# Shallow Reflection Surveys
# An Overview and Introduction

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# Introduction

**These are the notes and slides for a 1-hour course introducing shallow reflection surveys. This is a broad topic to cover in that time period. Nevertheless, we hope that by the conclusion, you will have begun to develop the following skills:**

**A basic understanding of how the earth is imaged with reflected seismic waves**

**How to recognize a seismic reflection, and how to manipulate a seismogram to make such events visible**

**The advantages and disadvantages of reflection surveys.**

**How to interpret a seismic section**

**Some practical applications**

**How to actually conduct a survey**

**The two basic field procedures, and how to choose which is appropriate**

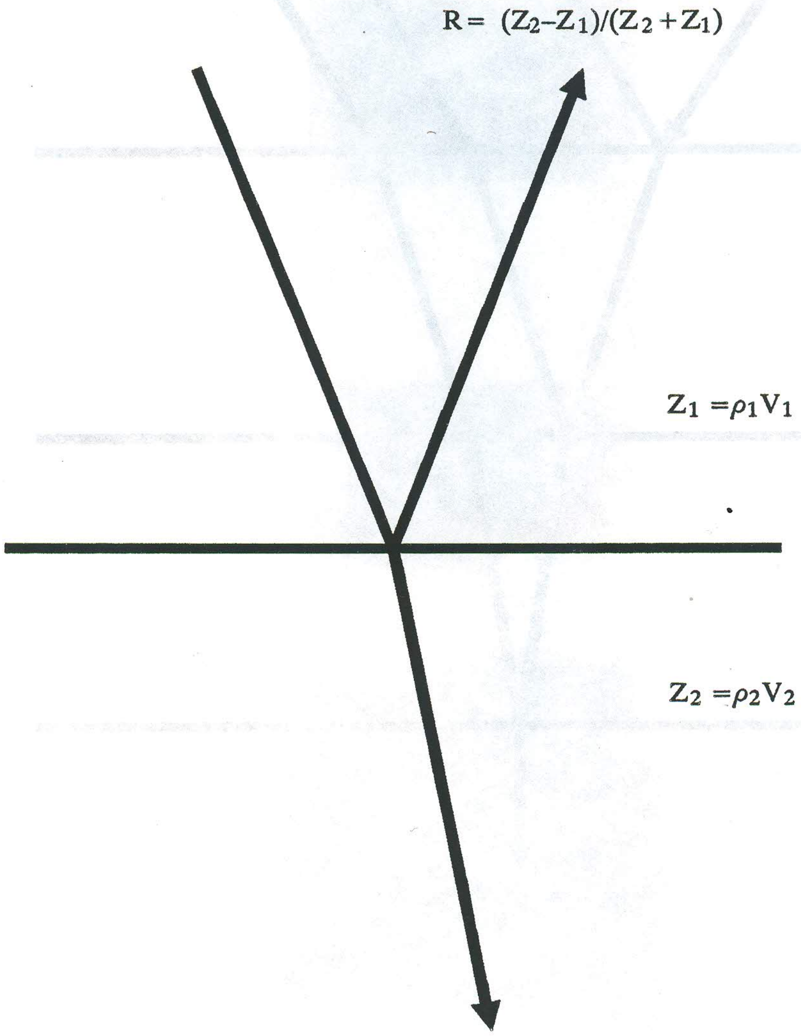
**How to choose a seismograph, geophones and energy source**

**How to [try to] predict when reflection will work**

**When to get some help**

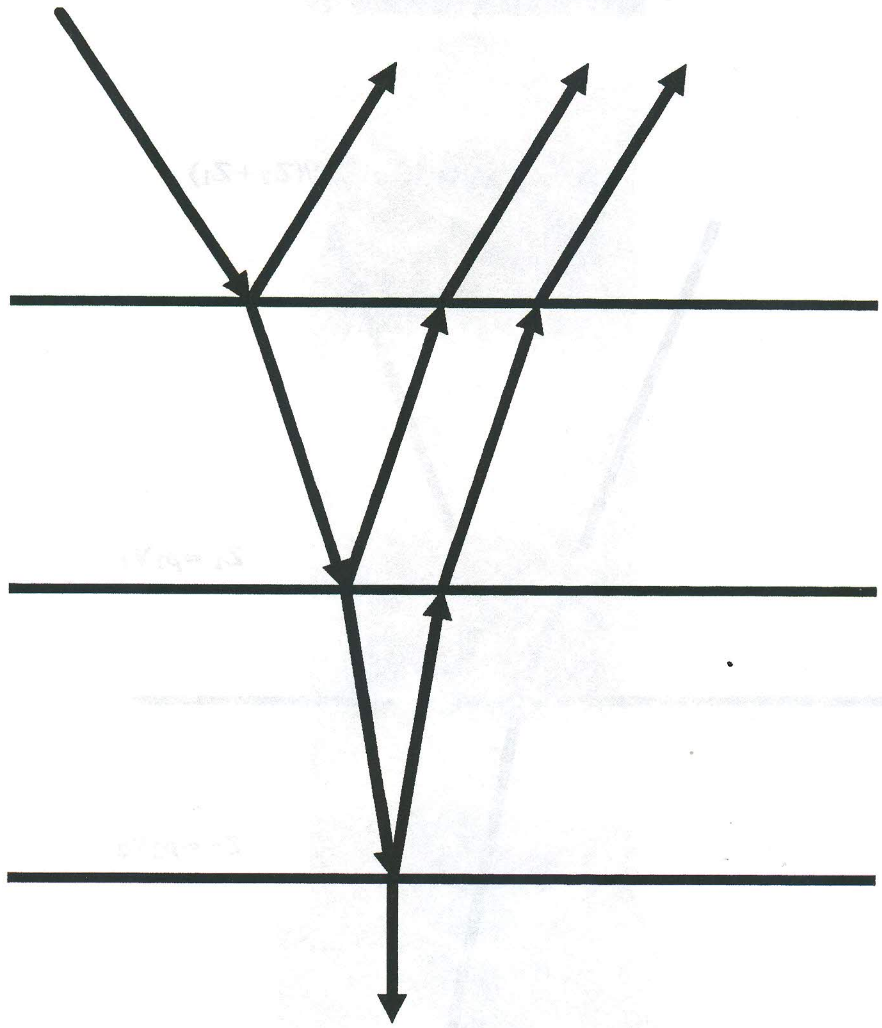
Slide

# What are reflections, when do you get them?



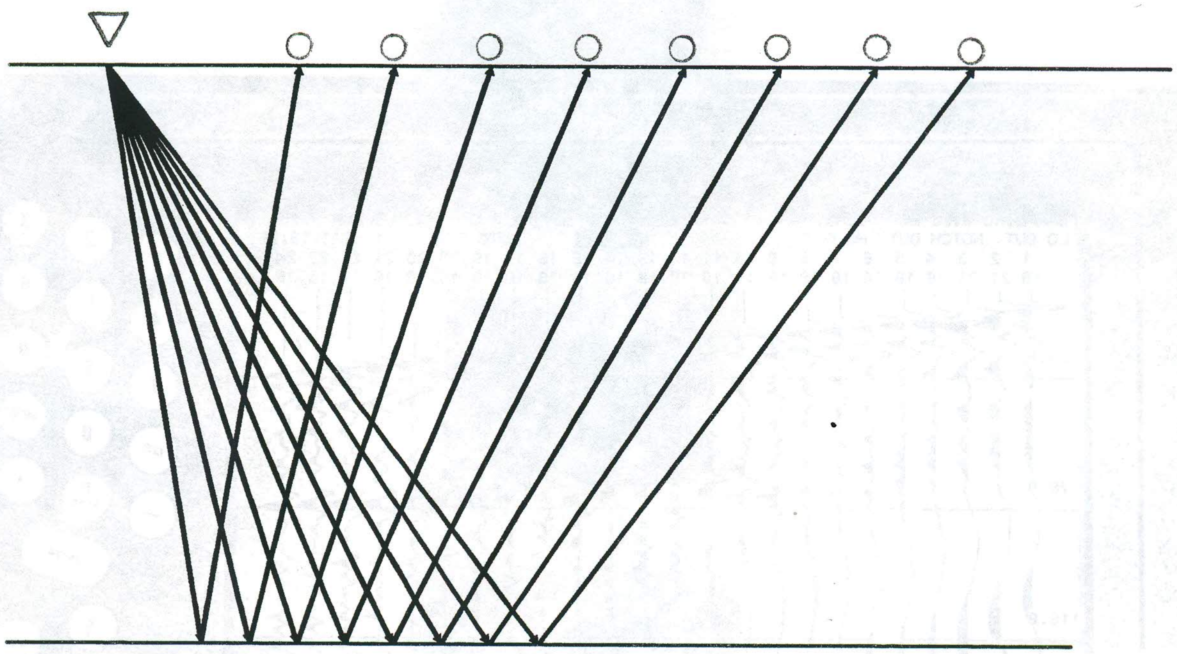

**As you might expect, the actual behavior is more complicated. The above equations are only true for vertical incidence, but are usable within 20 degrees. Some of the energy goes into reflected and refracted shear waves. See the Zoeppritz equations for the details.**

# Multiple interfaces create multiple reflections.



# How do you do a reflection survey?

**Like refraction, but shorter spreads for the same depth and some offset from the end of the line.**



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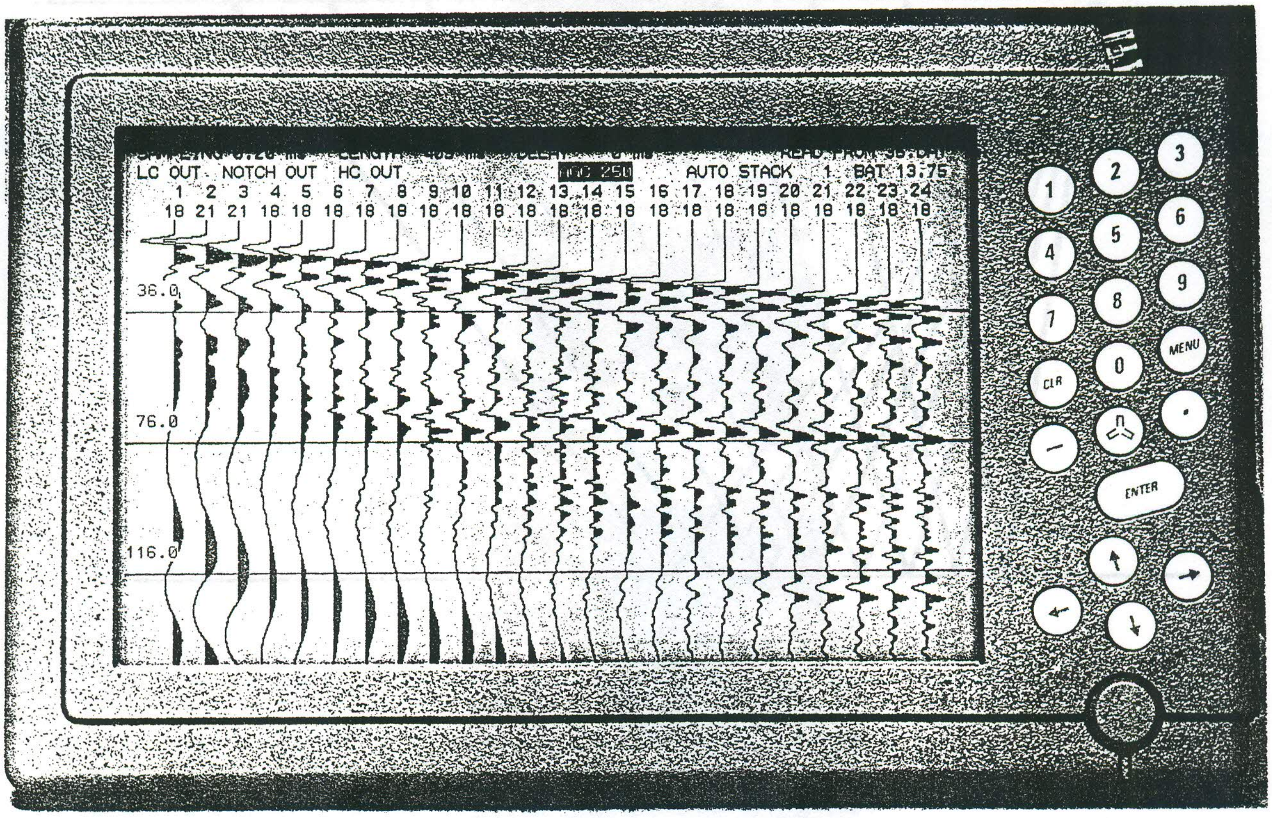
# Recognizing reflections.

**Reflections arrive in the middle of the seismic record, after the "first arrivals" They are nearly flat, slightly curved. Usually on some but not all of the traces.**



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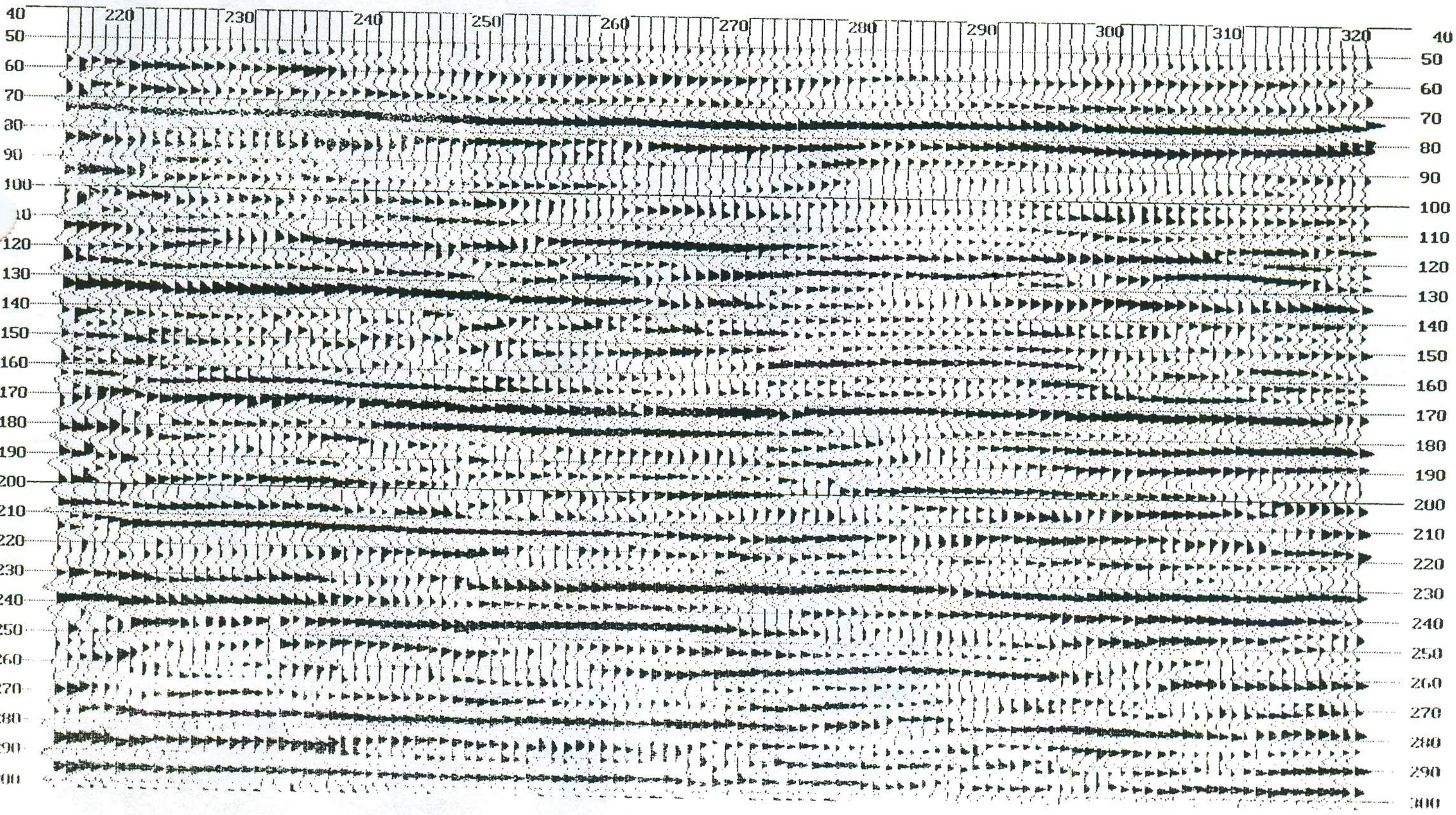
# Seismic Sections

