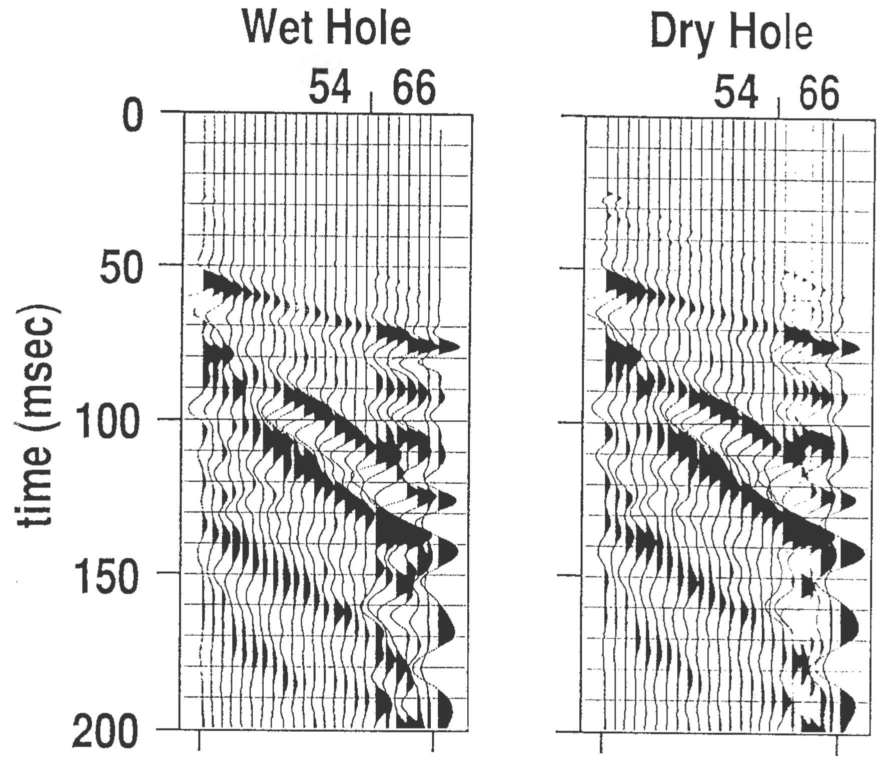


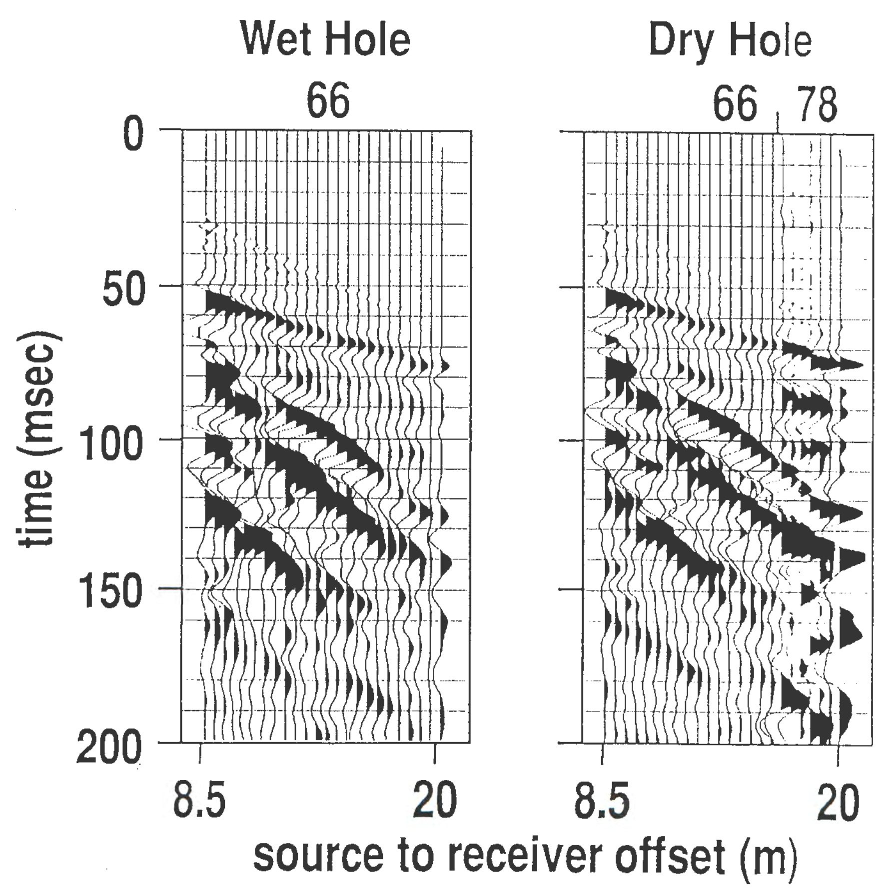

Figure 18.1b

SURFACE PROJECTILE SOURCES
WET HOLE VS DRY HOLE
ANALOG LOW CUT FILTER OUT
Total Gain Applied Individually To Each Trace (dB)

8 Gauge Betsy




30.06



SURFACE PROJECTILE SOURCES
WET HOLE VS DRY HOLE
LOW CUT FILTER OUT

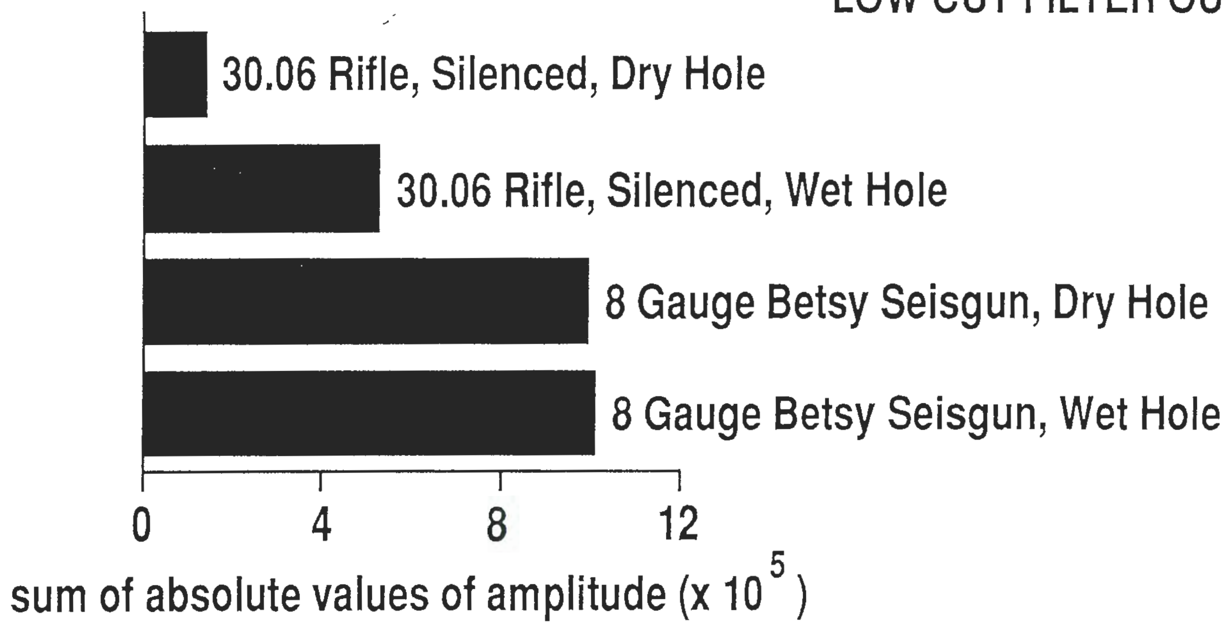



Figure 1916

SURFACE PROJECTILE SOURCES
WET HOLE VS DRY HOLE
110 Hz ANALOG LOW CUT FILTER
Total Gain Applied Individually To Each Trace (dB)
8 Gauge Betsy