**Individual shots or files are compiled and processed into a "seismic section". A "section" is not a cross-section geologic map, even though it looks like one. It is an illustration showing where material types change and their depth in <u>time</u> (not meters or feet).**

**The geologist or the interpreter looks at the section, adds some common sense and geologic knowledge, and hopefully a drill hole or two, and decides what the lines mean. After it is interpreted, it becomes geology.**



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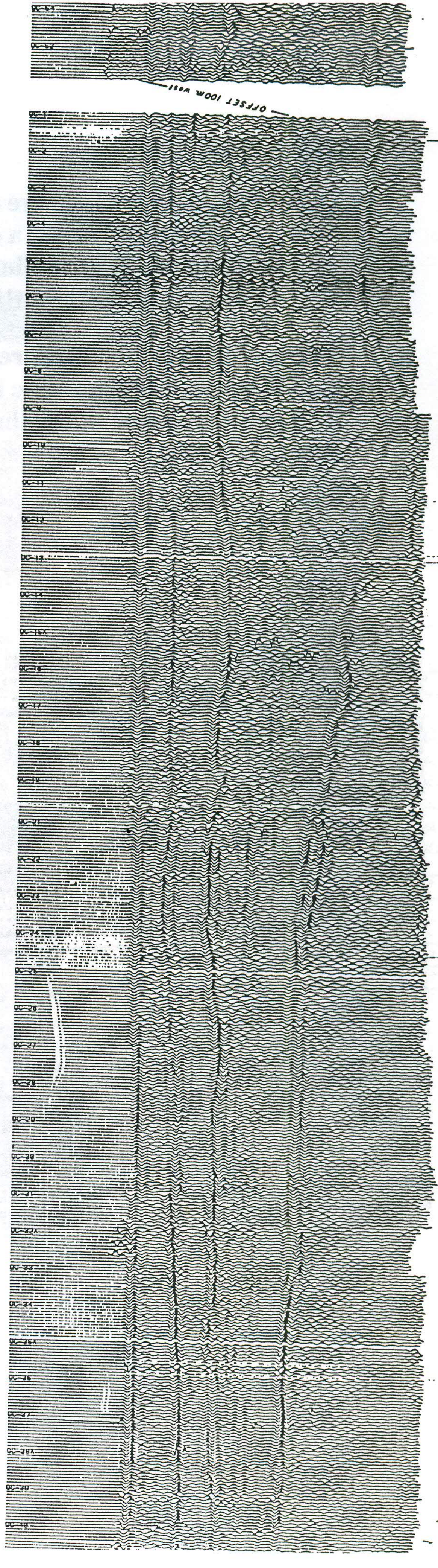
# A "typical" seismic section.

**From "Field Experience with the Optimum Window Hammer Seismic Reflection Technique, by Hunter, Burns, Gagne, Good, MacAulay and Pullan, Terrain Sciences Division, Geological Survey of Canada**

**Up** ⟵



Notes

The section on the prior page was created from data recorded by the team at the Geological Survey of Canada, Terrain Sciences Division, around 1983. That period was the dawn of modern shallow reflection methods and this group did much of the pioneer work in that area.

What you see resembles a cross-section slice of the earth. The lines are 3 meters apart and the depth is about 100 meters. The blank portion on top is the material above the water table which has been muted (or erased) from the record. Often there is no useful information above the water table.

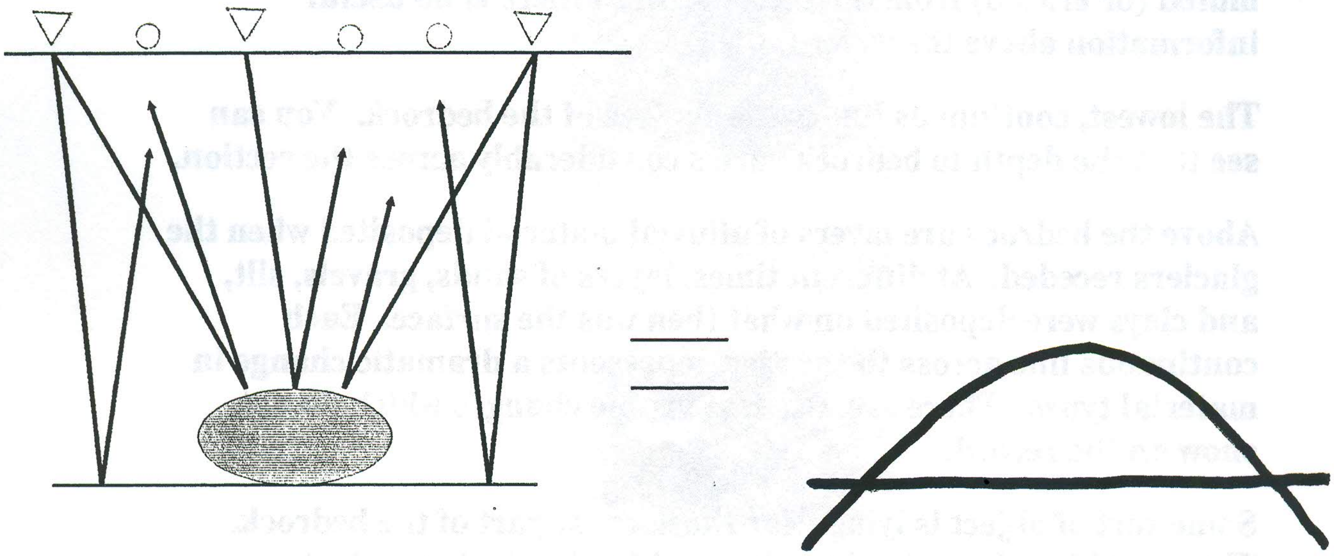
The lowest, continuous line is the surface of the bedrock. You can see that the depth to bedrock varies considerably across the section.

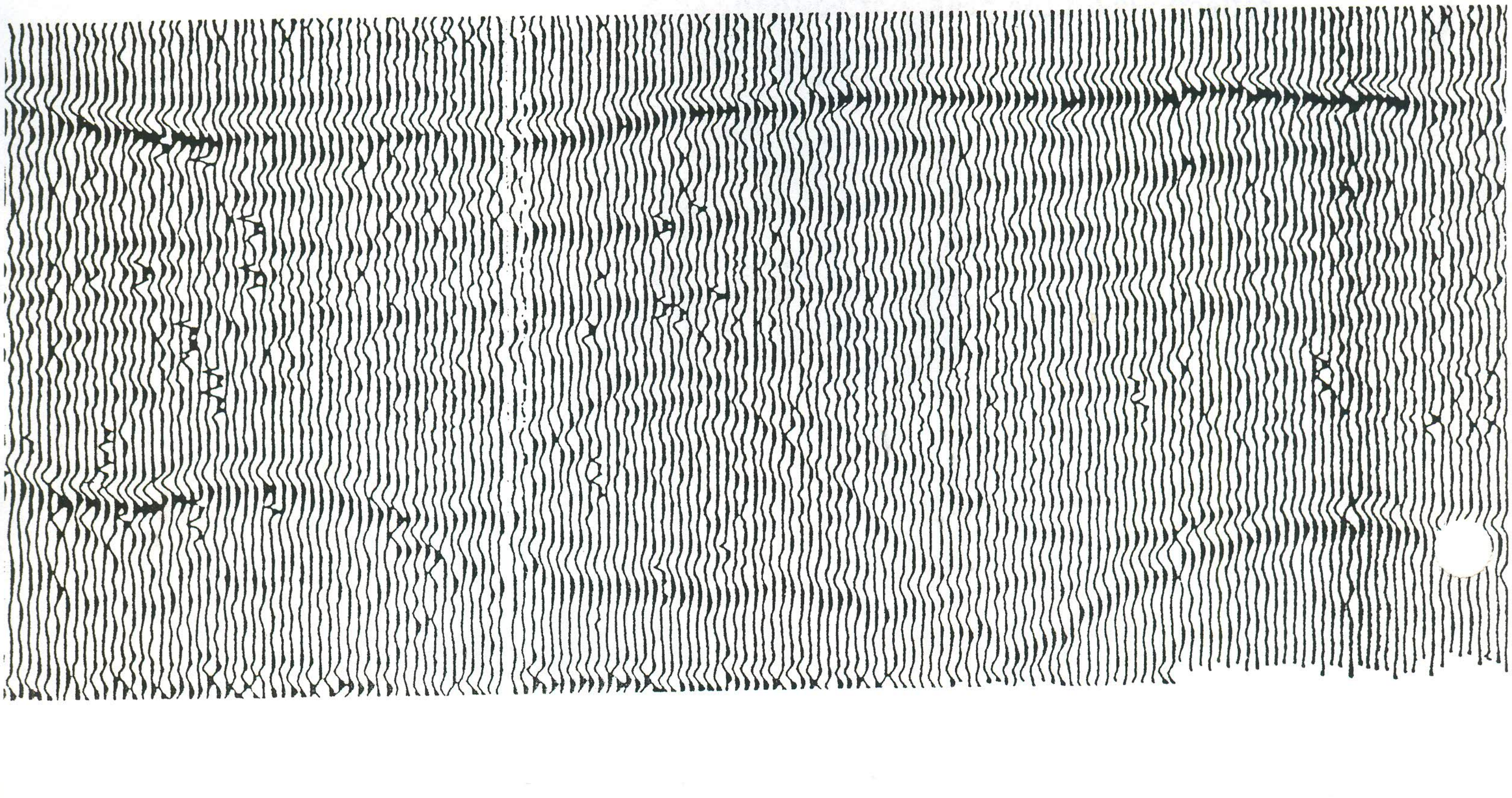
Above the bedrock are layers of alluvial material deposited when the glaciers receded. At different times, layers of sands, gravels, silt, and clays were deposited on what then was the surface. Each continuous line across the section represents a dramatic change in material types. There are also less visible changes which do not show on the record.

Some sort of object is lying near the deepest part of the bedrock. This could be a large boulder dropped by the glacier, or just a projection in the bedrock. The steeply angled edges are diffractions, reflections off the peak plotted to the side.

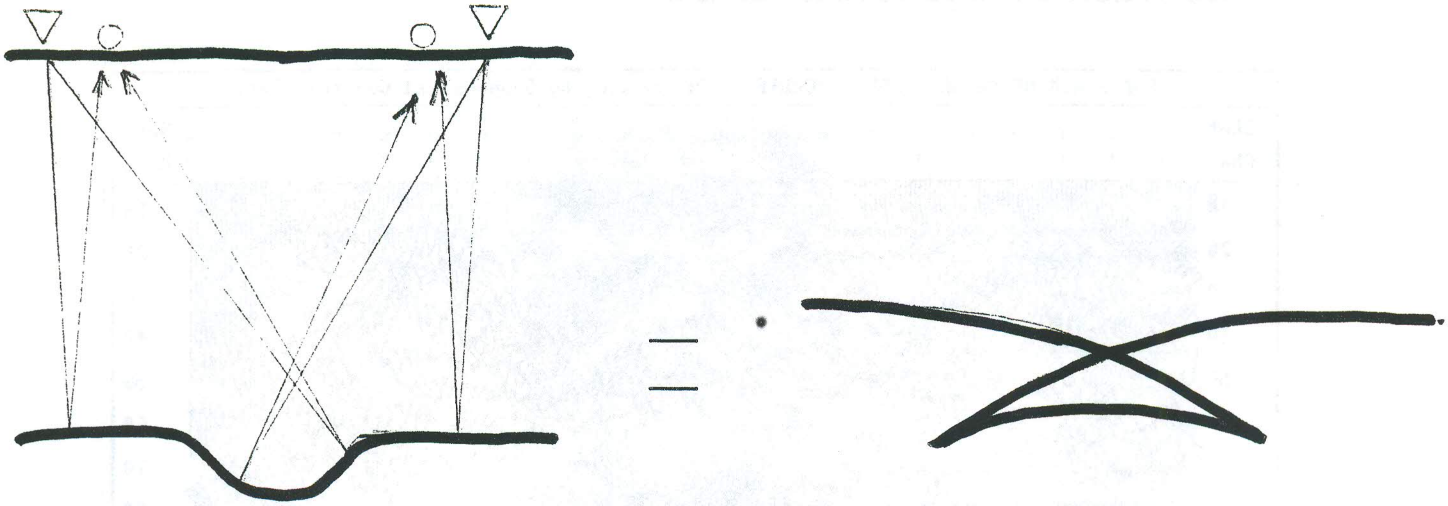
## Diffractions.

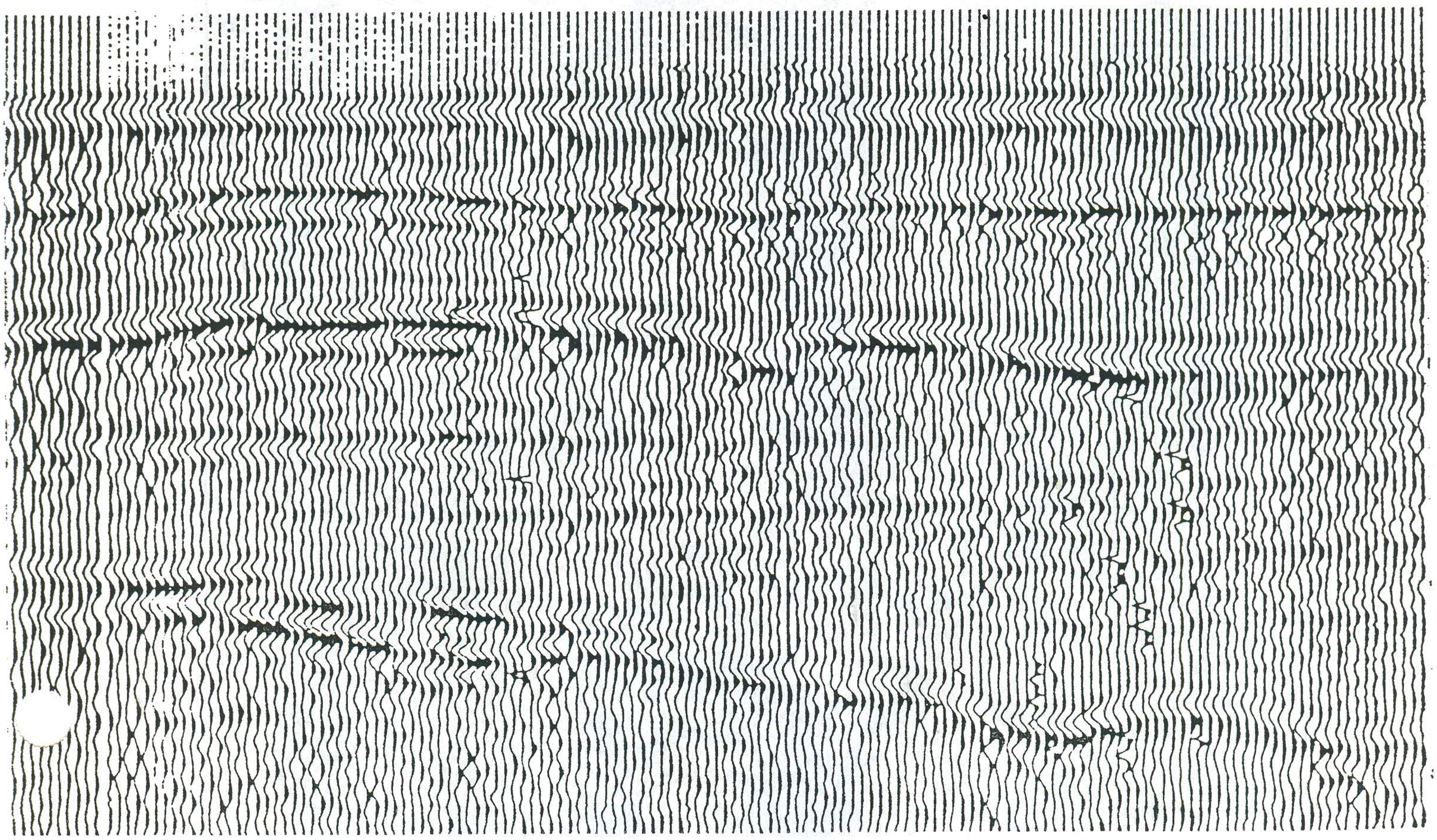
**By convention, reflection traces are plotted below the surface point midway between the source and geophone. Reflections don't always come from straight down, but when they are plotted that way, you get diffractions. When you interpret reflection data, do not confuse diffractions with real structure.**





# Diffractions (continued)





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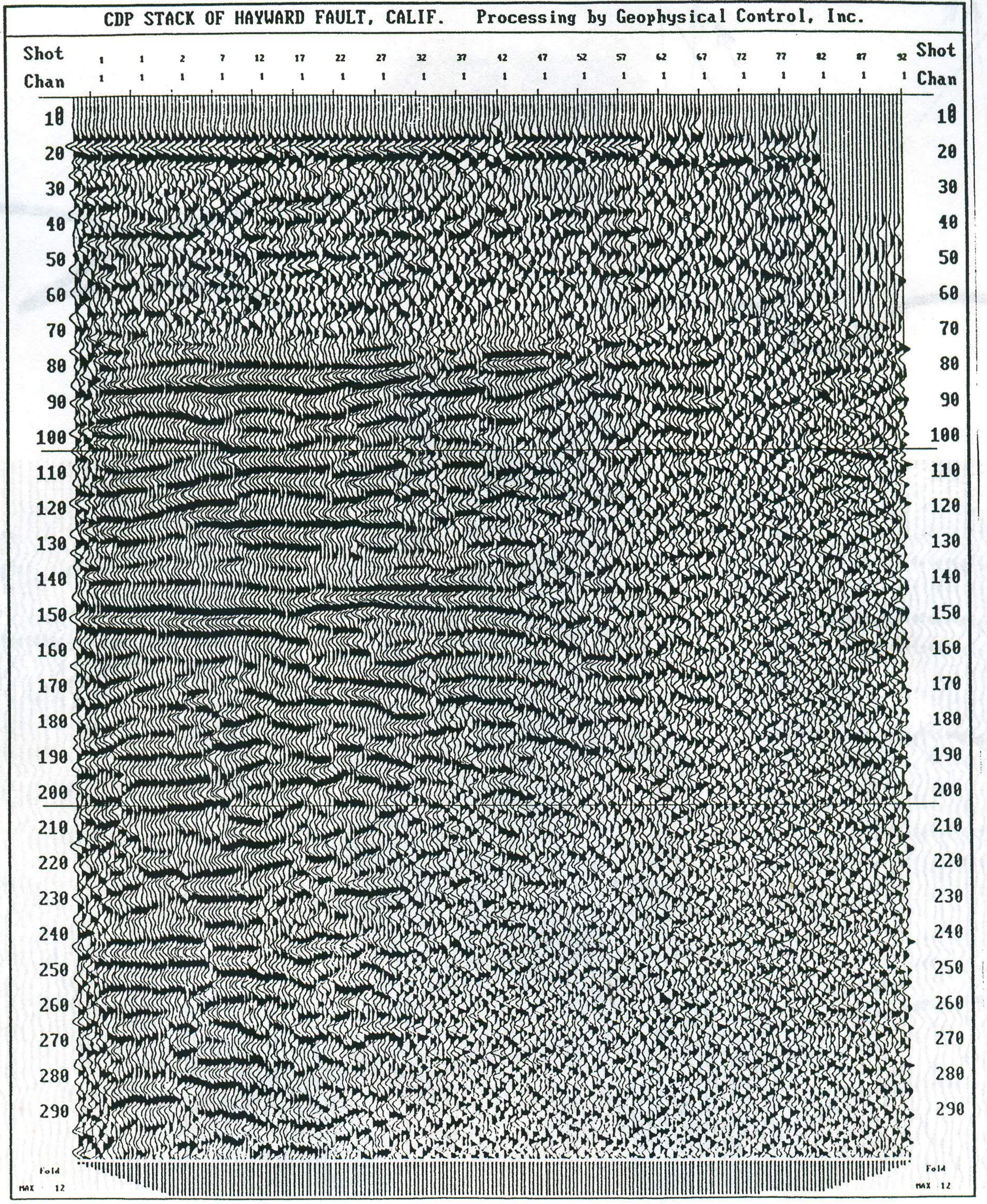
# Section across Hayward Fault

**Recorded by the Terrain Geophysics Section of the Geological Survey of Canada and processed by Geophysical Control Inc., on the Micromax™ Workstation. (energy source: in-hole shotgun, geophone intervals: 2 m. Approximate dimensions of the section are 200 m horizontal and 300 m vertical.**



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# Coyote Hills

**Recorded on East side of San Francisco Bay near the Coyote Hills by Rob Huggins from EG&G Geometrics.**

**Instrument:**
**48-channel ES-2401X**

**Energy source:**
**16 lb hammer**

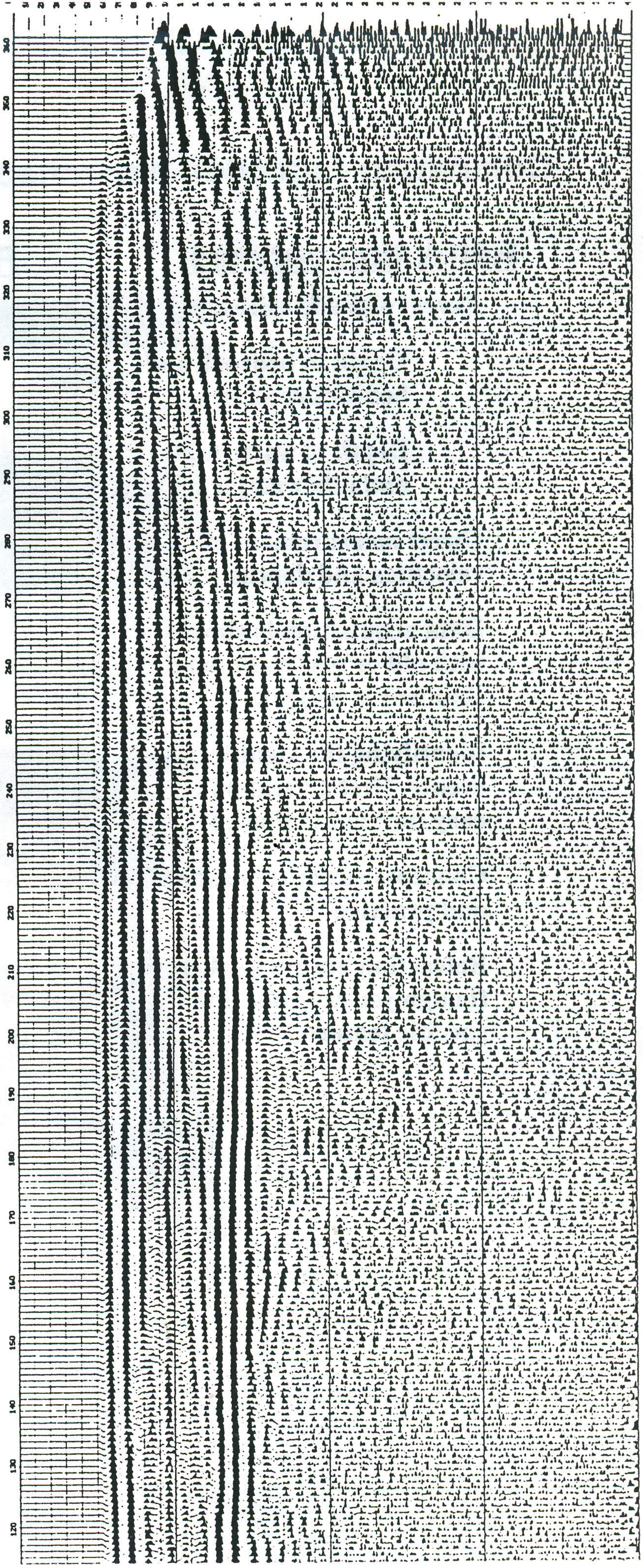
**Geophone interval:**
**10 ft**

**Shot interval: 5 ft**

**Shot offset: 50 ft**

**CMP processing by Rob Huggins on the Strataview R24 seismograph.**

UP ←



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# Comparing refraction and reflection surveys

## Refraction surveys

Reveal gross features:

Depth to bedrock and bedrock contours

Depth to water table and other major features

Direct measurement of velocities and depths

Data acquisition is simple with old or new equipment (but new is better).

Identifying the significant events (first arrivals) is easy (but not foolproof)

Concepts easier to master and practice

Refraction always works, though you may not find a specific feature

## Reflection surveys

Provide images:

Multiple layers with different velocities, including the elusive low-velocity layer.

Depth information is more general, velocities are averages

Data acquisition is simple with modern seismographs, but

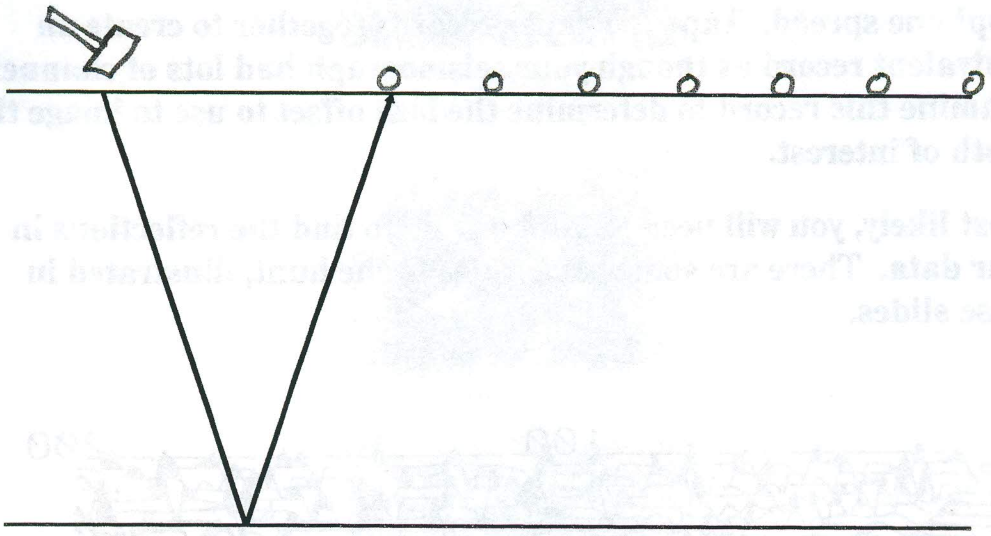
Extracting and recognizing reflections can be challenging

While the concepts are relatively easy to master, the practice (particularly processing) is difficult

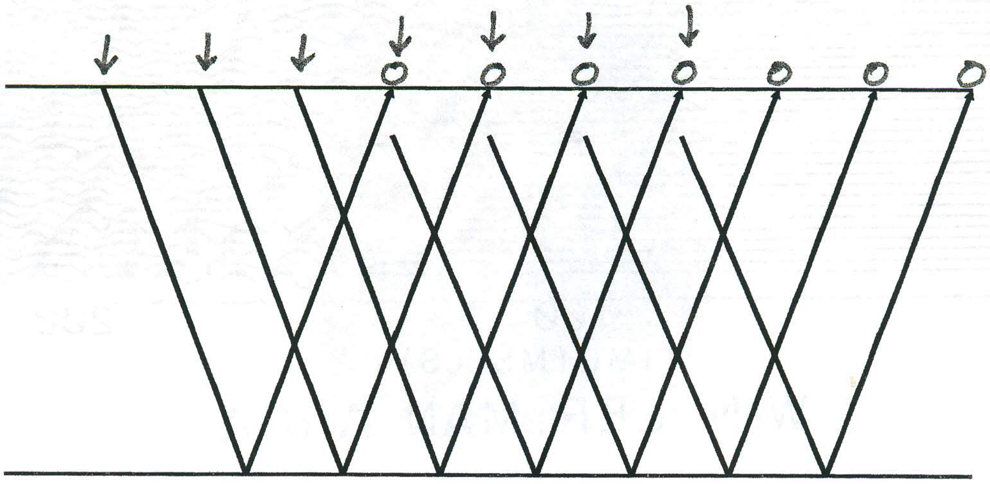
Reflection works really well on some sites and not at all on others

# Reflection survey Methods, Optimum Window

**Turn off every channel on the seismograph except 1, put the hammer at the optimum distance, and record data on that one channel.**



**Then, "freeze" that channel, turn on the second, move the hammer, record another trace, then repeat and continue the process until you acquire data on all 12 traces.**



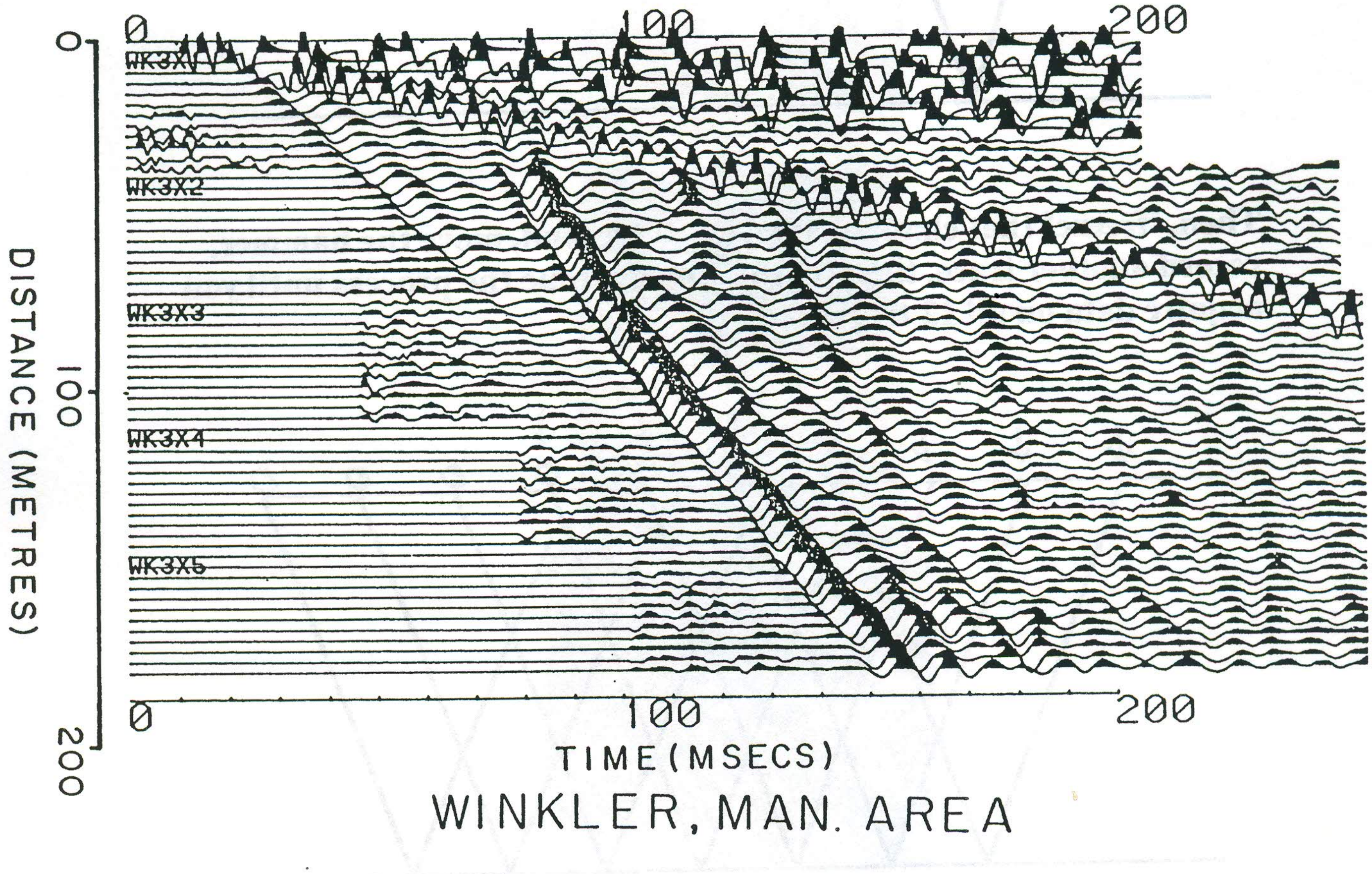
**Then, move the geophones and start all over. Continue until you acquire the whole line.**