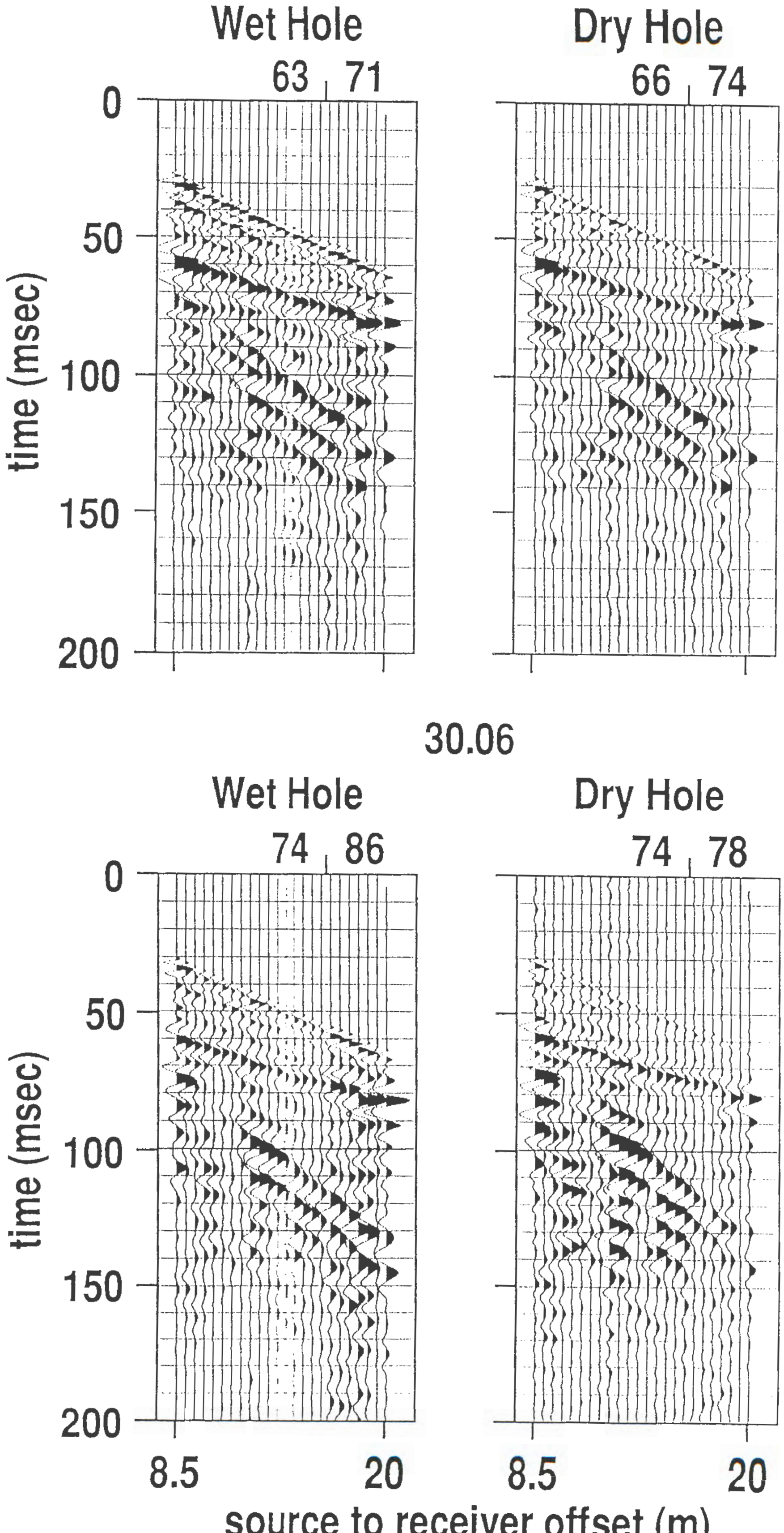



FIGURE 19.29

SURFACE PROJECTILE SOURCES
WET HOLE VS DRY HOLE
110 Hz LOW CUT FILTER

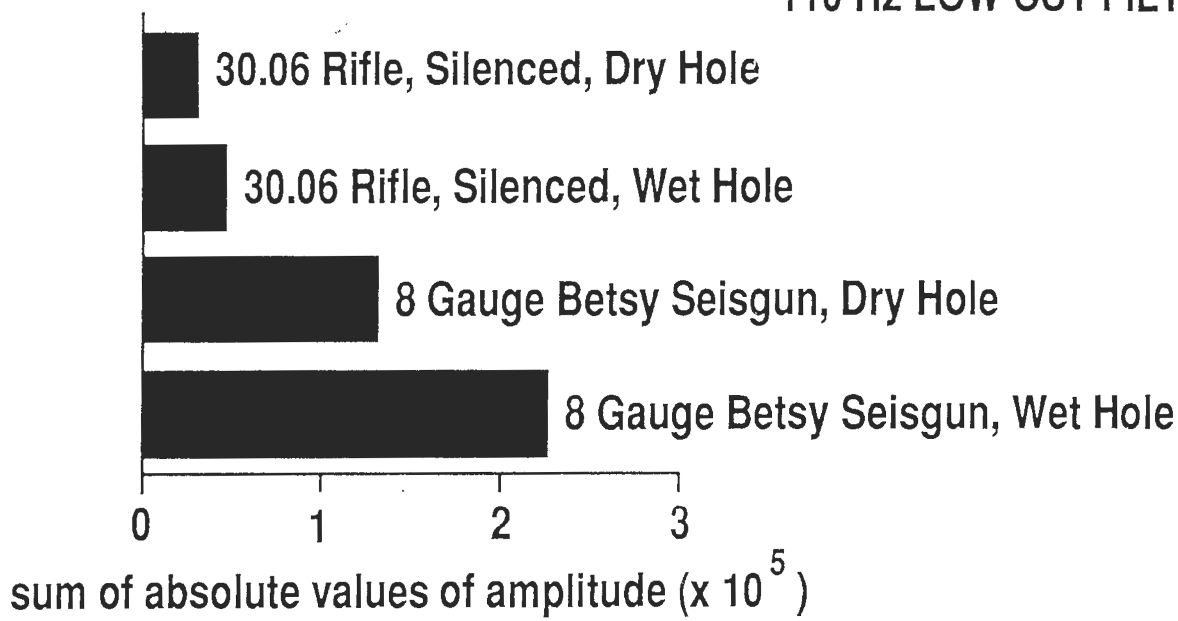
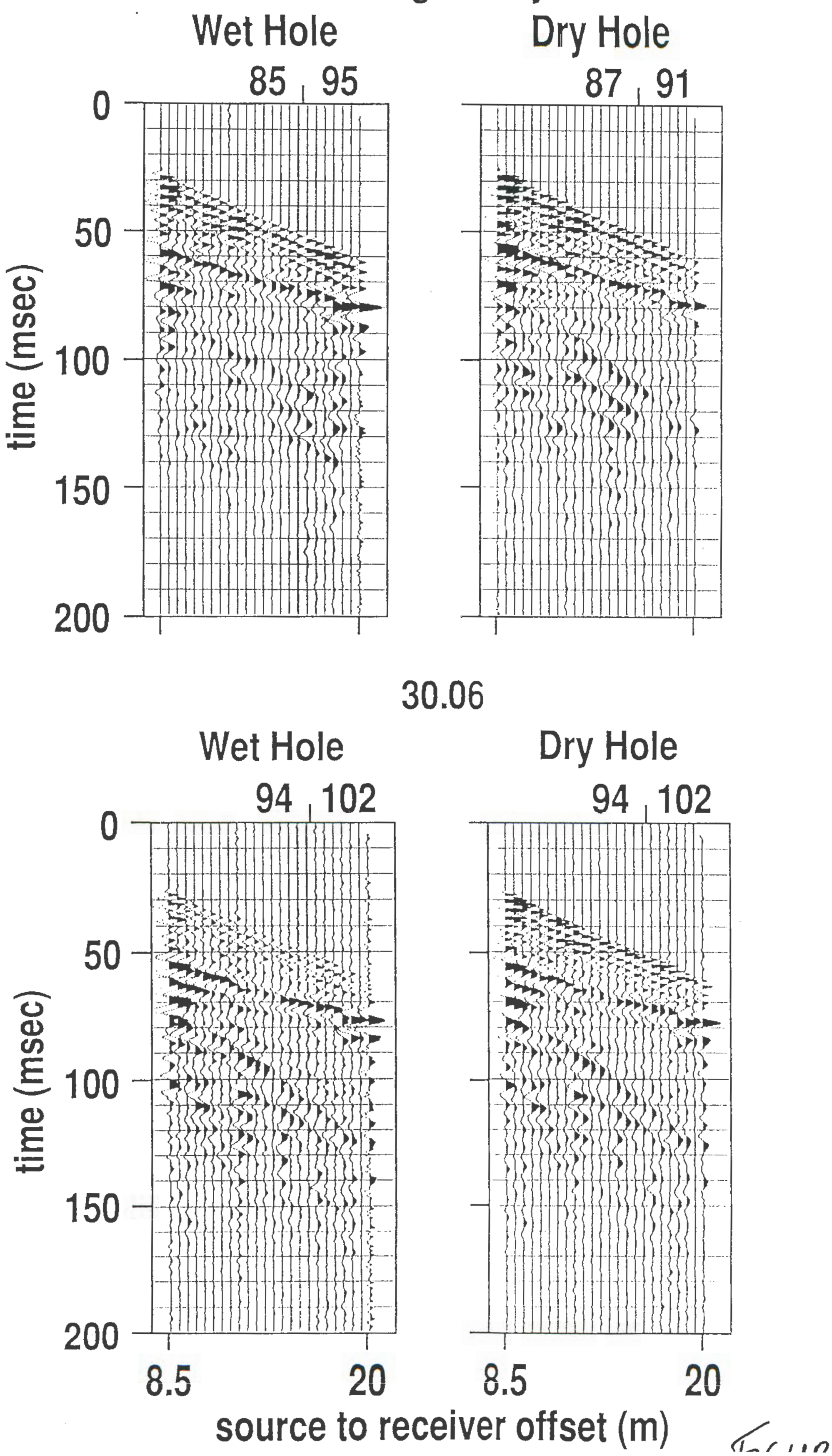



Figure 19.7b

SURFACE PROJECTILE SOURCES
WET HOLE VS DRY HOLE
220 Hz ANALOG LOW CUT FILTER
Total Gain Applied Individually To Each Trace (dB)
8 Gauge Betsy



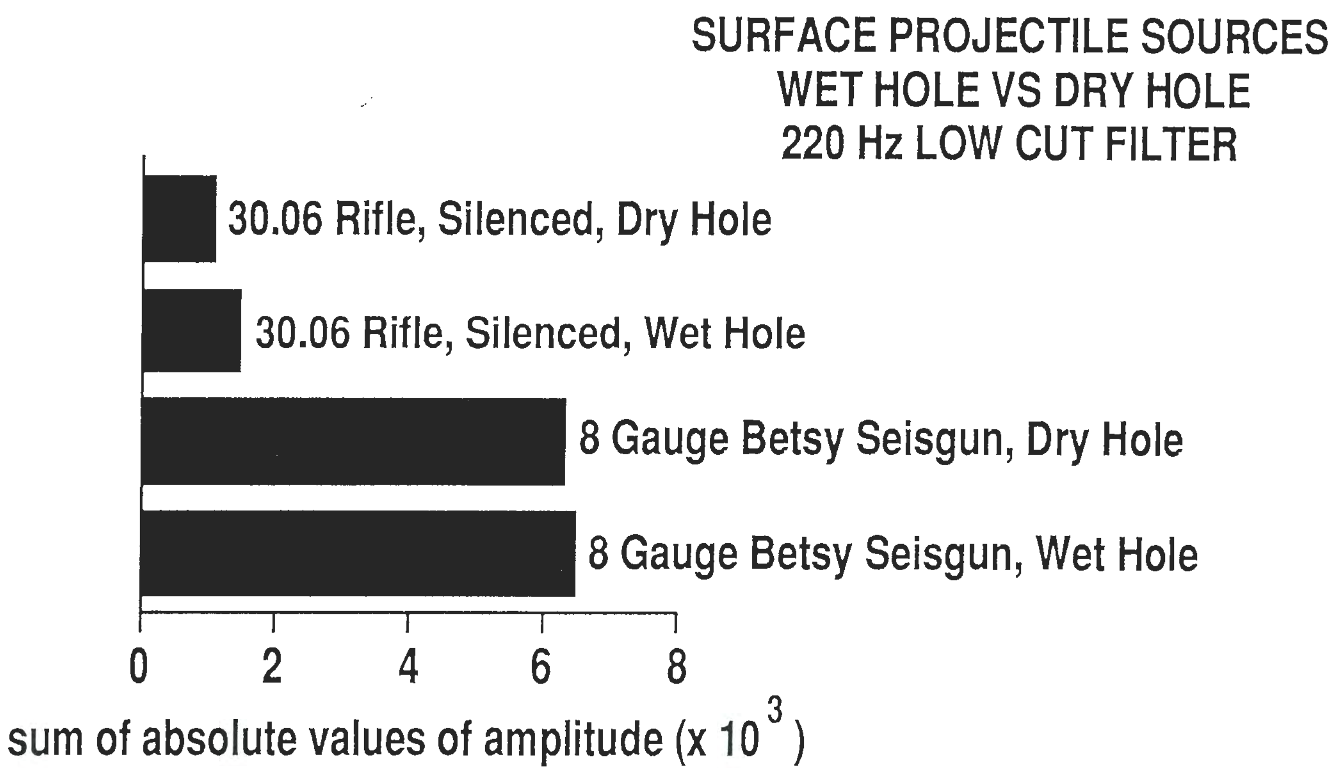

SURFACE PROJECTILE SOURCES
WET HOLE VS DRY HOLE
220 Hz LOW CUT FILTER
30.06 Rifle, Silenced, Dry Hole
30.06 Rifle, Silenced, Wet Hole
8 Gauge Betsy Seisgun, Dry Hole
8 Gauge Betsy Seisgun, Wet Hole
0
2
4
6
8
sum of absolute values of amplitude (x 10$^3$)

FIGURE 19.3b

50 CALIBER RIFLE (DOWNHOLE)
WATER FILLED VS DRY BOREHOLE
ANALOG LOW CUT FILTER OUT
Total Gain Applied Individually To Each Trace (dB)