## Field Procedures

## Do a noise test

**Gather records with increasing offsets between the source and geophone spread. Tape the paper records together to create an equivalent record as though your seismograph had lots of channels. Examine this record to determine the best offset to use to image the depth of interest.**

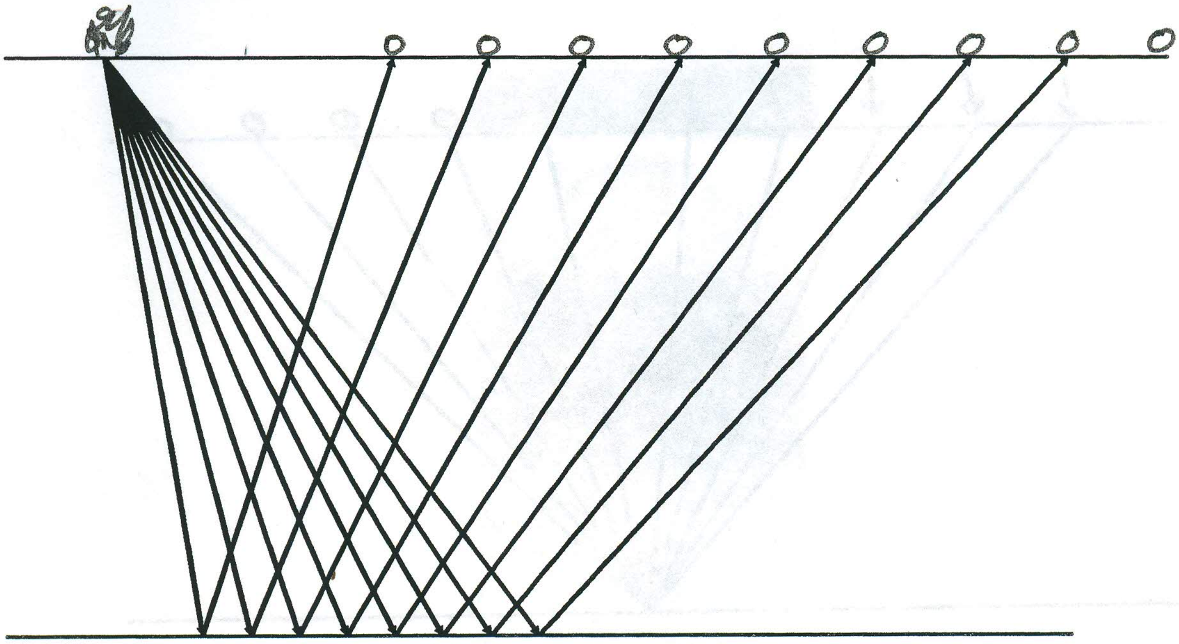
**Most likely, you will need to hunt a little to find the reflections in your data. There are some basic rules to the hunt, illustrated in these slides.**



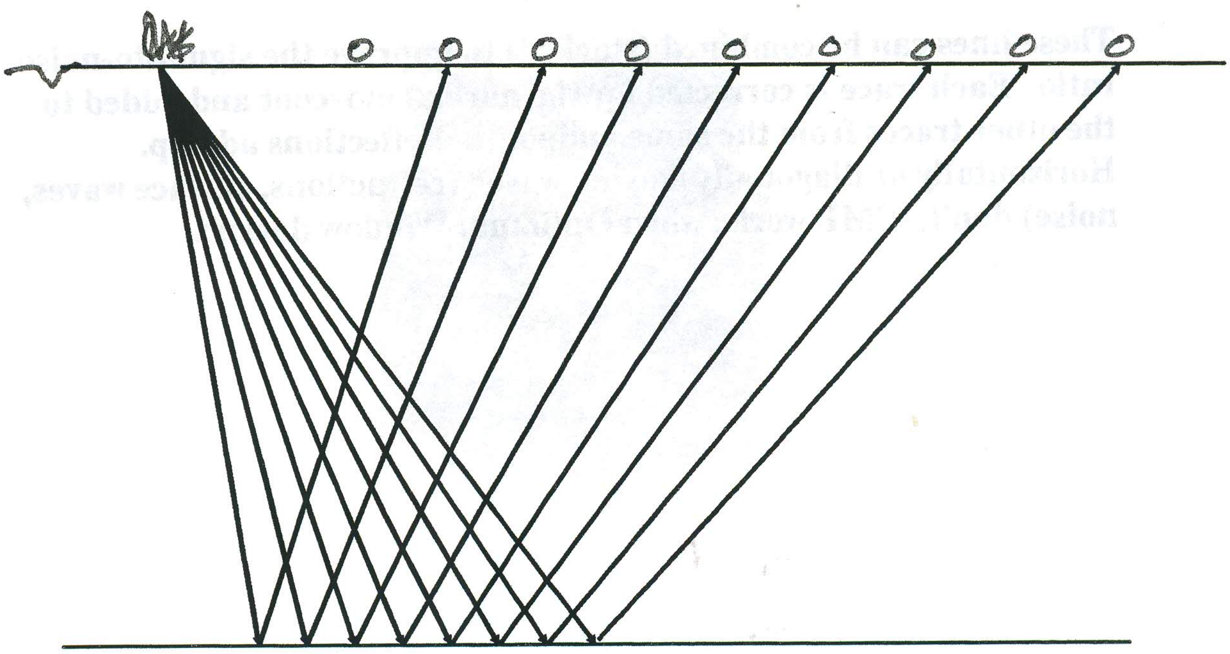

**Data from: <u>Field Experience with the Optimum Window Hammer Seismic Reflection Technique</u>, by Hunter, Burns, Gagne, Good, MacAulay and Pullan, Terrain Geophysics Section, Geological Survey of Canada**

# Reflection Methods, Common Midpoint Surveys

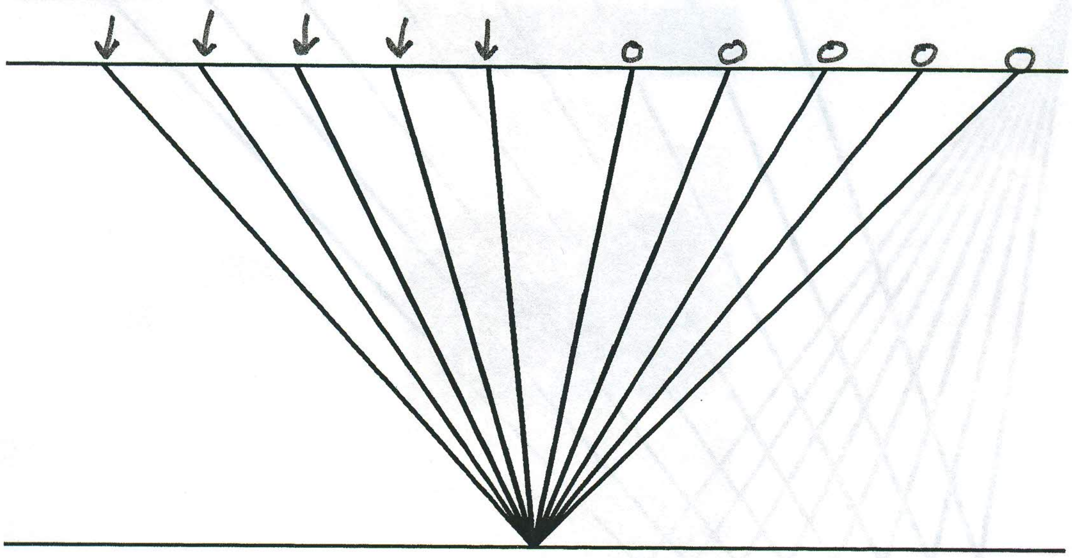
**Use all the geophones every shot.**



**Then move the whole spread a short distance (typically one geophone interval in shallow reflection surveys). Take another shot. Repeat and continue.**



# Reflection Methods, Common Midpoint Surveys continued



**After completing the line, you have a multiplicity of data from each reflection point. If you extract a trace from each shot, there are several redundant reflection lines.**

**These lines can be combined (stacked) to improve the signal-to-noise ratio. Each trace is corrected for the normal moveout and added to the other traces from the same midpoint. Reflections add up. Horizontally or diagonally moving waves (refractions, surface waves, noise) don't. CMP works when Optimum Window doesn't.**

# Comparing methods:

## Optimum Window Surveys

### Simple field procedure

### Short equipment list:

12-channel seismograph, one cable, 12 geophones, energy source

### High productivity

(say 1 mile/day in very round numbers)

### Relatively simple processing

(perhaps right on the seismograph)

### Works well in ideal or good conditions:

saturated, fine-grain materials

consolidated sediments

### Higher frequency data

CMP processing smears the events

## Common Midpoint Surveys

### More complex field procedure, more data

### More equipment:

12 or 24-channel seismograph, more cables (or CDP cables), more geophones, rollalong switch, energy source

### High productivity

(about the same) but more people to hustle equipment

### Pretty complex processing:

more options, more permutations, more iterations. Takes more time, usually more than doing the survey.

### Works in difficult (but not all) conditions

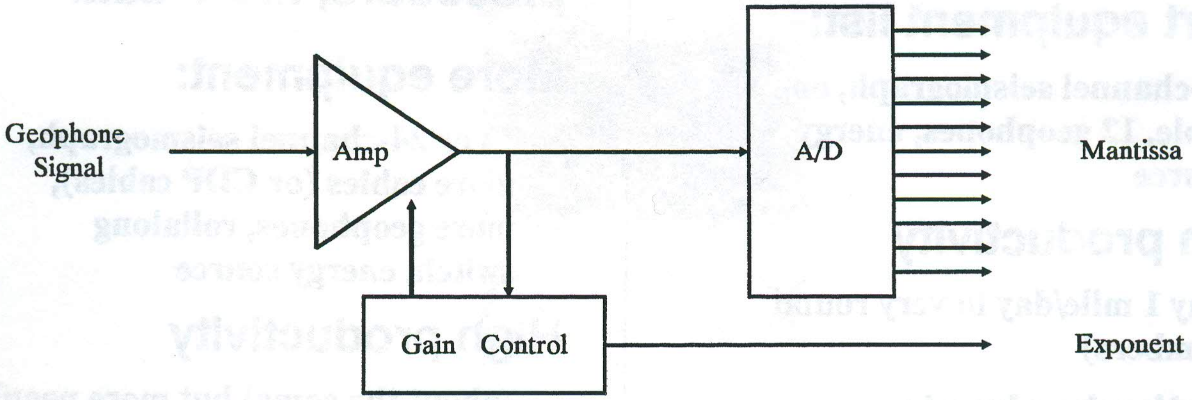
### Less likely to make non-reflectors into lines on the section

# Equipment Notes (Seismograph):

**Use a modern seismograph, even if you have to rent one. They are much better:**

## Instantaneous floating point amplifiers

**for dynamic range and easy operation**




## An A/D converter with at least 15-bits

**A high-resolution, analog-to-digital converter provides signal resolution to allow powerful digital filtering**

**8-bits = $2^8$ = one part in 256**

**16-bits = $2^{16}$ = one part in 65,536**

## Digital storage

**(floppy disk, hard disk, tape) – Virtually all reflection records are processed**

## Built-in QC processing

**Automatic gain control**

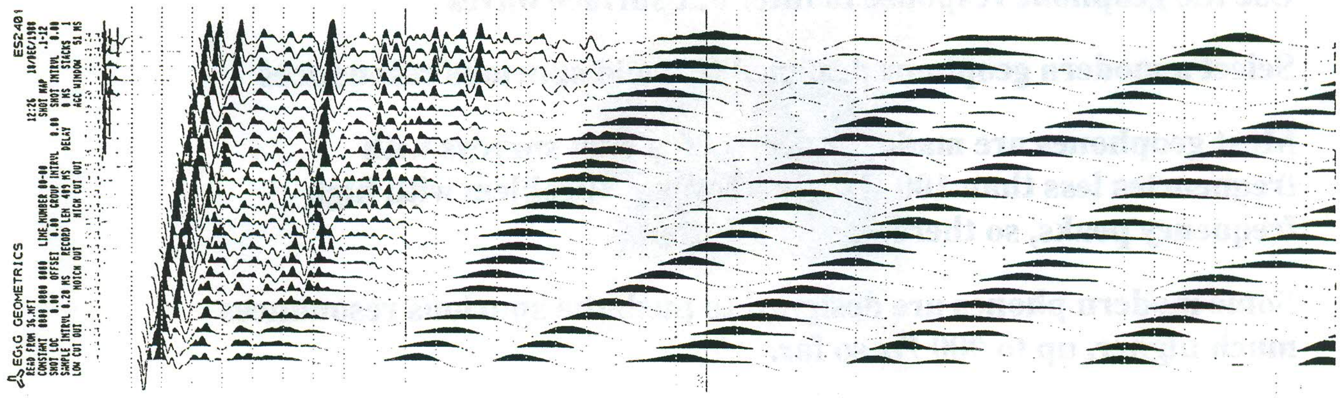
**Reflection QC**
- **Normal moveout**
- **Hyperbolic curve fitting**

**Digital filters (essential)**

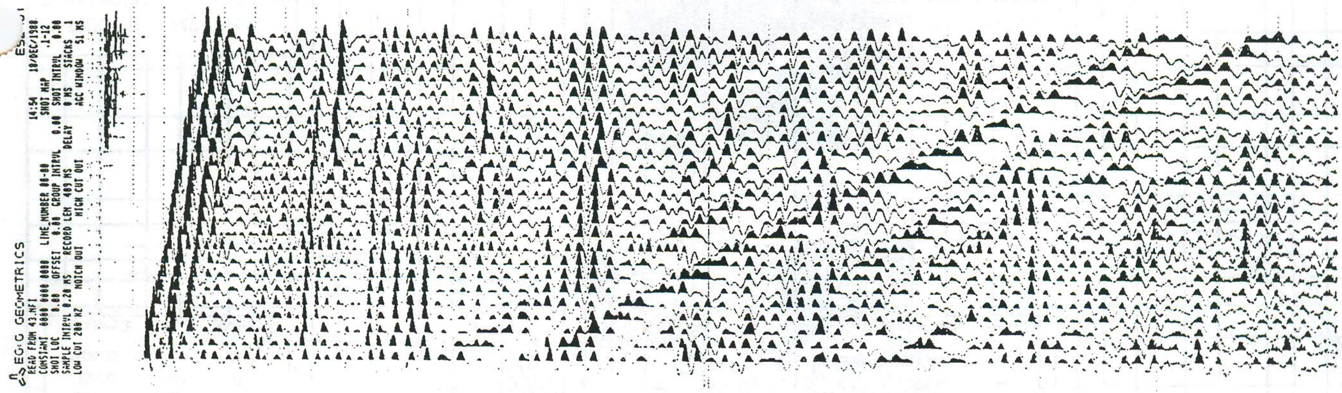
slide

# Comparing Analog & Digital Filters

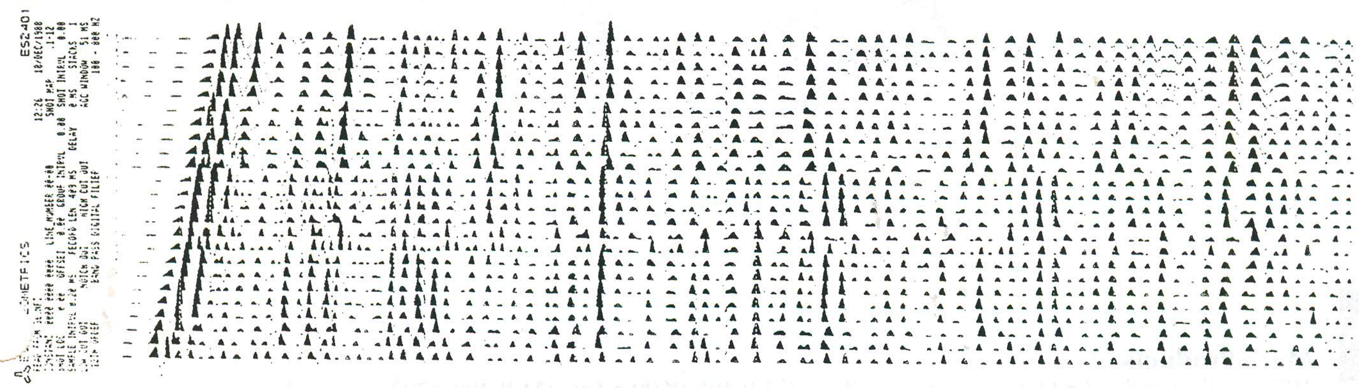
Filters are used to eliminate noise signals with frequencies different than the seismic data. They allow surveys with smaller energy sources and in the presence of interference from vehicles, power lines, or other noise source. Lowcut filters are used to eliminate surface waves in reflection surveys. Notch filters eliminate power line noise. Highcut filters eliminate wind noise and alias frequencies. The ES-2401 has a complete set of analog and digital filters. The digital filters are used after the data is recorded. They are much more selective and do not introduce time shifts in the arrivals. With digital filters, you can determine if your field methods are producing results that are adequate for later data processing. The complex filter calculations are performed by a 32-bit microprocessor, providing results in seconds.



Seismic record taken with no filtering. Notice arrivals of first breaks, some shallow reflections, and shear and Rayliegh surface waves. Record is plotted with digital AGC, adjusting amplitudes to keep traces visible throughout the record.



Same shotpoint, repeated with 200 Hz, analog, lowcut filter applied. Most of the surface waves are removed by filtering, bringing several more reflectors into view.



The original wideband record, processed with a 100-800 Hz bandpass digital filter. Note that the reflectors are much clearer throughout the record, and that the shallow reflections at 75 ms are no longer shifted in time. The ability to record with a wider bandwidth in the field simplifies field operations and provides flexibility in processing.

Slide

# Equipment, continued:

## Geophones

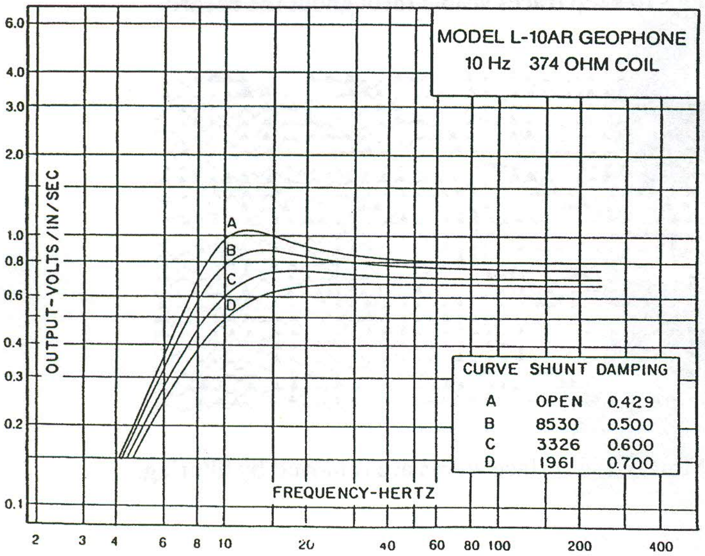
**14 to 40 Hz natural frequency is best if you have a modern seismograph**

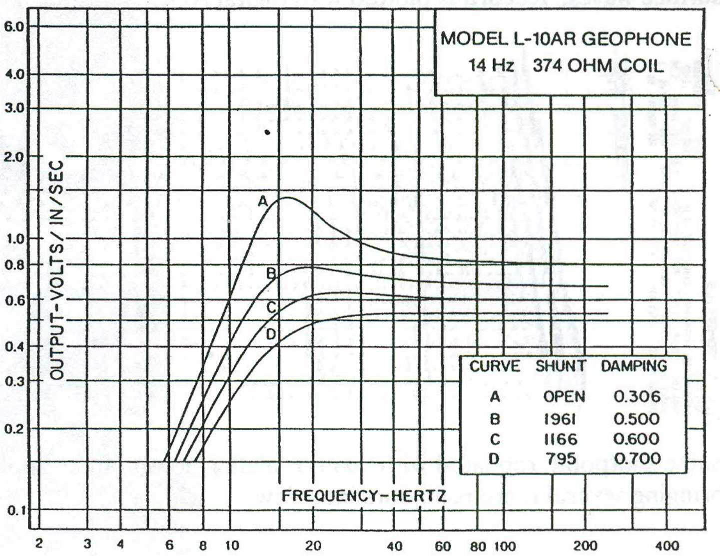
**100 Hz natural frequency if you have a 8 or 10-bit fixed gain system. Use the geophone response to filter out surface waves**

**Select a modern geophone designed to avoid spurious resonances**

**Most geophones are made for deep petroleum surveys with frequencies less than 100 Hz. There was no problem with high frequency peaks, so there was no solution.**

**Some modern phones are designed to push the spurious resonances much higher, up to 900 Hz so far.**



# Energy Sources:

**Sledgehammer – excellent source for reflection surveys**

- Portable
- Lightweight
- Safe
- Inexpensive
- Good high-frequency content

- May not have enough energy
- Generates strong surface waves

**Sledgehammer is used with a metal "striker plate" which should be about the same weight as the hammer.**

slide

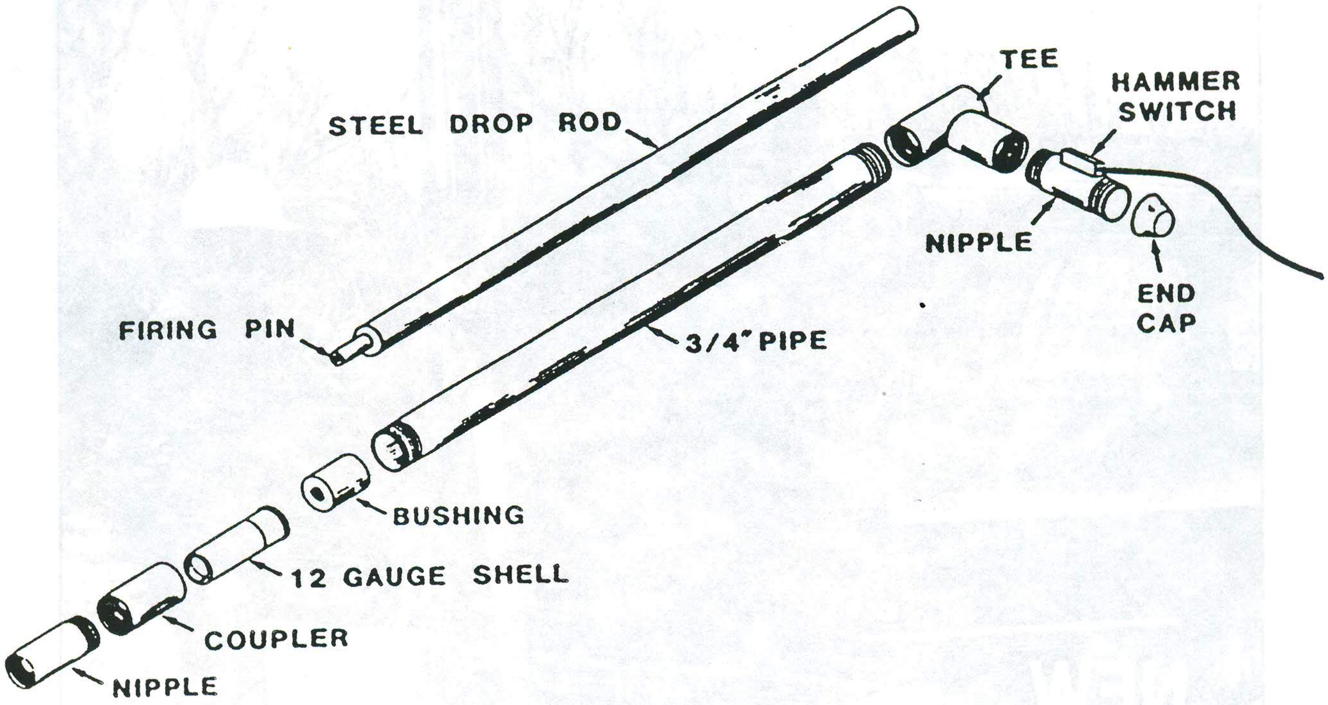
**Explosives** – absolutely the best source

- Plenty of energy
- Highest frequency content
- Bury when necessary to escape low-velocity surface materials
- Safe when used properly
- Cost effective
- Least surface waves

Severe regulatory problems which will either add cost or prohibit use in many areas

## <u>In-hole Shotgun</u> (Buffalo Gun)

- **Good compromise between explosives and sledgehammer**
- **Moderate energy**
- **Good frequency content**
- **Inexpensive, portable, lightweight**
- **Less safe than dynamite, must be used carefully, like a gun, but more so.**




**See Pullan & MacAulay, <u>An in-hole shotgun source for engineering seismic surveys</u>, Geophysics, Vol 52, No. 7 (July 1987) P. 985-996.**

**Note: Do not confuse the in-hole shotgun, which detonates the shell underground, with the Betsy Seisgun, which fires a slug into the ground. The Betsy Seisgun imparts much less energy into seismic waves, sacrifices portability, and is expensive.**

slide

## Weight Drop (and Accelerated Weight Drop)

**Favored choice when the sledgehammer is too weak and the Buffalo Gun is not usable**

- Safe
- Inexpensive to use (but not buy)
- Energy can be increased with bigger weights
- Frequency content varies with surface conditions
- Vehicle transport


BISON ELASTIC WAVE GENERATOR I
MODEL 1417-I
PORTABLE SEISMIC SOURCE

notes

## Vibrator

Potentially excellent source but still experimental. Requires substantial power (hydraulic or electrical), vehicle transport, expensive, and only a few shallow seismic instruments are available which can handle a swept source (you need very long record lengths and correlation in the instrument, or the data is unrecognizable)

## Sparker

Uses rapid discharge of electricity in conductive salt water. Common in ocean surveys, occasionally used in boreholes (gun modified to have its own container of salt water). Requires a high-voltage power supply.

## Air Gun

Uses rapid release of compressed air. Commonly used in marine surveys, occasionally in boreholes, rarely on land. Requires a compressor or scuba tank.

## Rifle

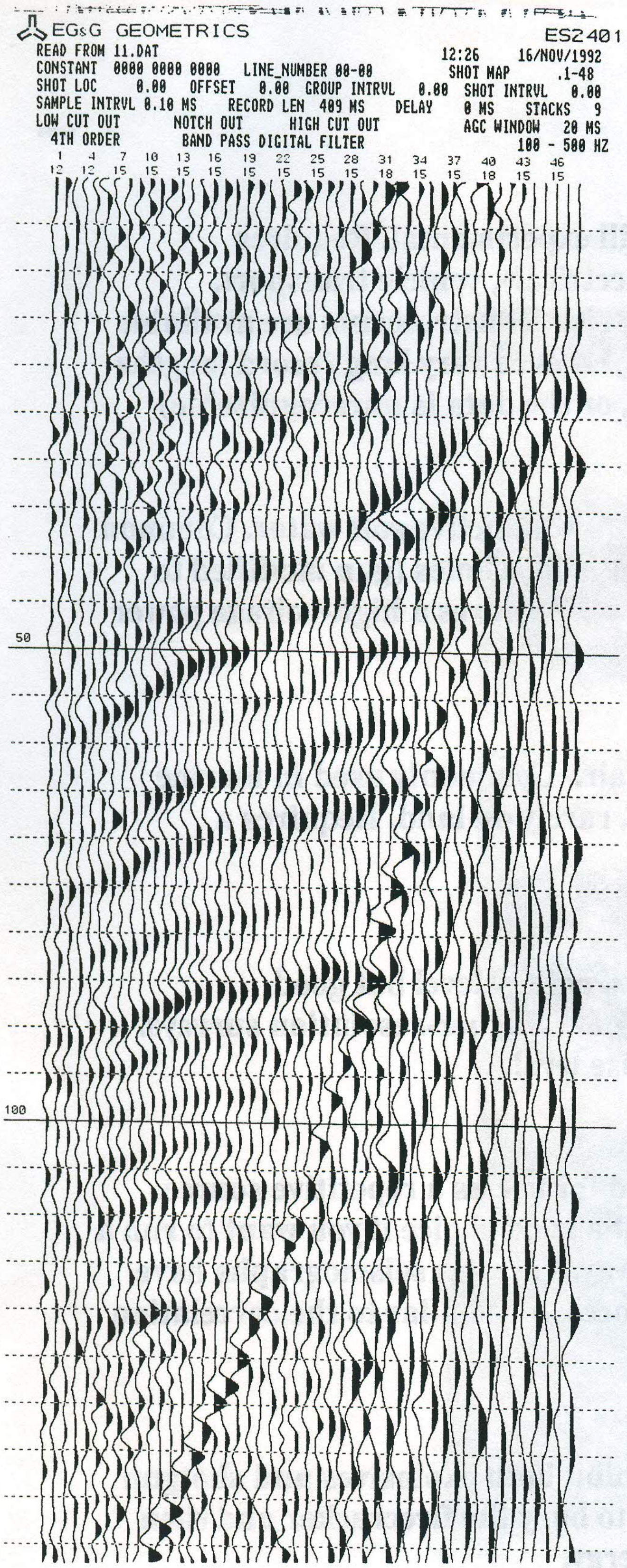
Fire bullet into the ground. Limited energy level but good high-frequency source for very-shallow, higher-resolution surveys. Strong surface waves and high noise level.

## Mini-Sosie

Earth compaction tamper modified for use as a repetitive source. Hype greatly exceeds its utility, but a good choice if you want to run a survey line in the middle of a freeway. Very few seismographs have capability to process this data (processing similar to the correlation required of vibratory sources).

## Firecrackers

Good choice in countries that prohibit both explosives and shotgun shells. Requires creative methods to bury the firecracker and then light the fuse. Limited seismic energy.