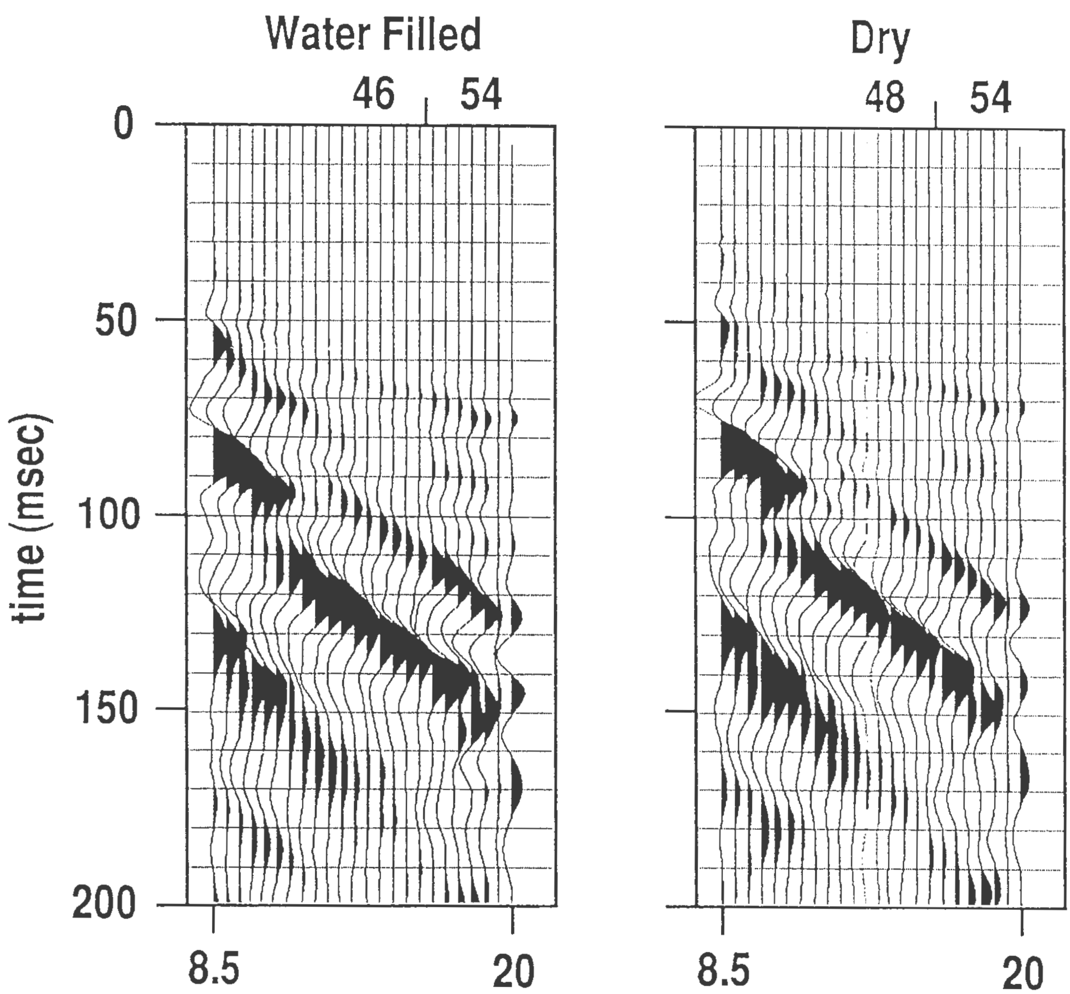



FIGURE 20.1a

50 CAL

[redacted] DOWNHOLE RIFLE
WET HOLE VS DRY HOLE
OPEN LOW CUT FILTER

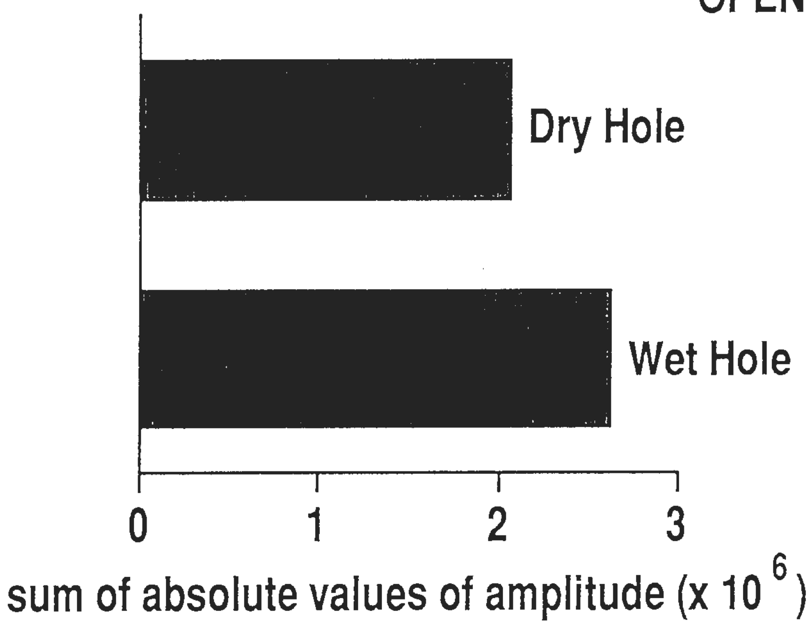



FIGURE 20.1b

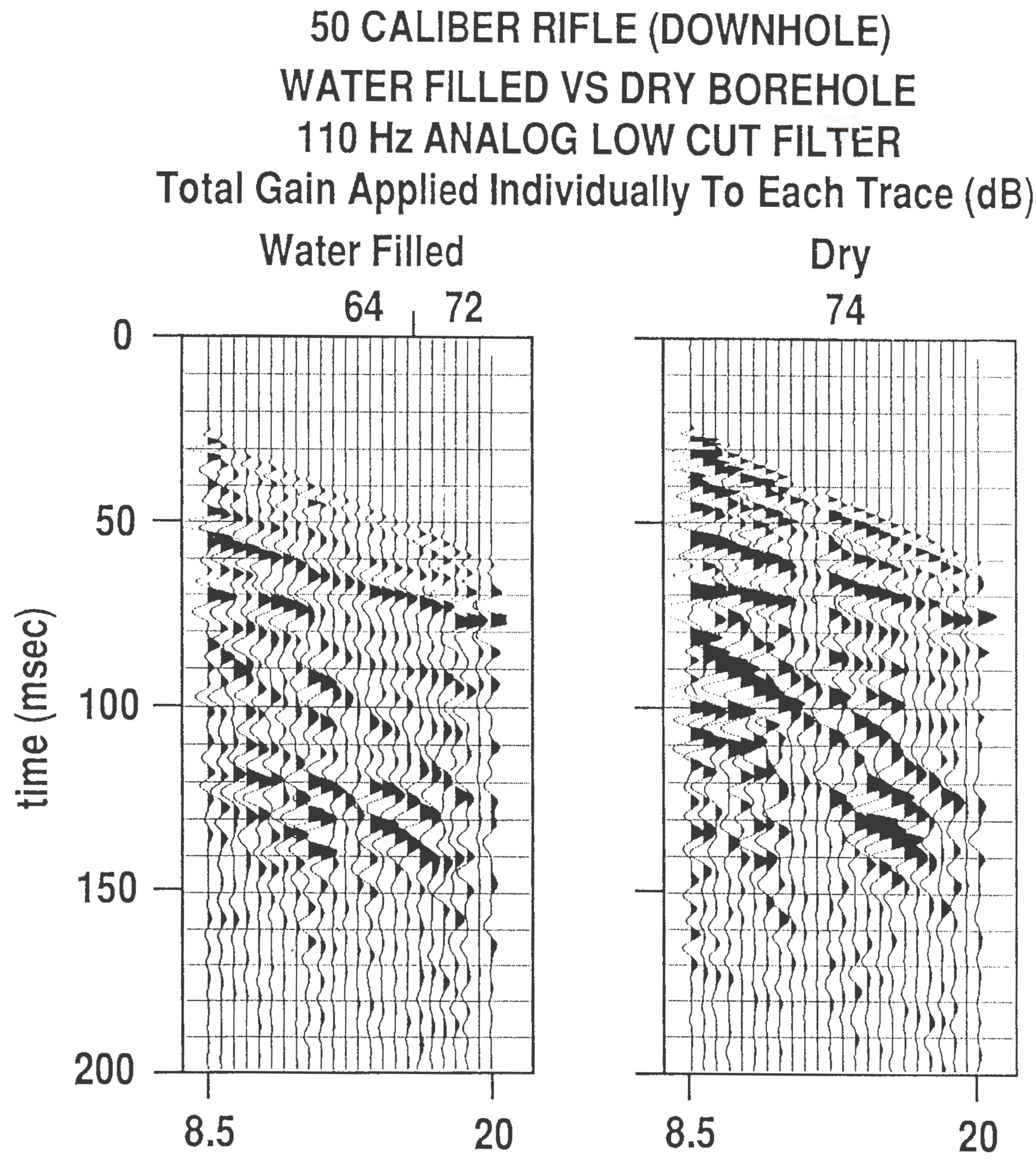

50 CALIBER RIFLE (DOWNHOLE)
WATER FILLED VS DRY BOREHOLE
110 Hz ANALOG LOW CUT FILTER
Total Gain Applied Individually To Each Trace (dB)
Water Filled
Dry
64
72
74
0
50
100
150
200
time (msec)
8.5
20
8.5
20

FIGURE 20.2a

SOCAL

[redacted] DOWNHOLE RIFLE
WET HOLE VS DRY HOLE
110 Hz LOW CUT FILTER

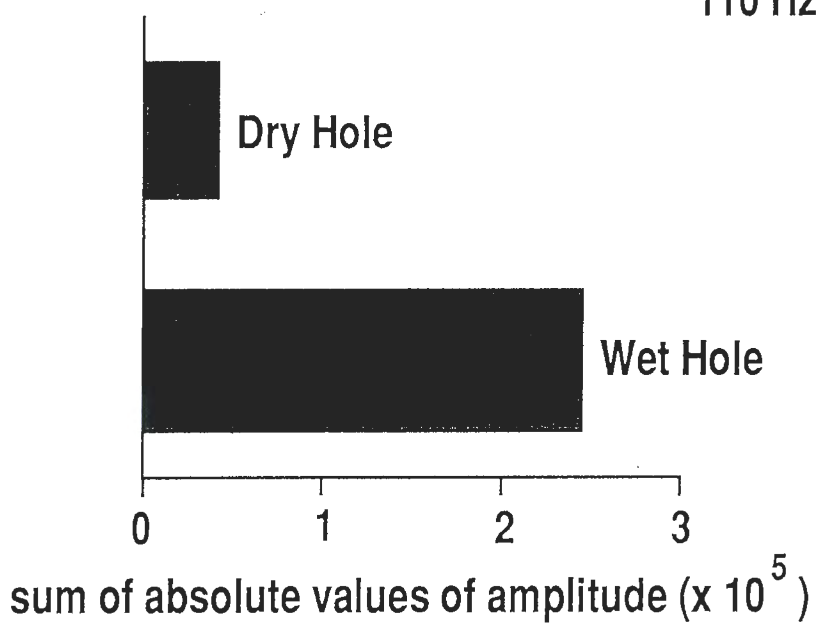



FIGURE 20.26

## 50 CALIBER RIFLE (DOWNHOLE)
## WATER FILLED VS DRY BOREHOLE
## 220 Hz ANALOG LOW CUT FILTER
## Total Gain Applied Individually To Each Trace (dB)