EG&G GEOMETRICS
ES2401
READ FROM 11.DAT
12:26 16/NOV/1992
CONSTANT 0000 0000 0000 LINE_NUMBER 00-00
SHOT MAP .1-48
SHOT LOC 0.00 OFFSET 0.00 GROUP INTRVL 0.00 SHOT INTRVL 0.00
SAMPLE INTRVL 0.10 MS RECORD LEN 409 MS DELAY 0 MS STACKS 9
LOW CUT OUT NOTCH OUT HIGH CUT OUT
AGC WINDOW 20 MS
4TH ORDER BAND PASS DIGITAL FILTER
100 - 500 HZ
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46
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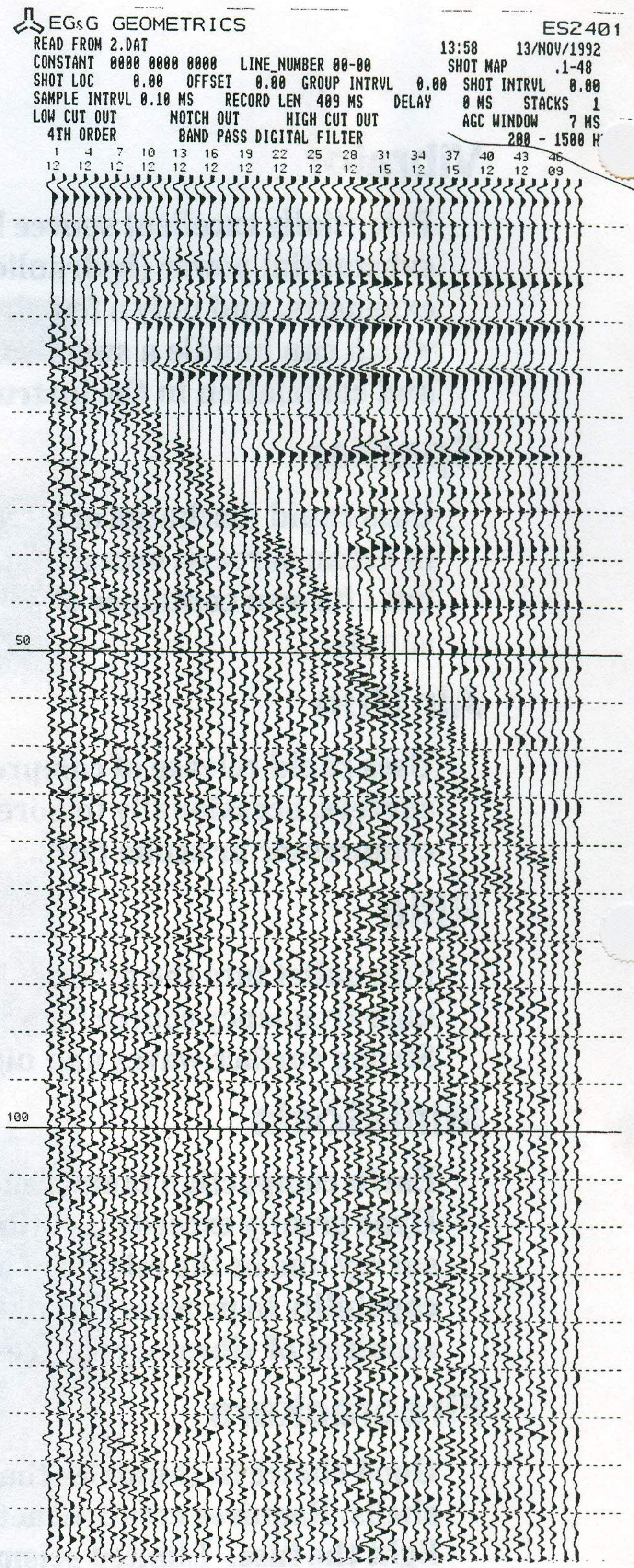
EG&G GEOMETRICS
ES2401
READ FROM 2.DAT
13:58 13/NOV/1992
CONSTANT 0000 0000 0000 LINE_NUMBER 00-00
SHOT MAP .1-48
SHOT LOC 0.00 OFFSET 0.00 GROUP INTRVL 0.00 SHOT INTRVL 0.00
SAMPLE INTRVL 0.10 MS RECORD LEN 409 MS DELAY 0 MS STACKS 1
LOW CUT OUT NOTCH OUT HIGH CUT OUT
AGC WINDOW 7 MS
4TH ORDER BAND PASS DIGITAL FILTER
200 - 1500 H
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46
12 12 12 12 12 12 12 12 12 12 15 12 15 12 12 09
50
100

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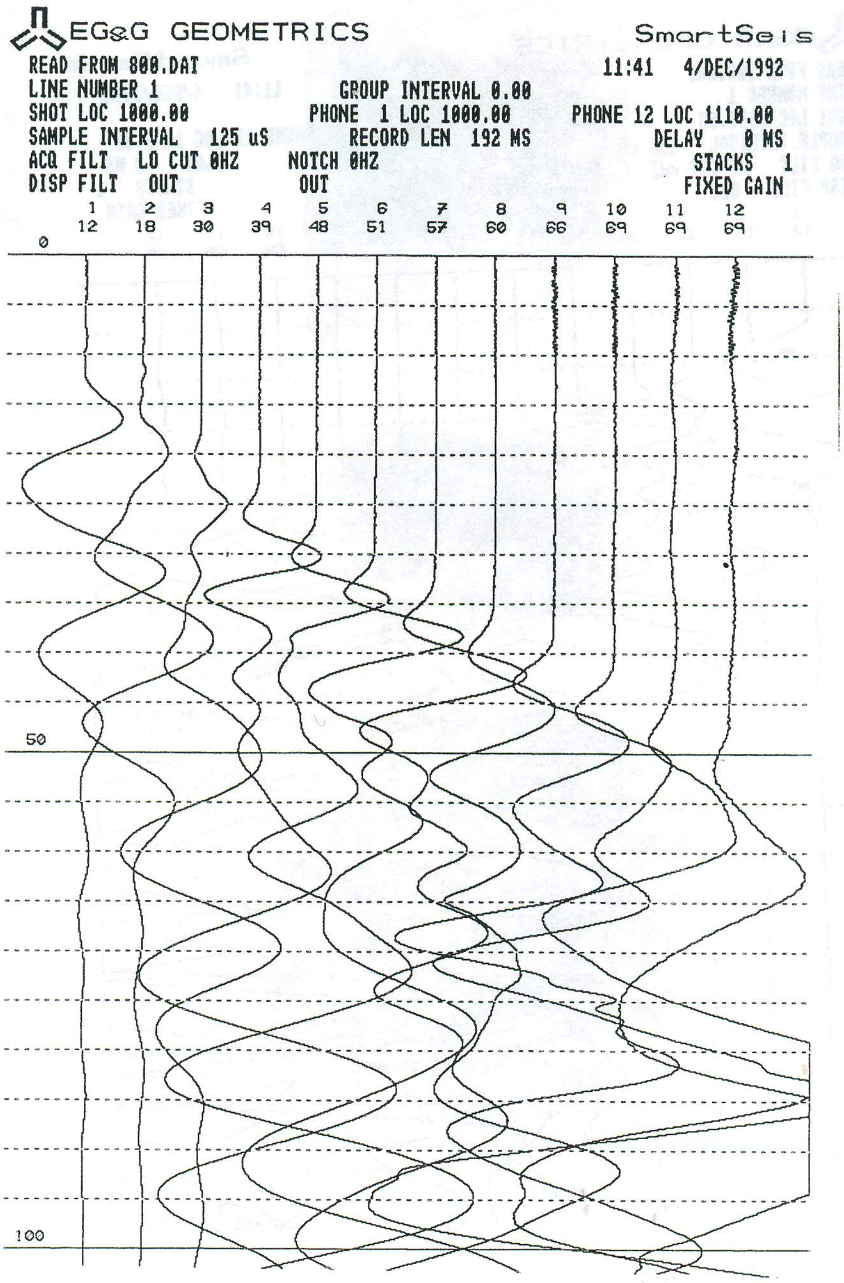
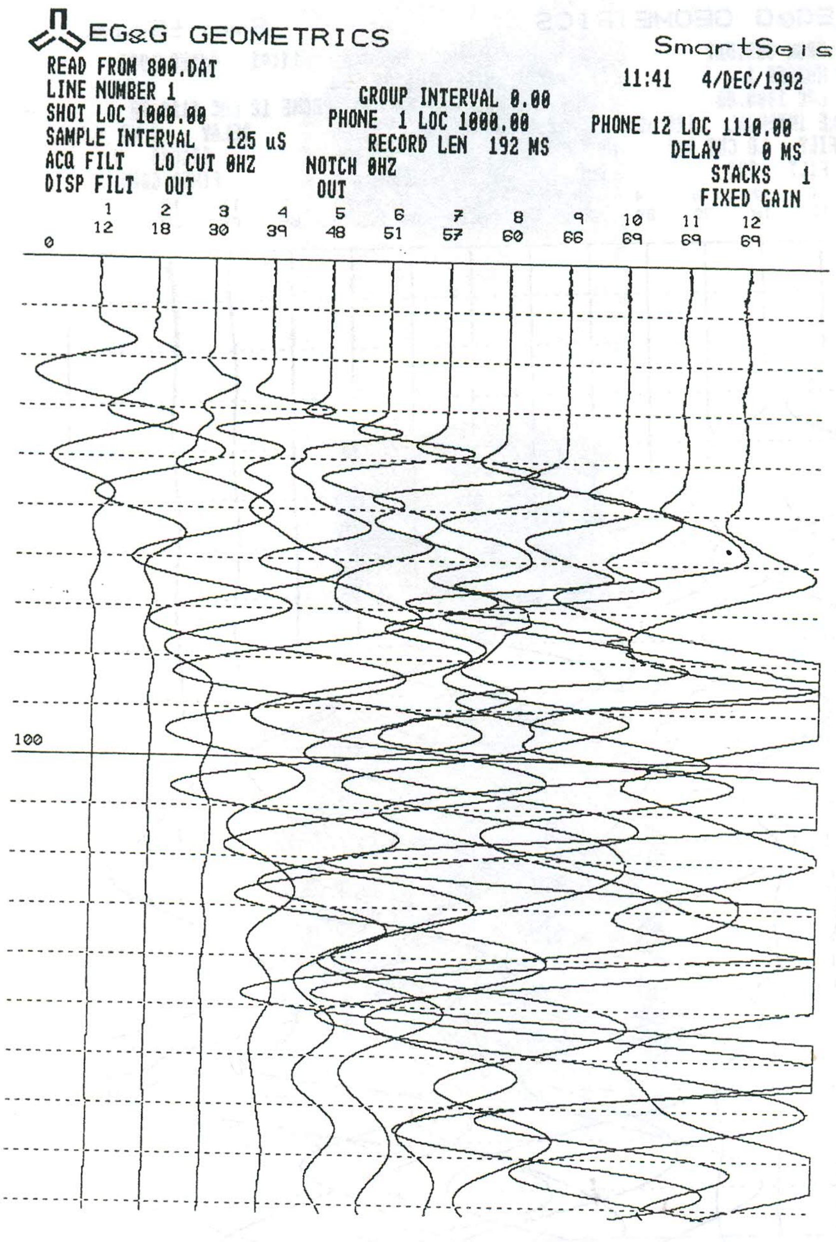
# Optimizing Records

## 1. A good refraction record is not a good reflection record..



# 2. Start by expanding your time scale so that more time and later arrivals are displayed on the record.

**That's where the reflections are. The time scale is expanded by using a slower sample interval or a longer data memory.**

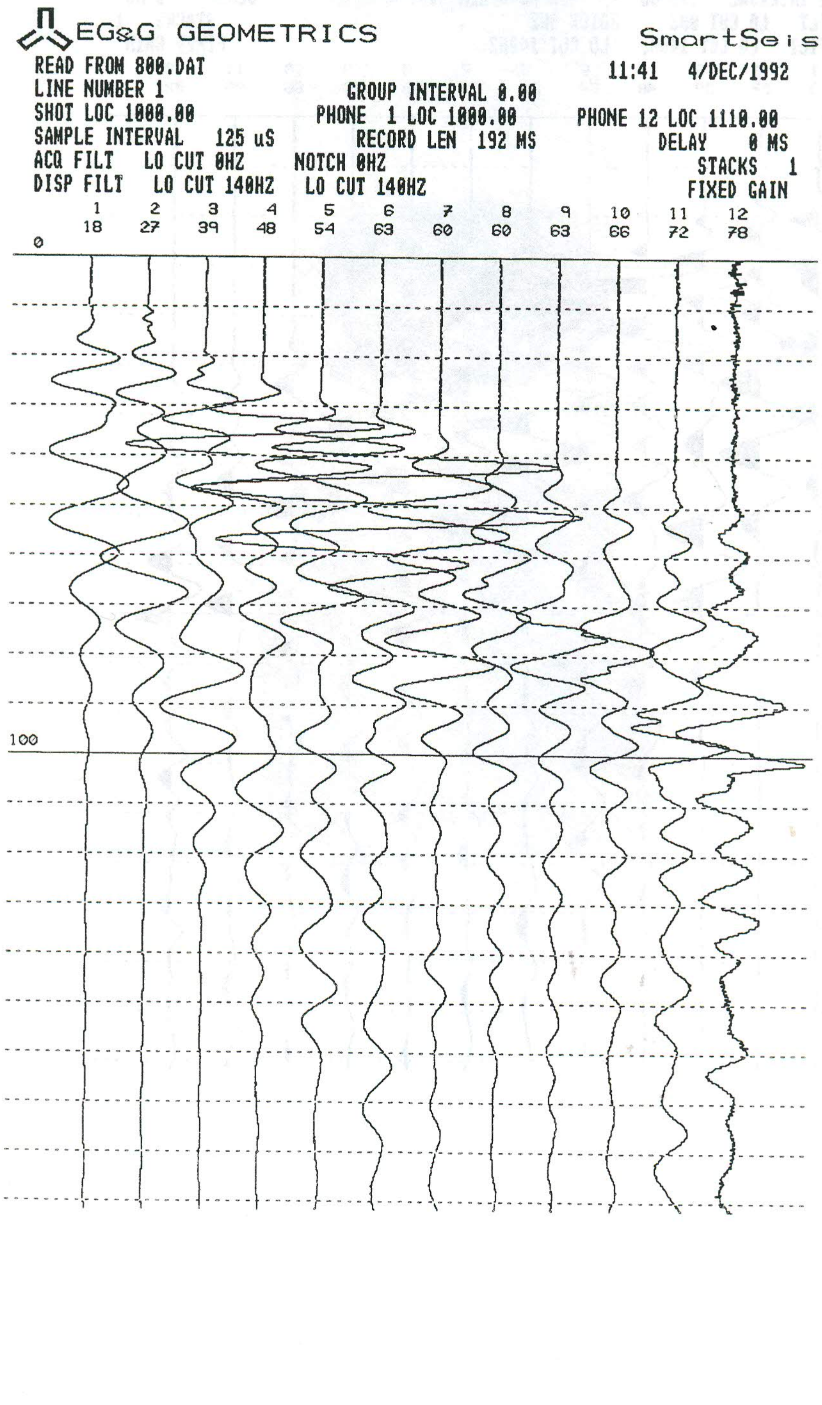


# 3. Adjust your trace sizes so that the excursions are on scale

(do this repeatedly as needed in the following steps). You have to see the wiggles to see the reflections.

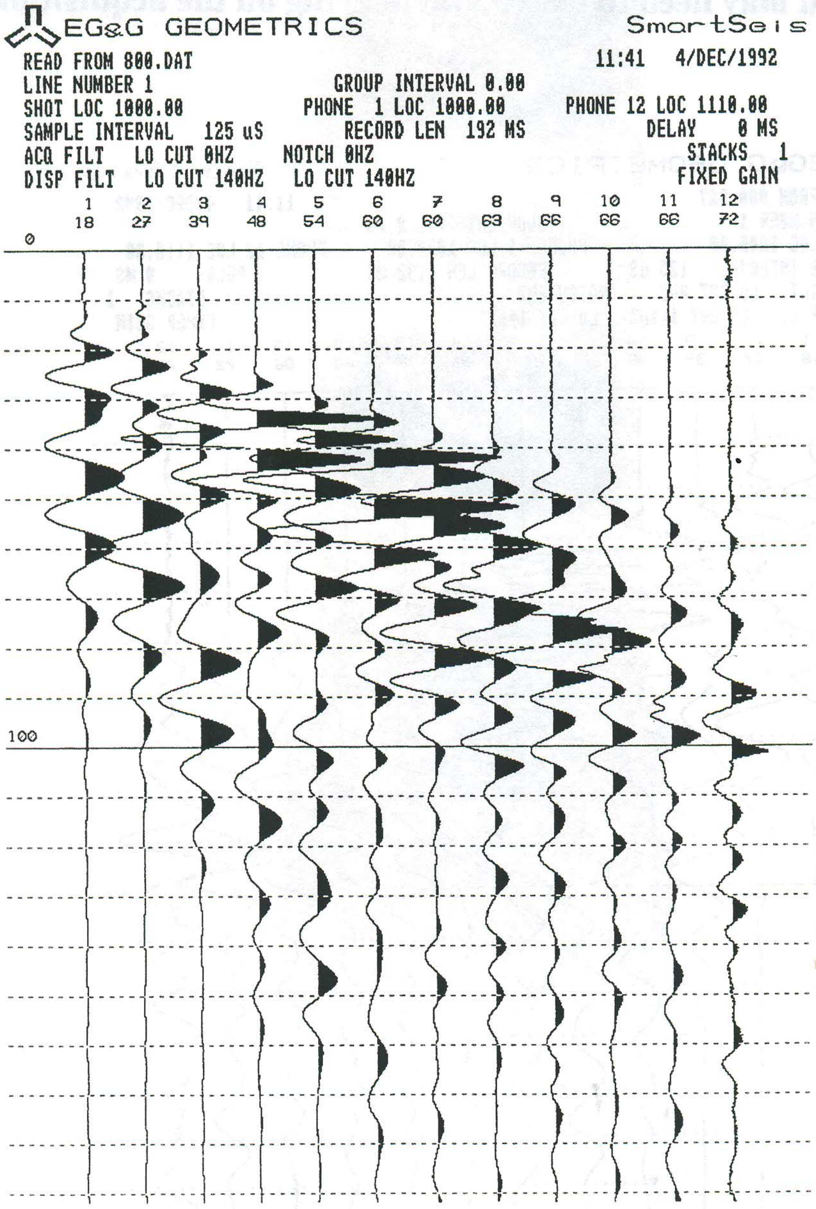
# 4. Use some filters to reject the low frequencies (lowcut or highpass filters).

Shallow reflections are virtually always higher-frequency signals than the surface waves. It's better to use the digital post-acquisition filters, but you may need to use a little filtering on the acquisition as well.



# 5. Turn on variable area to shade in the excursions so that your eye can see time-coherent events in the record.

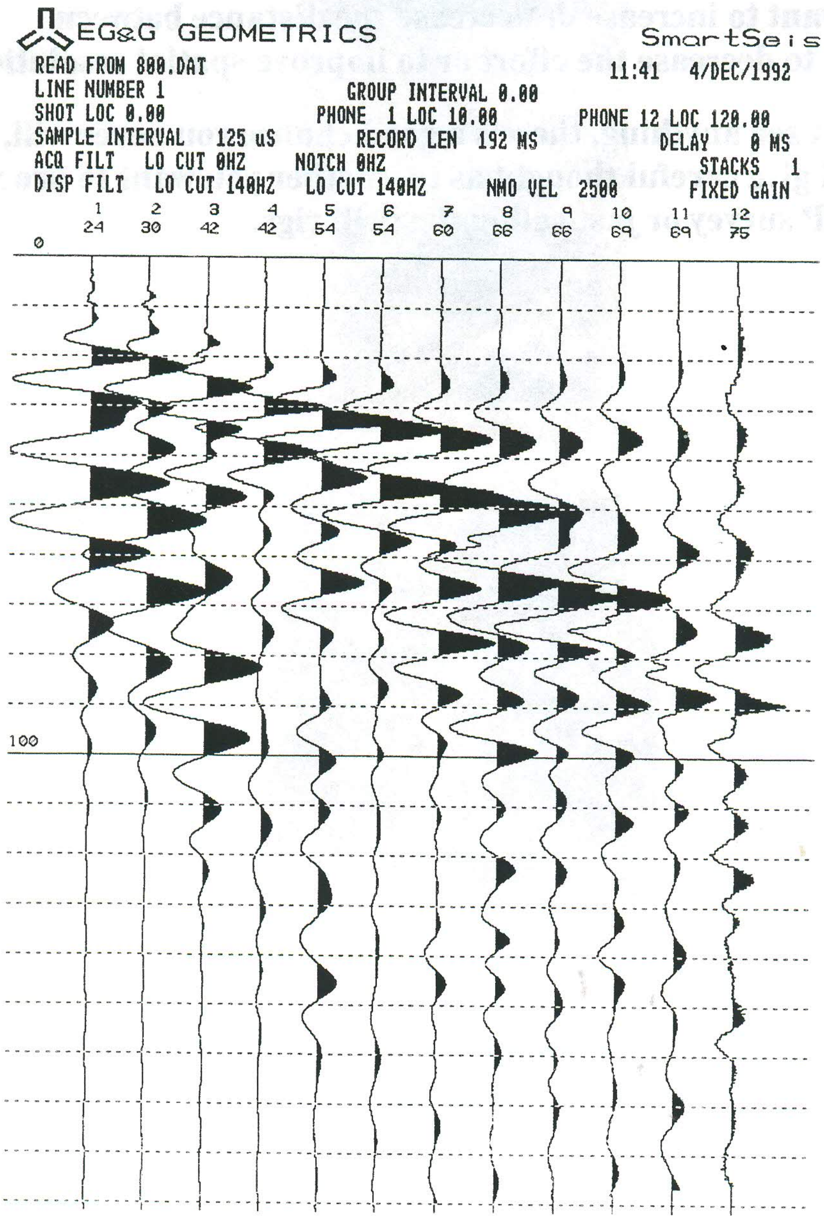
**Look for the events. Do events occur on multiple channels at about the same time? Is there a curve downward on the farther channels? Maybe that's a reflection.**



# 6. If your seismograph has AGC (automatic gain control) on the display, use it. If your instrument will do NMO (normal moveout corrections) on the screen, try flattening the traces.

**Use the NMO velocity and time to estimate depth. Use any other QC processing as appropriate.**

**Once you have established the best combination of filtering, trace size, and AGC. Play back all the records from your noise test, tape them together, and take another look at the data.**



Notes

## Go into "Production Mode"

Decide if you are going to use "Optimum Window" or Common Midpoint Surveys (assuming you have the equipment).

If you see several reflectors, and feel reasonably confident that your target is one of them, "optimum window" will do the job easier with less processing. In fact, if you don't have much of a statics problem, you can do the processing on most seismographs.

If you see one or just a few weak reflections, use CMP methods. CMP data, properly processed, will improve greatly over the raw field records.

You may want to increase or decrease the distance between geophones to decrease the effort or to improve spatial resolution.

If you don't see anything, there's a good chance you never will, and you should give careful thought as to whether you want to proceed with a CMP survey or just call in the drill rigs.

# Actually acquiring the data is pretty routine.

Modern seismographs are pretty good at making sure you get quality data. Once you pick your parameters, things get automatic.

You will need elevations and locations for each geophone point

Locate your geophones and shotpoint, gather the data for your first file, save the data on disk. Minimize the use of input filtering if you can filter the data later.

That way you can change your mind to improve the record. No matter how good things look in the field, you can get them better in a comfortable office.

Move the geophones and shotpoint, take another shot, save the file. Continue until you cover the area.

Periodically, take a look at the emerging section to check the quality and information. If your seismograph does filtering, AGC, and NMO corrections, tape the field records together to make a 100% section. It's much cheaper to make adjustments while you are on the site.

## Process the data.

This can range from fairly simple for Optimum Window surveys in good conditions to quite difficult for CMP surveys in poor conditions. You can pay people to process your data, or to help you get started. Caution"most petroleum processing companies don't handle shallow high rez data well. Make sure your vendor has experience and references in your kind of survey.

You can process your own data on a personal computer. This is the best way to get the most out of it. There are lots of tradeoffs to emphasize certain areas that you personally know how to make. If you don't do the processing, at least talk to the guy doing it often.

If your job is longer than a day or so, it's good to process a section in the motel in the evening. This lets you see what you are getting, whether you are acomplishing the objective, before continuing with the data acquisition. Some seismographs have built-in PC's which make this convenient.

# Processing reflection data.

In the dark ages, reflection data was processed by hand, just like refraction, but harder. Now we use computers"normally PC's for shallow reflection surveys.The amount and type of processing required depends on anumber of factors:

## Method

How the data was acquired. CMP and Optimum Window methods are processed different effort.

## Quality of data

Some data jumps right out of the record. Quality often depends more on the earth more than the collector.

## Objective

Some targets are easier to see than others.

## Operator's skill and inclination

There is more skill and experience applied to processing than acquisition. You can often pull out more information with more iterations.

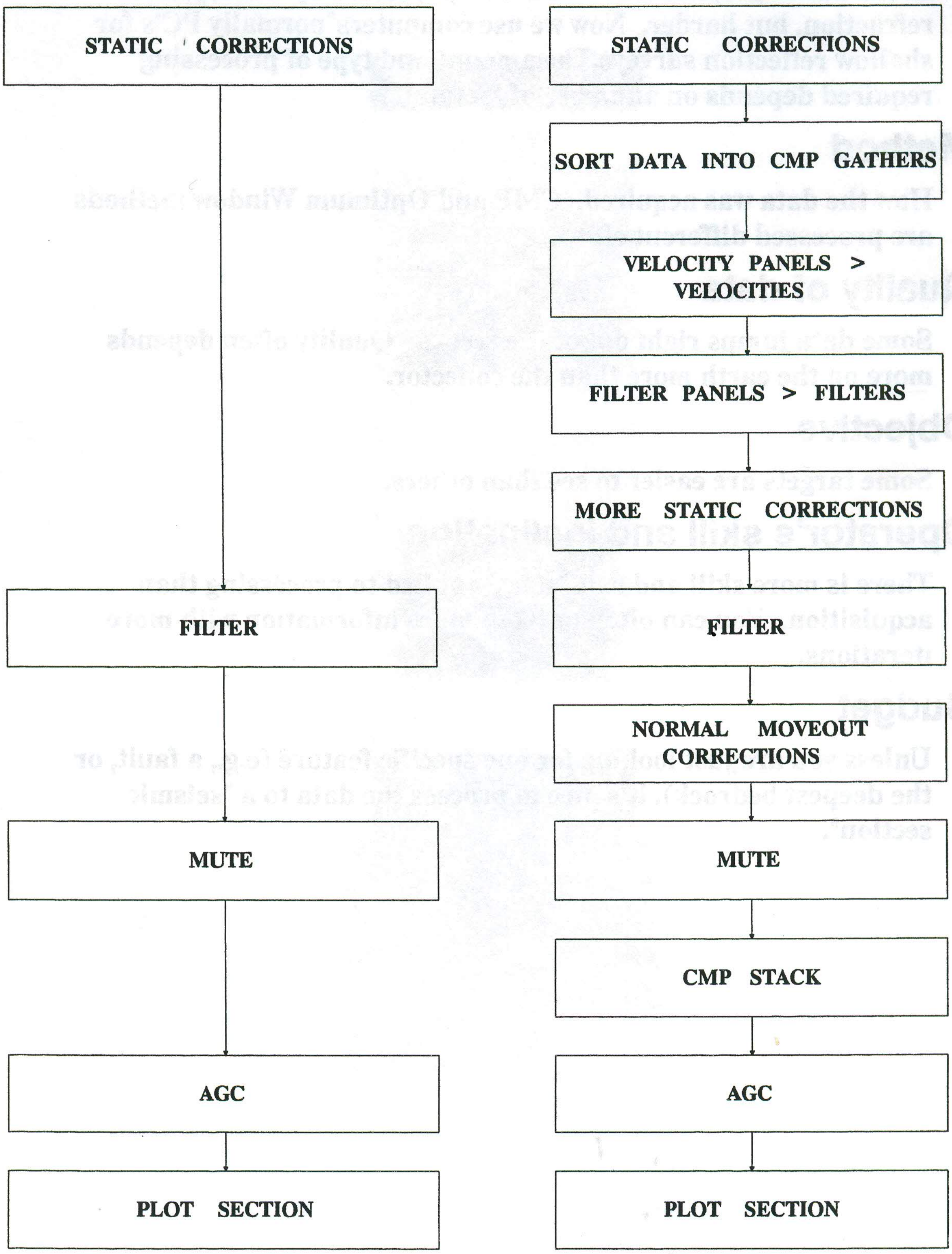
## Budget

Unless you are just looking for one specific feature (e.g., a fault, or the deepest bedrock), it's nice to process the data to a "seismic section".

Slide

## Optimum Window Processing

## Common Midpoint Processing



## Predictors of success

You need a couple of basic conditions to get good shallow reflection data:

1. The ability to transmit high frequencies: which means firmly consolidated and/or saturated materials.

2. Something to reflect the seismic waves back towards the geophones: which means layers of dissimilar materials, reasonably perpendicular to the wave propagation, and physically sized like the wavelength

## It works really well in:

Saturated, fine-grain materials (sands, gravels, clays, glacial deposits)

Sedimentary layers (unless they have complex folding), coal

## You will have problems with:

Dry fluffy material, like loose sand, dry peat. If these are on top, it's hard to see through to good conditions below.

It's difficult to image anything above the water table.

Almost never in a landfill because of the methane gas percolating through the material (although you can image sediments outside the landfill and identify the landfill by the absence of data)

Material that has been excavated and replaced doesn't image well

Very shallow reflectors (say less than a few feet) are difficult to image.

Volcanics are difficult

Coarse, rocky material

You can not image small objects (small relative to the wavelength of the seismic waves).

Notes

## Conclusions:

**For over 50 years, geoscientists performed refraction surveys and deep reflection surveys. Not until the mid 1970's did petroleum seismographs progress to the point where a few experts were able to do shallow reflection surveys.**

**In 1978, engineering seismographs advanced to where a few experts could routinely do shallow reflection surveys. By the early and mid 1980's, these special techniques had spread to early adopters in China, India, and other countries. They were still rare in the U.S.**

**In the 1980's, the power of desktop computers expanded almost as fast as prices dropped. Reflection software became commercially available for these PC's from multiple vendors. Early programs that did minimal CDP processing were replaced with more powerful packages with advanced features like migration and spatial filtering.**

**In 1988, new engineering seismographs appeared which improved the quality of the data and simplified the acquisition process. With these new instruments, a non-geophysicist could acquire decent reflection data. Evolutionary products have been introduced since then with better QC features and lower equipment costs.**

**In the space of 10 years, shallow reflection surveys have made the transition from a scientific curiosity to a usable tool. As their capability and utility becomes more widely known, they will become a routine tool in many applications.**

**For further reading:**
**<u>Exploration Geophysics of the Shallow Subsurface</u>, H. Robert Burger, published by Prentice-Hall, ISBN 0-13-296773-1**

**Papers from the Terrain Sciences Division of the Canadian Geological Survey (anything by Hunter, Pullen, etc.).**

**Papers from the Kansas Geological Survey (anything by Steeples, Miller, Birkelo, etc.)**

**<u>Seismic Data Processing</u>, Özdogan Yilmaz, published by the Society of Exploration Geophysicists, ISBN 0-931830**

# Shallow seismic reflection surveys – CDP or "optimum offset"?

S.E. Pullan[1], R.D. Miller[2], J.A. Hunter[1], and D.W. Steeples[2]

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## SUMMARY

The last decade has seen the development and general acceptance of shallow seismic reflection methods as a viable geophysical tool for groundwater, engineering, urban, environmental, and surficial geological studies. During this period there have been two approaches to collecting and processing shallow seismic reflection data; one being the modification of traditional common-depth-point (CDP) methods for shallow applications, and the other being the collection of single channel data using the "optimum" source-receiver offset. The last decade has also brought a revolution in engineering seismographs and in personal computing and data storage capabilities. This paper examines the CDP and "optimum offset" approaches to shallow seismic surveys in the light of these developments, and attempts to clarify the potential, limitations, and general usefulness of each technique.