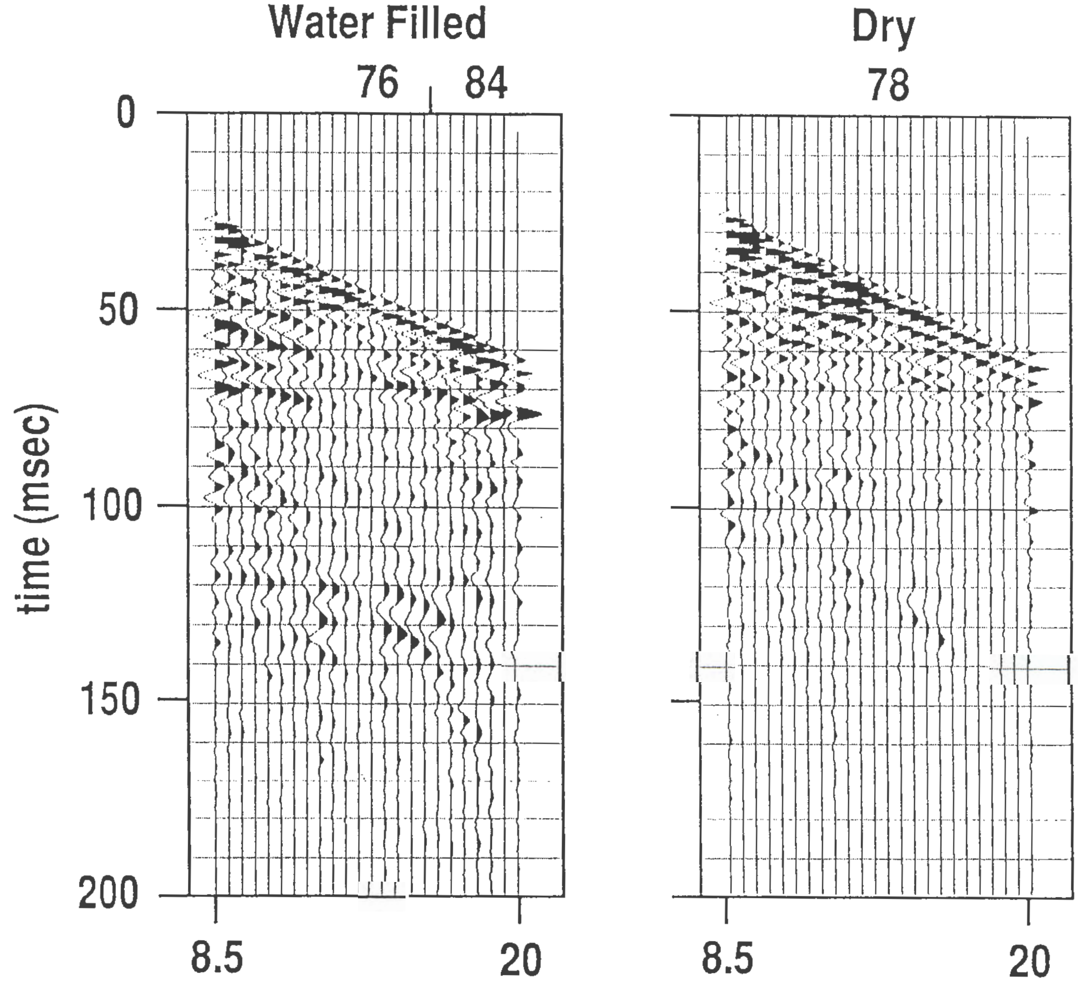



FIGURE 20.3a

50 Cal

[redacted] DOWNHOLE RIFLE
WET HOLE VS DRY HOLE
220 Hz LOW CUT FILTER

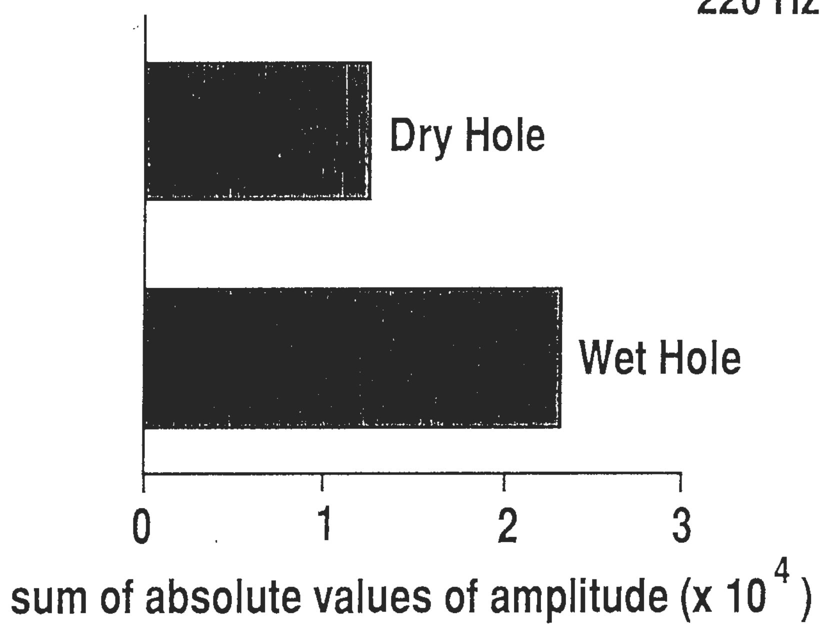



FIGURE 20.36

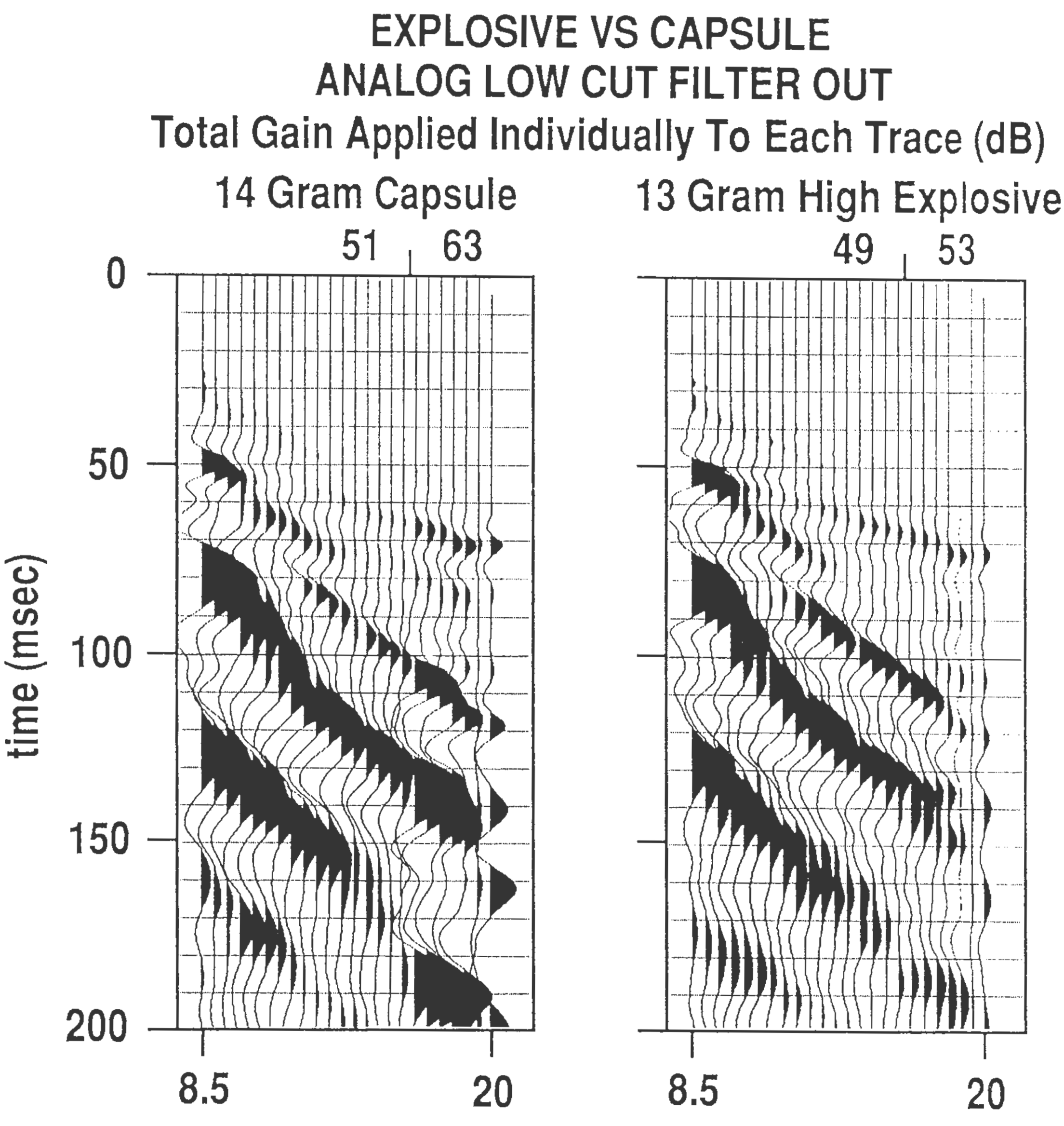

EXPLOSIVE VS CAPSULE
ANALOG LOW CUT FILTER OUT
Total Gain Applied Individually To Each Trace (dB)
14 Gram Capsule
13 Gram High Explosive
51
63
49
53
0
50
100
150
200
time (msec)
8.5
20
8.5
20

Figure 21 1a

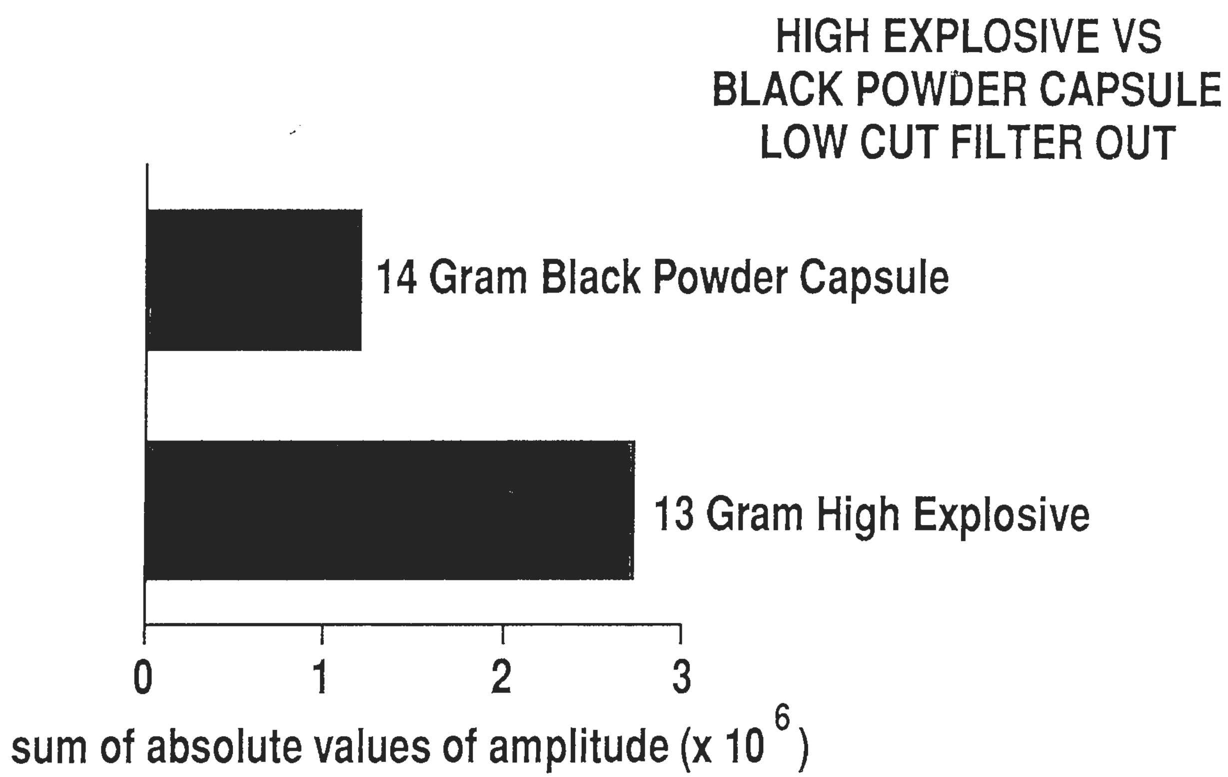

HIGH EXPLOSIVE VS
BLACK POWDER CAPSULE
LOW CUT FILTER OUT
14 Gram Black Powder Capsule
13 Gram High Explosive
0
1
2
3
sum of absolute values of amplitude (x 10 6 )

Figure 21.1b

EXPLOSIVE VS CAPSULE
110 Hz ANALOG LOW CUT FILTER
Total Gain Applied Individually To Each Trace (dB)