## INTRODUCTION

Seismic reflection techniques have been in widespread use in the petroleum industry for over 60 years. Except for a few isolated attempts (e.g. Pakiser and Warrick, 1956), refraction rather than reflection techniques were routinely applied to "shallow" (engineering, urban, groundwater) problems prior to about 1980. The microelectronic revolution of the last two decades, resulting in the development of digital engineering seismographs and powerful microcomputers, has now made the collection and processing of shallow seismic reflection data a viable and cost-effective alternative.

The pioneering work in the development and testing of shallow seismic reflection methods was carried out in the early 1980's, when the first digital engineering seismographs with enhancement and filtering capabilities became available. At this time, two different approaches to the collection and processing of shallow seismic reflection data evolved. One was the adaptation of conventional common-depth-point (CDP) data acquisition and processing techniques for shallow, high-resolution applications. Two groups were notable in this development: the Kansas Geological Survey (Steeples and Knapp, 1982; Knapp and Steeples, 1986), and the University of Utrecht in the Netherlands (Doornenbal and Helbig, 1983). Meanwhile, researchers at the Geological Survey of Canada developed a second approach to shallow seismic reflection surveying. The "optimum offset" technique was designed with the aim of keeping equipment and computing requirements to a minimum, and providing a reflection technique that could be applied by small geophysical contracting companies (Hunter et al., 1984).

Over the last decade the Kansas Geological Survey and the Geological Survey of Canada have gained a great deal of experience in the application of shallow seismic techniques, as well as an appreciation for their pitfalls and limitations (Steeples and Miller, 1990; Pullan and Hunter, 1990). The purpose of this paper is to examine the CDP and optimum offset approaches to shallow seismic reflection surveying in light of this experience and of the hardware and software developments of the last decade.

## FIELD PROCEDURES

The optimum offset technique is the simplest form of shallow seismic reflection profiling possible. Each trace of the final section is obtained by recording the output of a single geophone separated from the source by a given offset. The "optimum" offset is chosen after examination of a number of multichannel records shot at test sites around the survey area. The test records are also used to identify the target reflection and other events on the seismic record (such as possible groundroll and airwave interference), and to determine recording parameters such as filter settings, amplifier gains, and record length. The optimum offset section is then produced trace-by-trace by moving the position of the source and recording geophone progressively down the line in equal increments. Multichannel records are required, at least intermittently along the line, for velocity analysis. In most cases, it is recommended that these data be recorded along with the optimum offset data.

The choice of the optimum offset is critical to the success of an optimum offset survey. The greatest resolution of the shallow subsurface is obtained by using as small an offset as possible, but the offset must be large enough that the target reflection is not lost in airwave or groundroll interference at any point along the survey line. As a rule of thumb, the source-receiver offset should not exceed the depth to the target of interest.

Once the choice of the optimum offset is made, any geophone spacing can be used depending on the desired subsurface coverage (on an optimum offset section, the spacing of subsurface data points is equal to the spacing between geophones chosen for the field survey), and on the object of the survey. Geophone spacings of 1-5 m will provide detailed subsurface information, while larger spacings may be used when the object of the survey is to obtain regional coverage with limited time and resources.

As each trace that is recorded becomes a trace on the final optimum offset section, the ground coupling at every shot point and receiver position has a direct effect on the quality of the final result. Therefore, it is important that consideration be given to each and every source position and geophone plant.

A CDP shallow seismic reflection survey also requires a number of test records (walkaway-noise tests) to be shot in the survey area in order to determine recording parameters such as filter settings, amplifier gains, record length and source and geophone spacings. Once these parameters have been set, the survey is carried out by moving the source progressively down the line and "rolling" through the series of planted geophones, so as to record a multichannel (usually 12 or 24 channel) record with the chosen offset and receiver geometry at each shot point. The "fold" of the final-section depends on the relationship between the source and receiver positions, but if a shot position corresponds to each geophone position, the fold will be half the number of channels on each record.

The criteria for choosing the source offset and geophone spacings used in a CDP survey differs from those described above for optimum offset surveys. Since accurate velocity analyses are critical to the quality of the final CDP stack, the target reflection should show significant moveout on the field records. In general, at least 4 geophones should be closer to the shotpoint than the shallowest depth of interest, while the most distant geophones should not be farther from the shotpoint than the maximum depth of interest. Geophone spacings of about 1 m have been used routinely during shallow CDP production surveys.

The stacking procedure is the essence of the CDP technique. By combining traces with the same source-receiver midpoint but different source and receiver locations, some traces with marginal data quality (resulting from anything from a bad takeout to environmental noise) can be overlooked during acquisition. As a result, data acquired using the CDP method does not require the same level of concern for the quality of individual traces as that acquired using the optimum offset method.

## DATA PROCESSING

The data processing required to produce a final optimum offset reflection section is shown in diagram form in Figure 1. The processing is largely cosmetic, and a preliminary section can easily be produced on a microcomputer in the field office within hours of collecting the data. Static corrections are usually simply a matter of aligning first arrivals, to remove the effect of variations in the low velocity layer immediately below ground surface. The depth scale is produced independently from a velocity-depth function determined from velocity analyses of the multichannel records.

The data processing required to produce a final CDP shallow reflection section is shown in diagram form in Figure 2. Before even a preliminary section can be produced the data must be sorted into CDP gathers, velocity analyses performed and normal moveout corrections made.

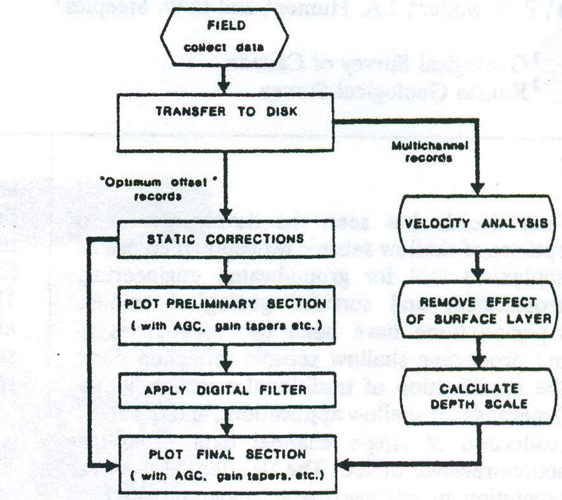


**Fig.1** Block diagram of optimum offset processing sequence.

These operations require the manipulation of large amounts of data, and in the early 1980's could only be practically carried out on a mainframe computer. The introduction of increasingly powerful personal computers, now available with large capacity, fast access hard drives, has made CDP processing on a microcomputer a viable option (Somanas et al., 1987). There are now several reasonably-priced CDP data processing software packages available for personal computers.

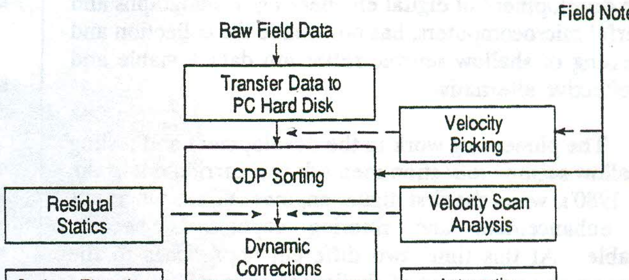


**Fig.2** Block diagram of standard CDP processing sequence.

## EXAMPLE CASE HISTORIES

### 1) Casselman, Ontario

The seismic survey at Casselman, Ontario, was conducted to map the bedrock topography and overlying stratigraphy to investigate the possible cause of large-scale slumping in the area. The surface material was fine-grained and water table was within 1 m of the ground surface. The data were collected using a 12-gauge in-hole shotgun as the seismic source, and groups of three accelerometers, closely spaced, as receivers. Six-fold CDP data were recorded, using a source-to-closest-receiver distance of 6 m, and a 1.5 m shot and group station interval.

This site proved to be an excellent one for shallow seismic reflection surveying. The dominant reflection frequency observed on the raw field files is on the order of 350 Hz. The bedrock reflection is a large-amplitude event, and several reflections from shallower horizons within the overburden are visible.

A comparison of the optimum offset and CDP processed sections from these data (Figure 3) shows that the CDP processing results in a decrease in the dominant frequency of the reflection events, even when great care was taken over the velocity analyses and static corrections. At this site, the optimum offset section provides higher resolution of the bedrock surface and the overlying stratigraphy than can be obtained from a CDP stack.

### 2) Pittman Lateral, Henderson, Nevada

The Pittman transect in Henderson, Nevada, is a site where polluted waters from an unknown source are moving laterally toward the intake facilities for the Las Vegas water supply. A 260 m long 12-fold CDP line was acquired to determine the location of topographic lows in the bedrock surface. The data were collected using a silenced .30-06 hunting rifle as the seismic source and single 100 Hz geophones as receivers. An end-on source/receiver configuration with a source-to-closest-receiver distance of 3.7 m and a 0.6 m shot and receiver station interval were used to collect the data.

Reflection events were not obvious on the raw field files, but could be identified on the filtered and scaled shot gathers. The dominant reflection frequency on these

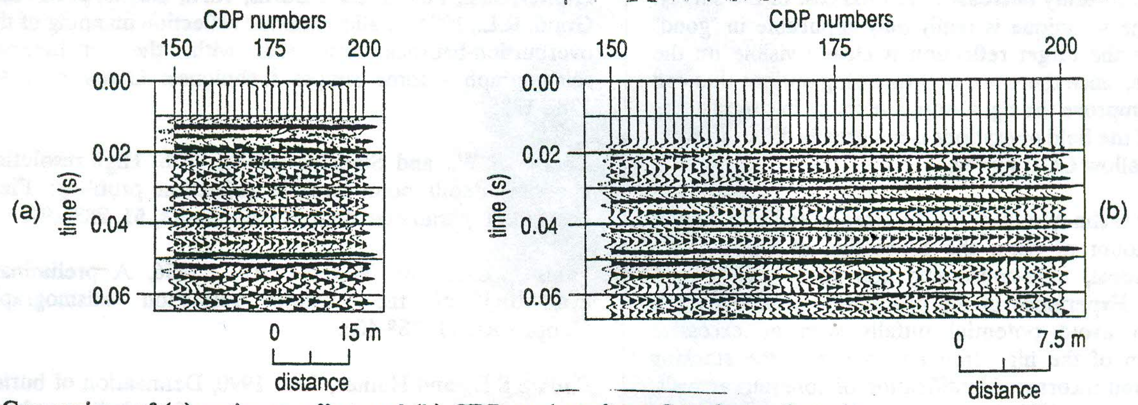


**Fig.3** Comparison of (a) optimum offset and (b) CDP sections from Casselman, Ontario.

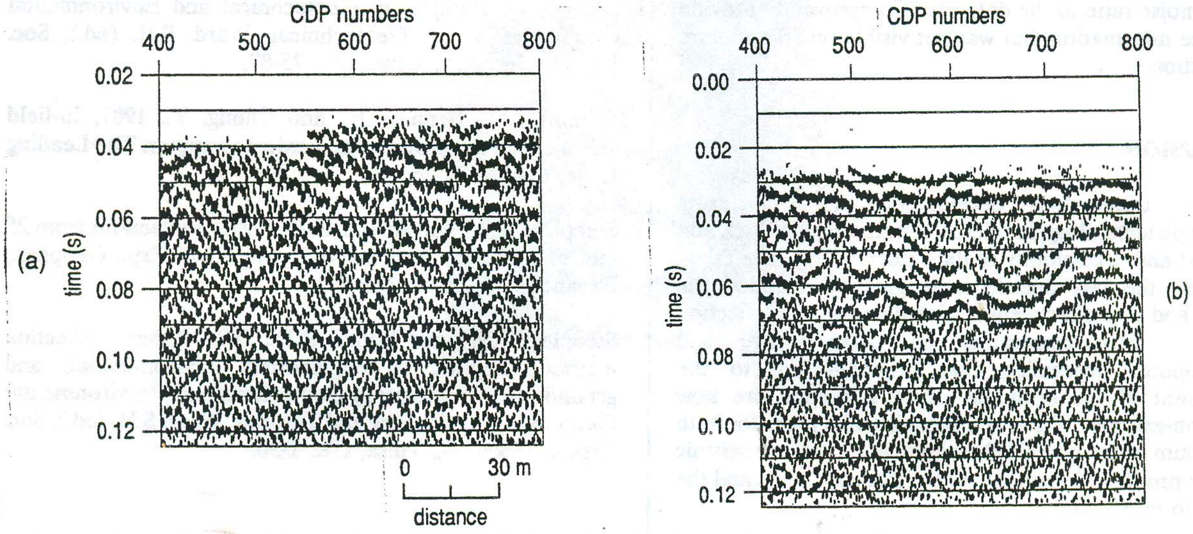


**Fig.4** Comparison of (a) optimum offset and (b) CDP sections from Henderson, Nevada.

records is in excess of 150 Hz. The stacking velocity ranges from 500 to 650 m/s for reflections identified from depths of 8 to 22 m below ground surface.

A comparison of the optimum offset and CDP sections derived from these data (Figure 4) clearly shows the necessity of CDP processing at this site. There are simply no confidently interpretable seismic reflections on the optimum offset section. Reflections interpretable on the filtered field files can be correlated to the events on the CDP stacked section. The signal enhancement capabilities of the CDP method are essential to produce a useable shallow seismic reflection profile at this site.

## DISCUSSION

The optimum offset technique is a very simple form of seismic reflection profiling that requires a minimum amount of data storage, handling and processing. It was developed at a time when the hardware costs (for the seismograph, data storage capabilities, and the computing hardware necessary for data processing) involved in these operations were substantial. The minimal data processing required significantly decreases the total cost of the survey. However, the technique is really only applicable in "good" areas where the target reflection is clearly visible on the field records, since there are no processing options that can potentially improve the signal-to-noise ratio. In contrast, the efficiency of the field operations is not greatly different from that of a shallow CDP survey.

CDP techniques require the storage and handling of a large amount of data, the processing of which is an integral, critical, time-consuming and costly part of the procedure. Experience in the processing of CDP data is essential to avoid potential pitfalls such as excessive deterioration of the high frequencies during the stacking procedure and incorrect identification of coherent arrivals. The great power of CDP techniques, however, is that the signal-to-noise ratio of the data can be improved to provide subsurface information that was not visible on an optimum offset section.

## CONCLUSION

The tremendous developments in engineering seismograph technology, in microcomputing capabilities, and in the cost and accessibility of data storage that have taken place over the last decade have greatly expanded the potential and cost-effectiveness of shallow seismic reflection methods. The constraints on data storage and microcomputer processing that originally led to the development of the optimum offset technique are now largely non-existent. However, there is still a place for both the optimum offset and CDP techniques of shallow seismic reflection profiling depending on the site conditions and the problem to be solved.

The added cost of conducting CDP surveys is primarily incurred in the processing of the data, while recording parameters (source offsets and geophone spacings) can often be chosen to be suitable for both CDP and optimum offset processing. Where logistics and the objectives of the survey permit, it is recommended that CDP data be collected in the field, allowing common offset panels to be pulled from the data set and examined before a final decision about the requirement for CDP processing be made. This procedure gives the interpreter the flexibility to use the optimum offset sections if they are sufficient to answer the geological problem at hand, while maintaining the option to produce the CDP sections if they could provide valuable additional information.

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