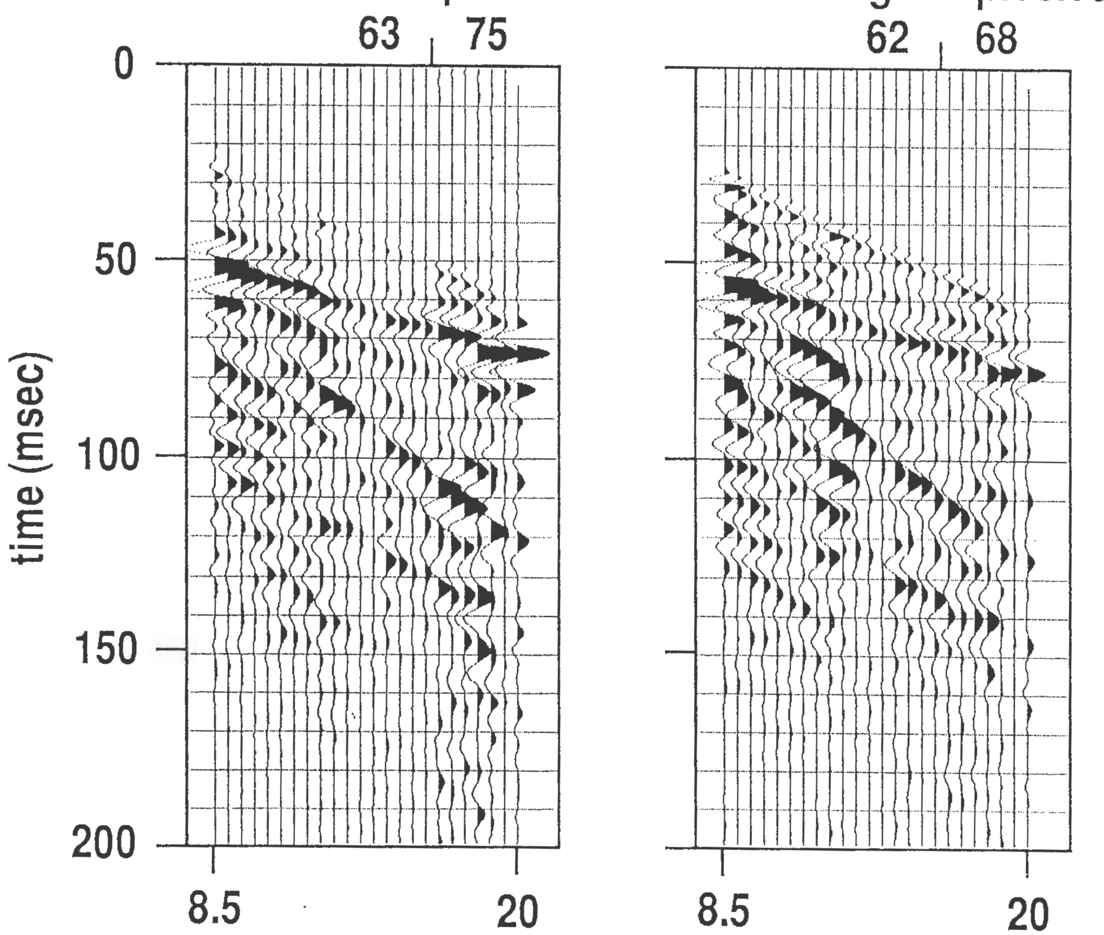



FIGURE 21.2c

HIGH EXPLOSIVE VS
BLACK POWDER CAPSULE
110 Hz LOW CUT FILTER

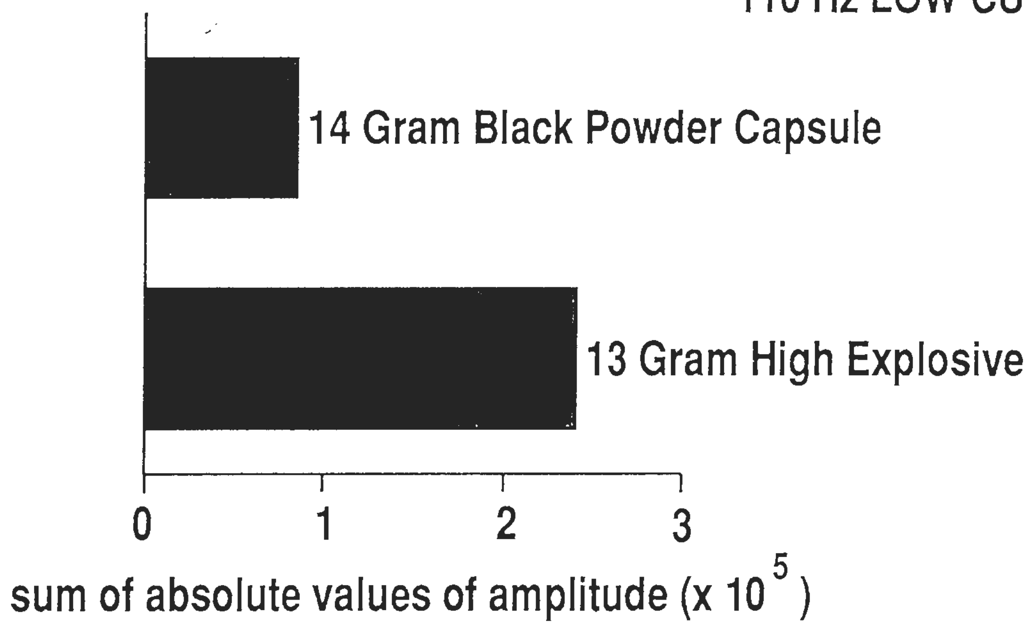



FIGURE 21.26

EXPLOSIVE VS CAPSULE
220 Hz ANALOG LOW CUT FILTER
Total Gain Applied Individually To Each Trace (dB)

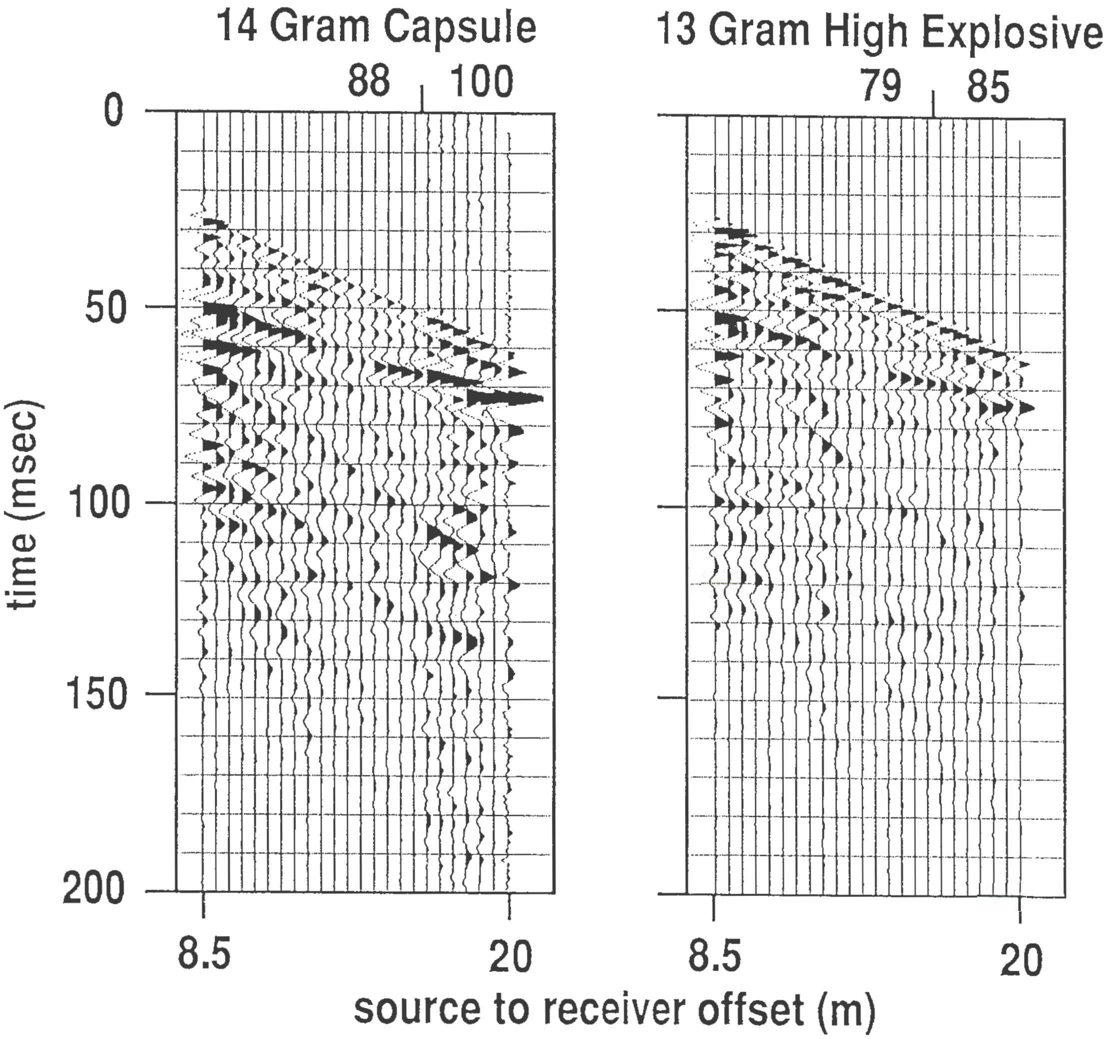



FIGURE 21.3a

HIGH EXPLOSIVE VS
BLACK POWDER CAPSULE
220 Hz LOW CUT FILTER

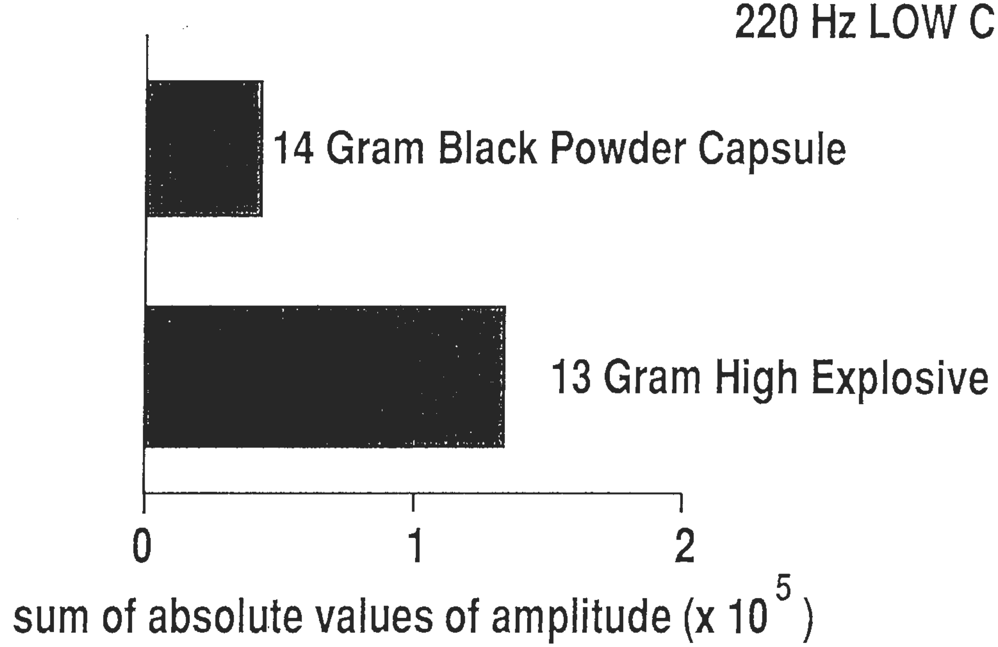



FIGURE 21.36

## 30.06 RIFLE, SURFACE VS DOWNHOLE
## (FIRED INTO WATER FILLED HOLE)
## OPEN LOW CUT FILTER
### Total Gain Applied Individually To Each Trace (dB)

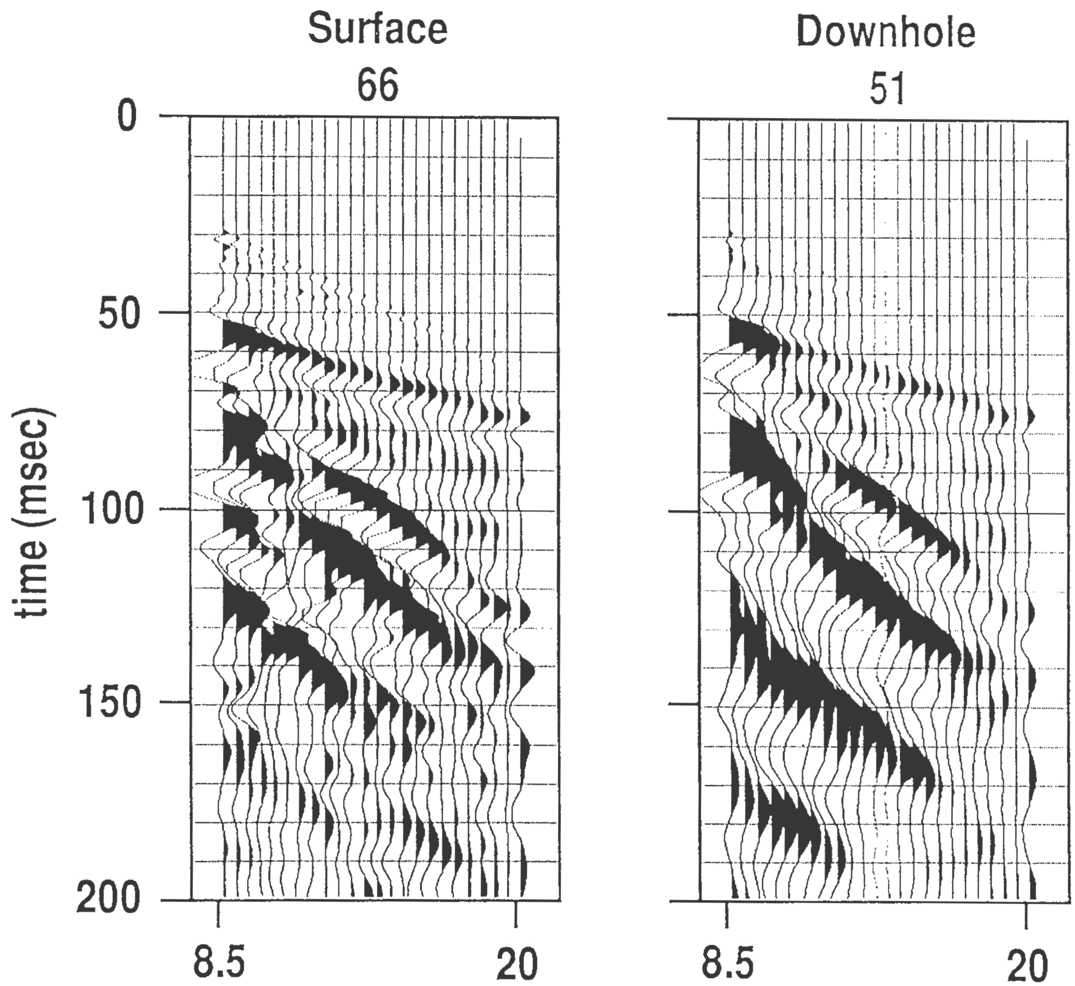
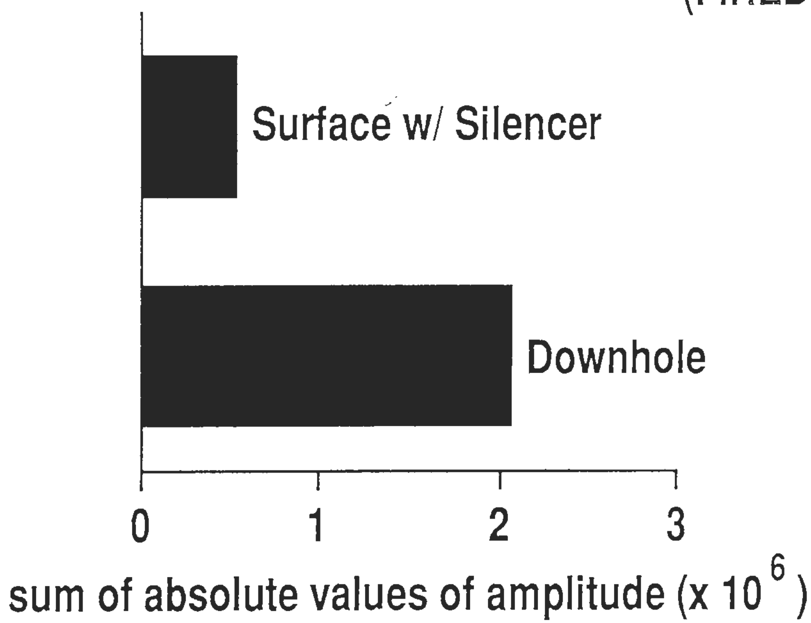



FIGURE 22.1a

30.06 RIFLE
SURFACE VS DOWNHOLE
OPEN LOW CUT FILTER
(FIRED INTO WATER-FILLED HOLES)



30.06 RIFLE, SURFACE VS DOWNHOLE
(FIRED INTO WATER FILLED HOLE)
110 Hz LOW CUT FILTER
Total Gain Applied Individually To Each Trace (dB)

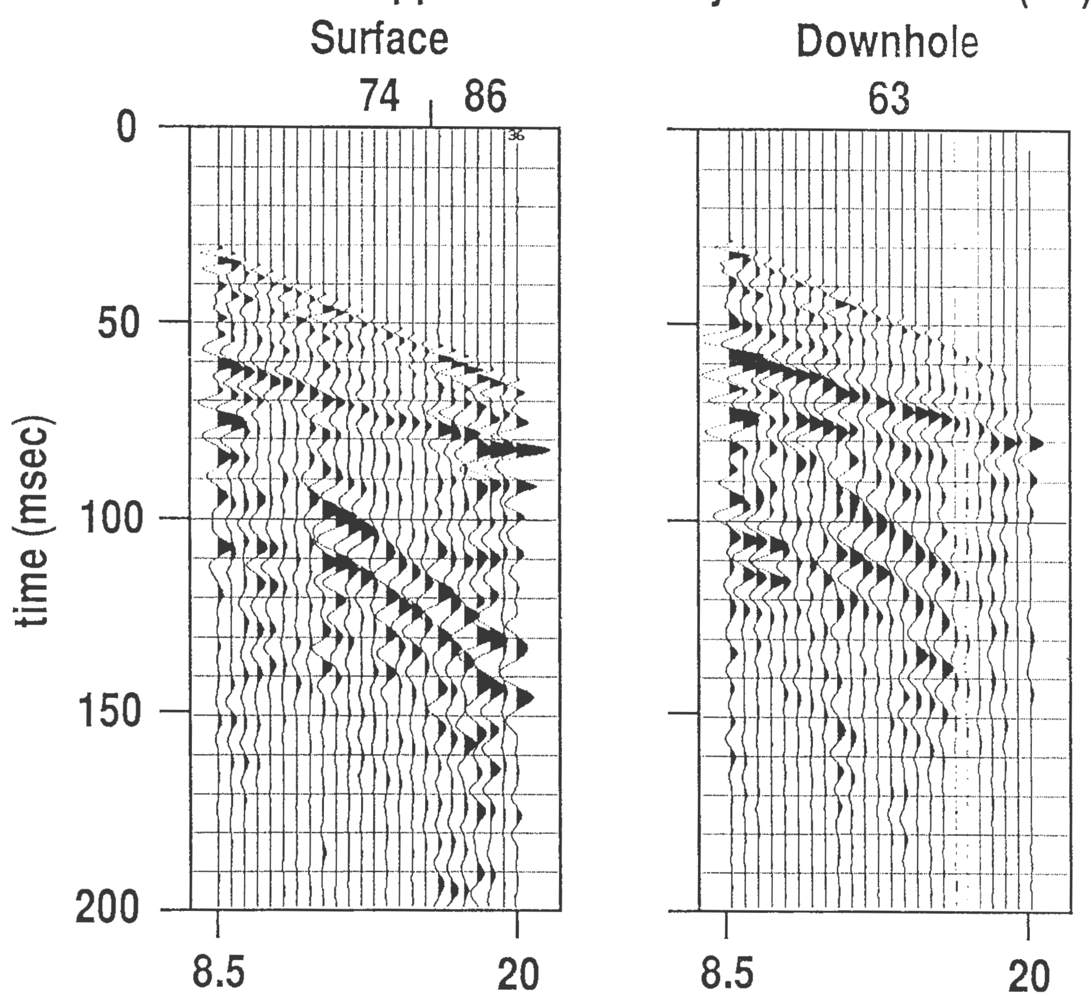



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FIGURE 22.

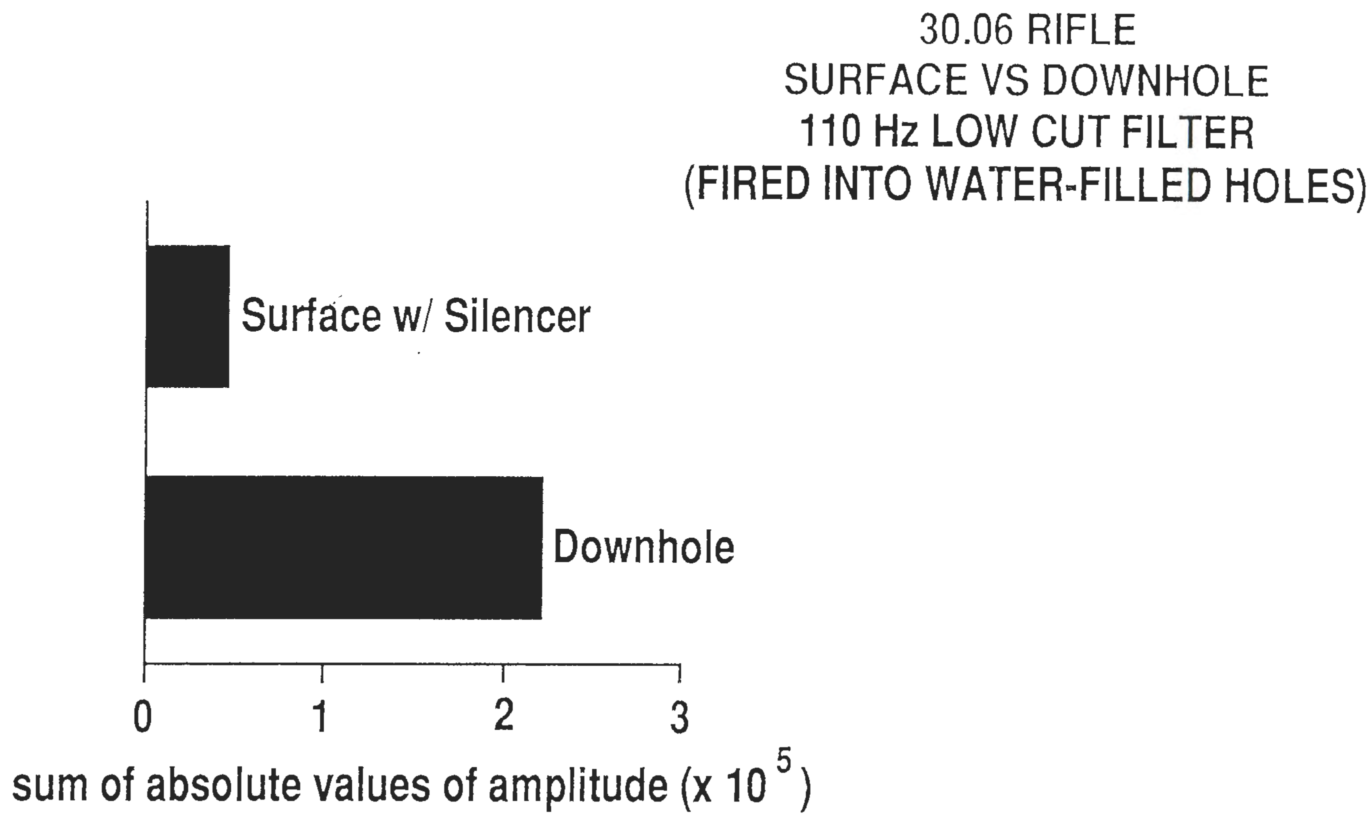
30.06 RIFLE
SURFACE VS DOWNHOLE
110 Hz LOW CUT FILTER
(FIRED INTO WATER-FILLED HOLES)
Surface w/ Silencer
Downhole
0
1
2
3
sum of absolute values of amplitude (x 10 5 )

FIGURE 22.26

# 30.06 RIFLE, SURFACE VS DOWNHOLE
# (FIRED INTO WATER FILLED HOLE)
# 220 Hz LOW CUT FILTER

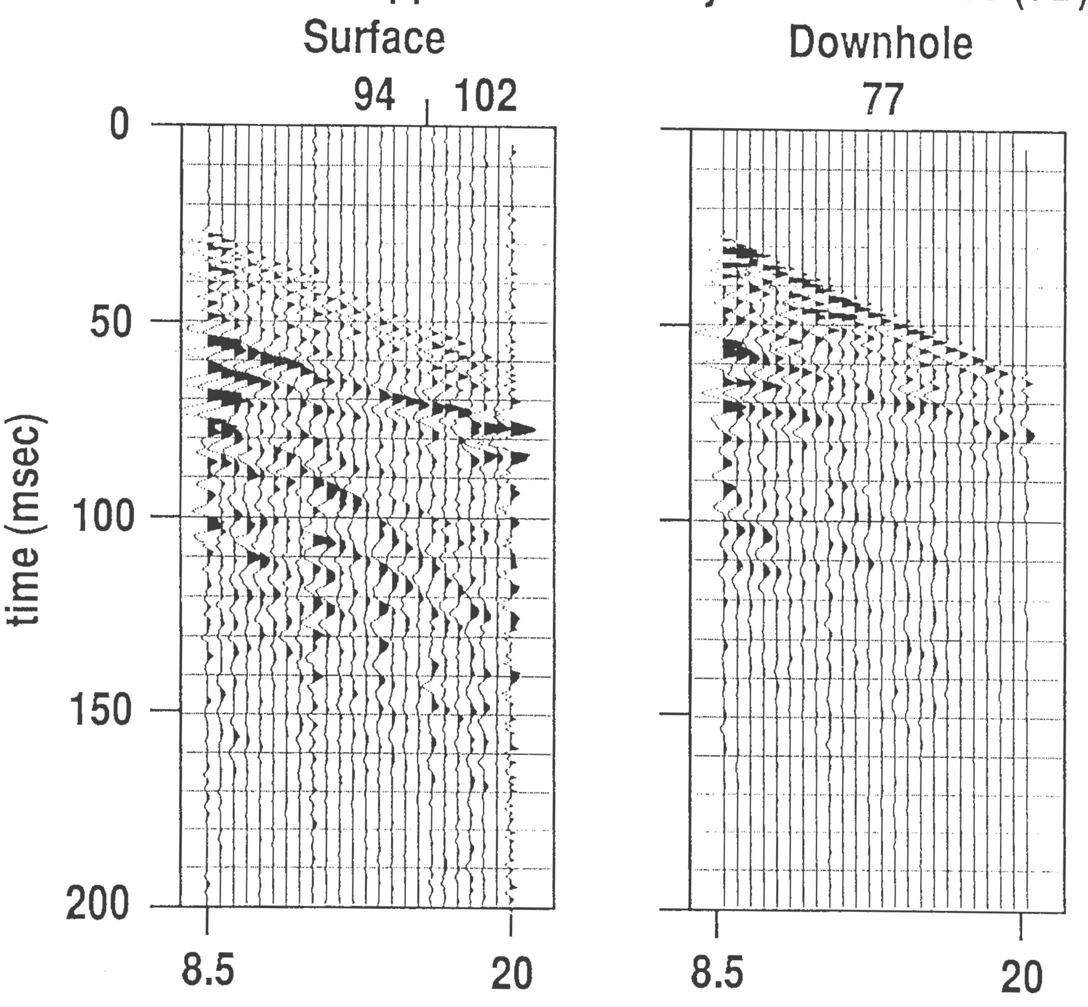


FIGURE 22.3a

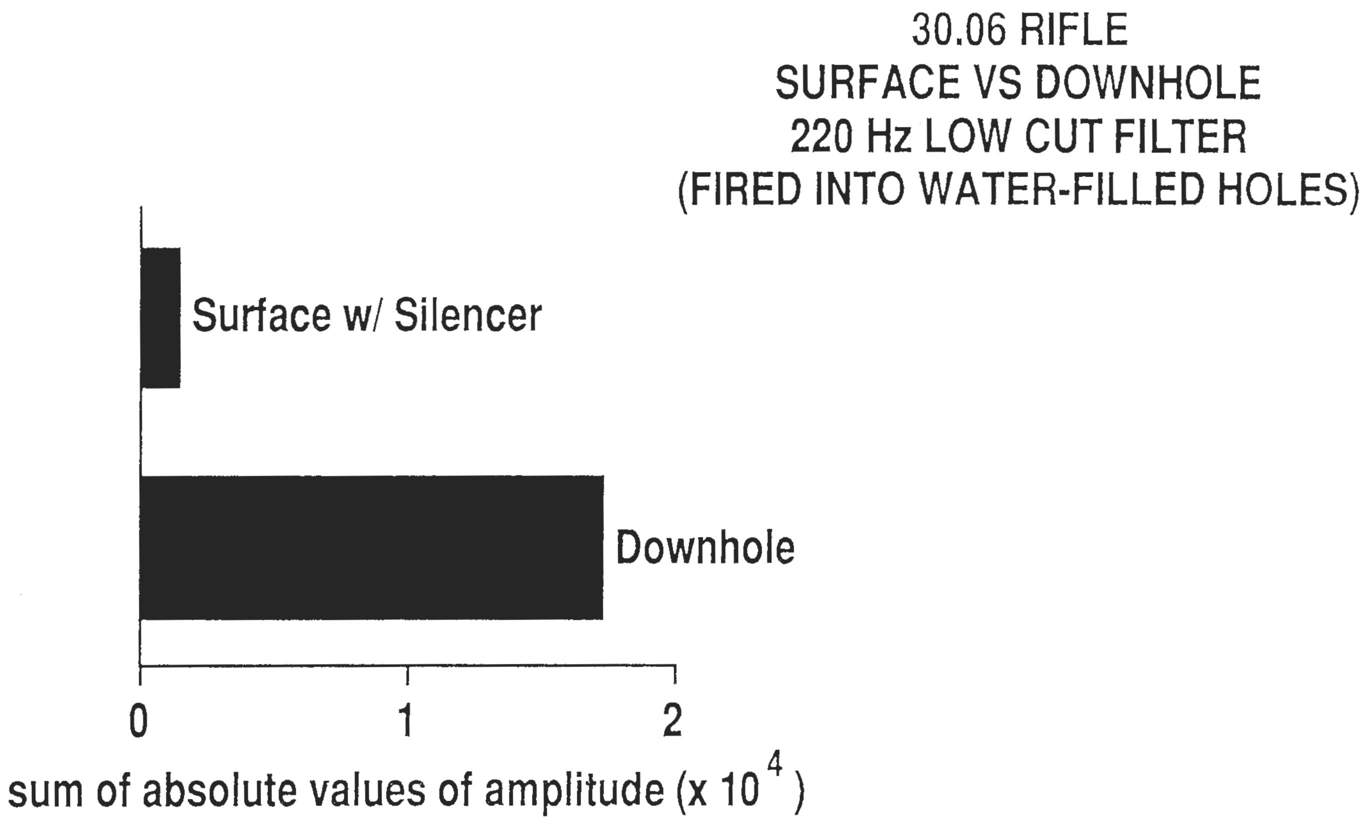
30.06 RIFLE
SURFACE VS DOWNHOLE
220 Hz LOW CUT FILTER
(FIRED INTO WATER-FILLED HOLES)
Surface w/ Silencer
Downhole
0
1
2
sum of absolute values of amplitude (x 10 4 )

Figure 22.3b

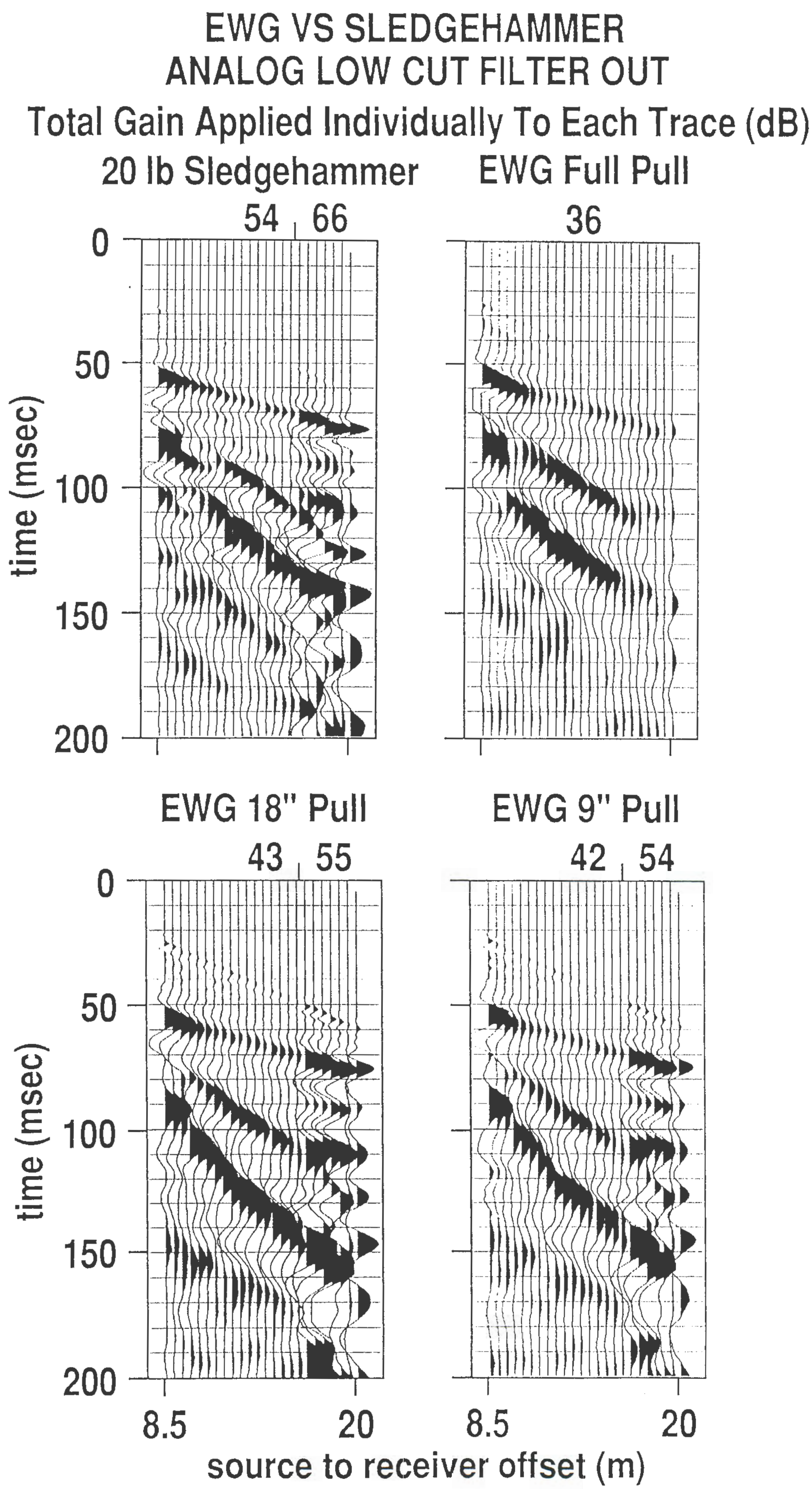
EWG VS SLEDGEHAMMER
ANALOG LOW CUT FILTER OUT
Total Gain Applied Individually To Each Trace (dB)
20 lb Sledgehammer
54
66
EWG Full Pull
36
EWG 18" Pull
43
55
EWG 9" Pull
42
54
0
50
100
150
200
time (msec)
8.5
20
source to receiver offset (m)

FIGURE 23.1a

EWG VS 20 lb SLEDGEHAMMER
OPEN LOW CUT FILTER

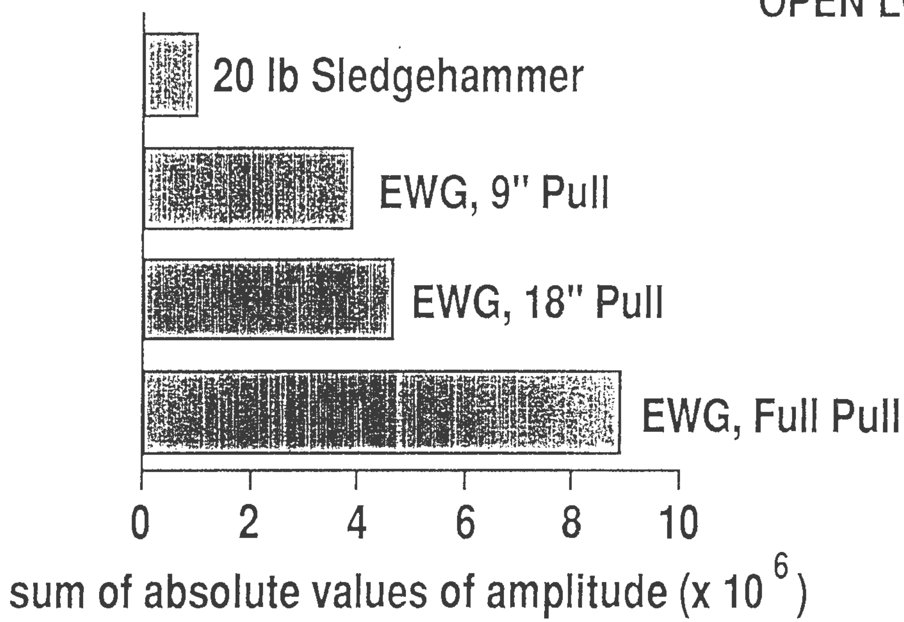


FIGURE 23.1b

EWG VS SLEDGEHAMMER
110 Hz ANALOG LOW CUT FILTER
Total Gain Applied Individually To Each Trace (dB)

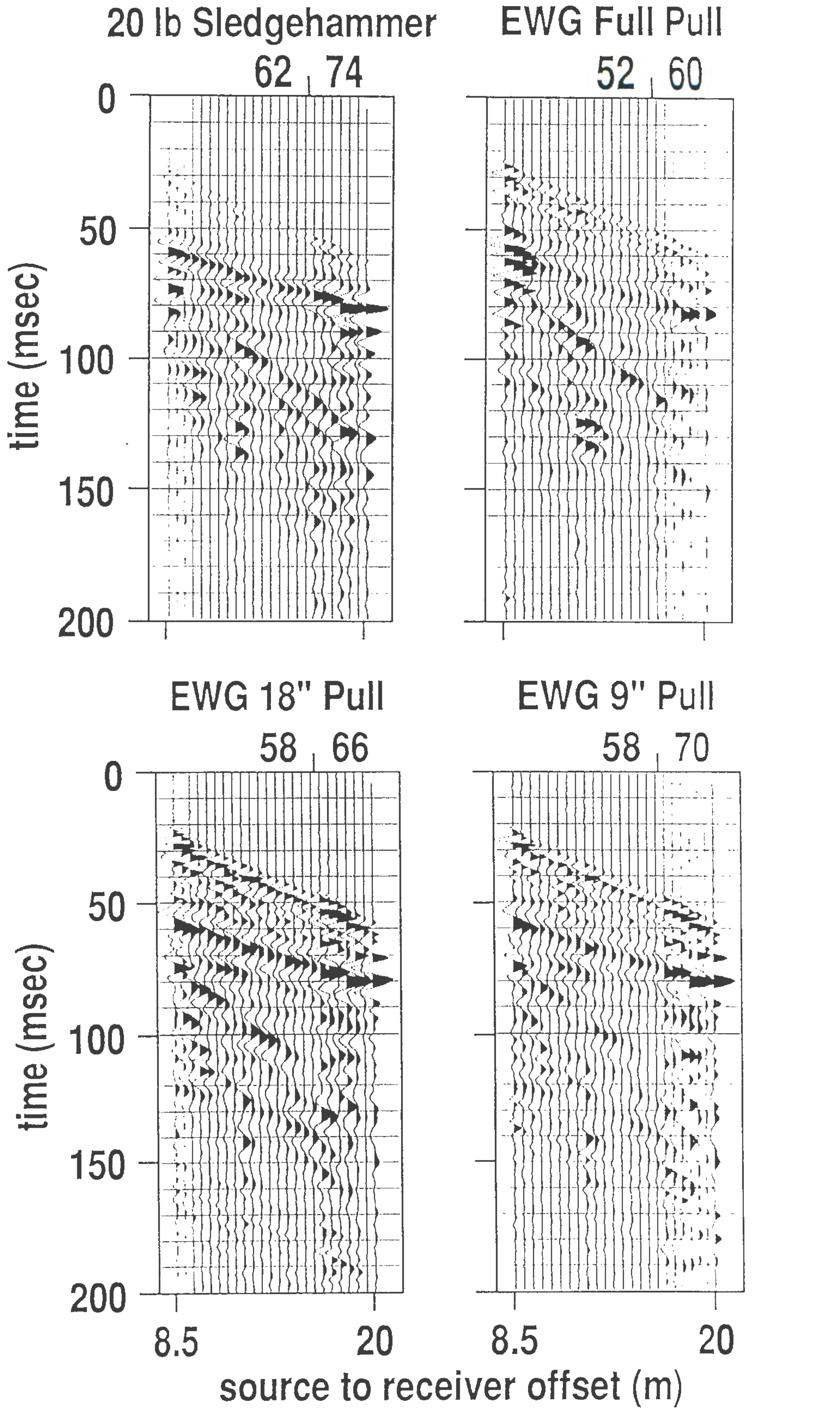


FIGURE 23.2a

EWG VS 20 lb SLEDGEHAMMER
110 Hz LOW CUT FILTER

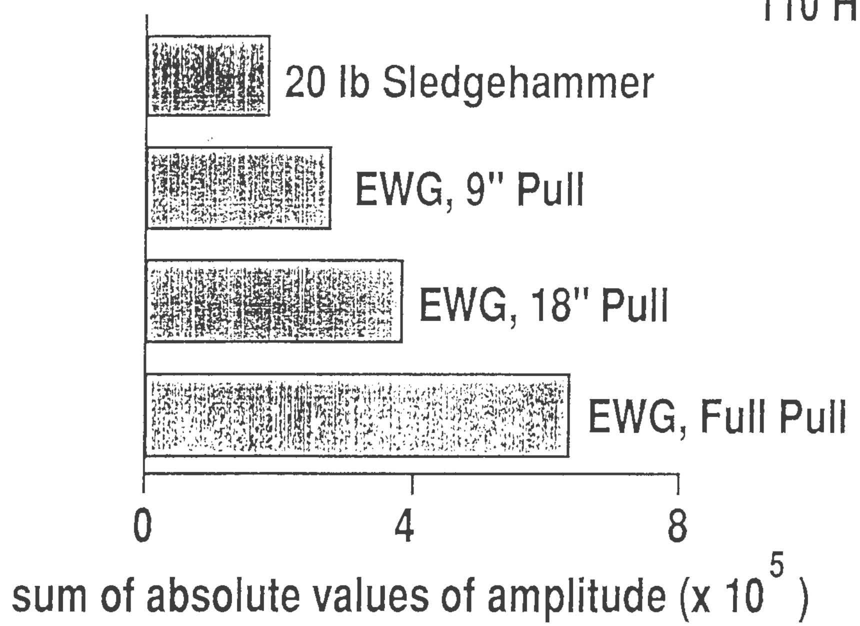


FIGURE 23.26

EWG VS SLEDGEHAMMER
220 Hz ANALOG LOW CUT FILTER
Total Gain Applied Individually To Each Trace (dB)

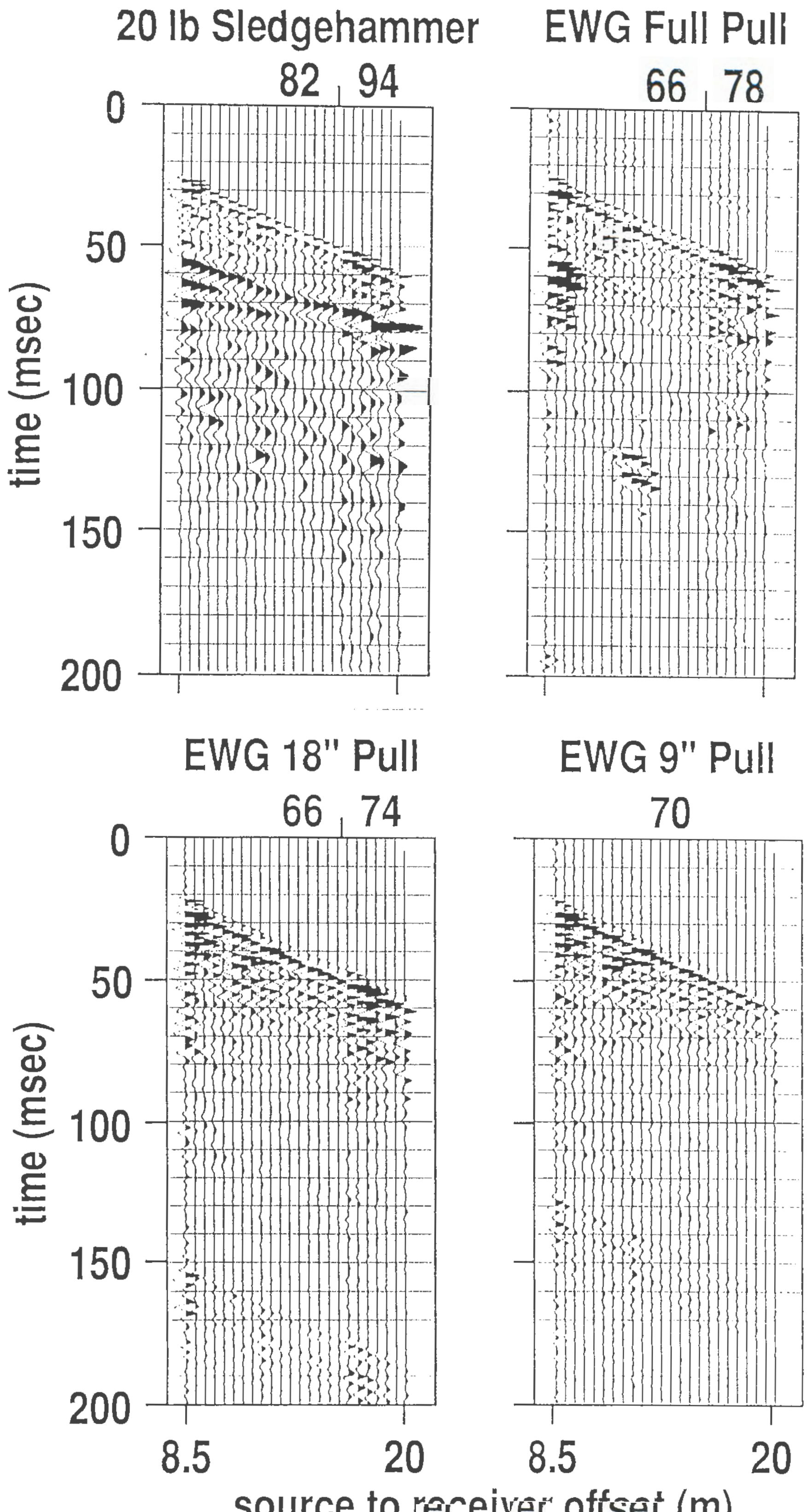


FIGURE 23.3a

EWG VS 20 lb SLEDGEHAMMER
220 Hz LOW CUT FILTER