<u>How we measure sound emitted from a seismic source.</u>

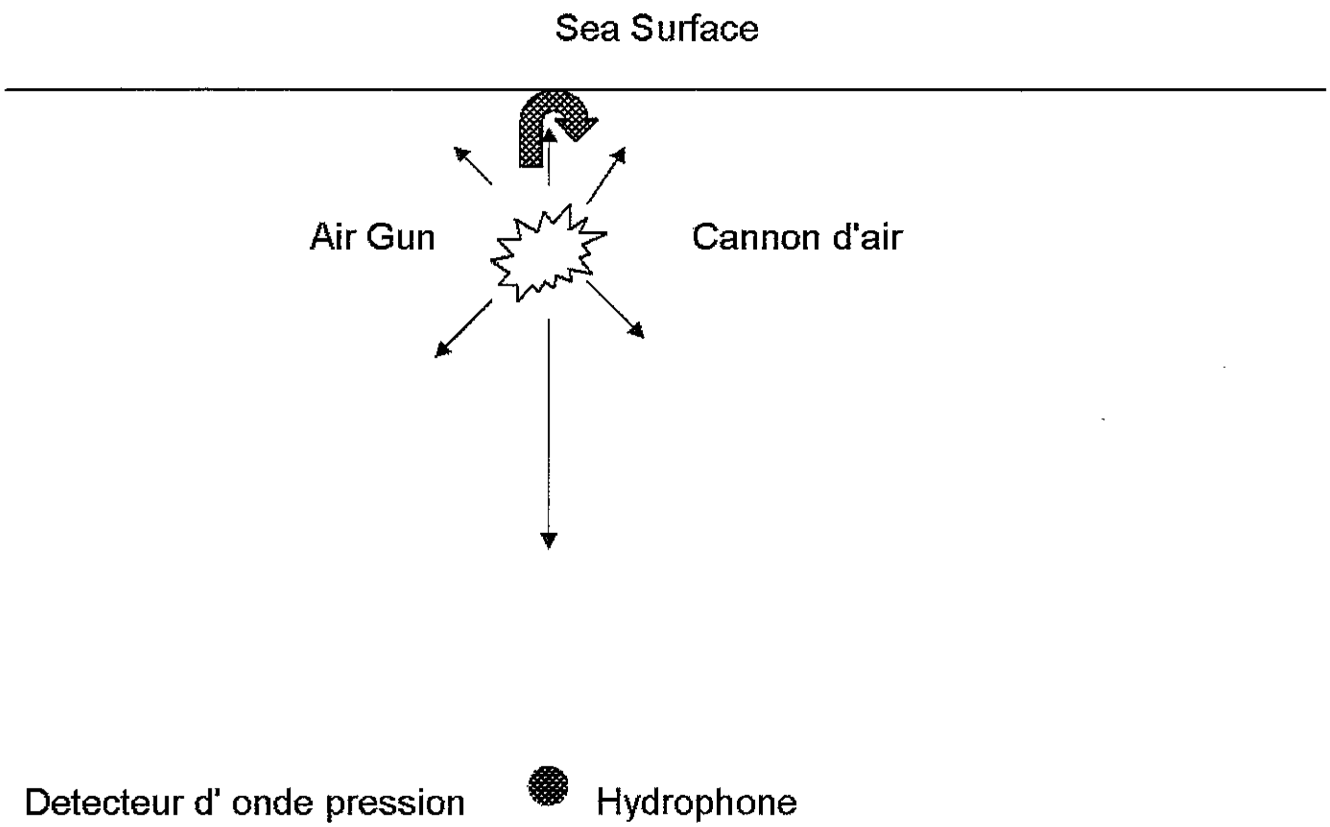

Figure 1 Position of hydrophone for measuring the output pressure signature of an air gun

A hydrophone is a detector that changes a pressure wave into an electrical signal. The voltage generated by the hydrophone is proportional to the amplitude of the pressure wave as it passes by the hydrophone.

The pressure waveform produced by a seismic source such as an airgun is usually measured at a point directly beneath the source at some distance away, say 50m. For the multiple source arrays, the measurement hydrophone would be directly beneath the centre of the array and more distant, say 200m or more. See Figure 1.

In order to compare the pressures produced by different guns it is usual to refer the pressure measurements back to reference position, usually 1m.

Because sound spreads out and attenuates with distance travelled, measurements referred back to 1m will always be numerically higher that those measured by a hydrophone at a distance from the source.

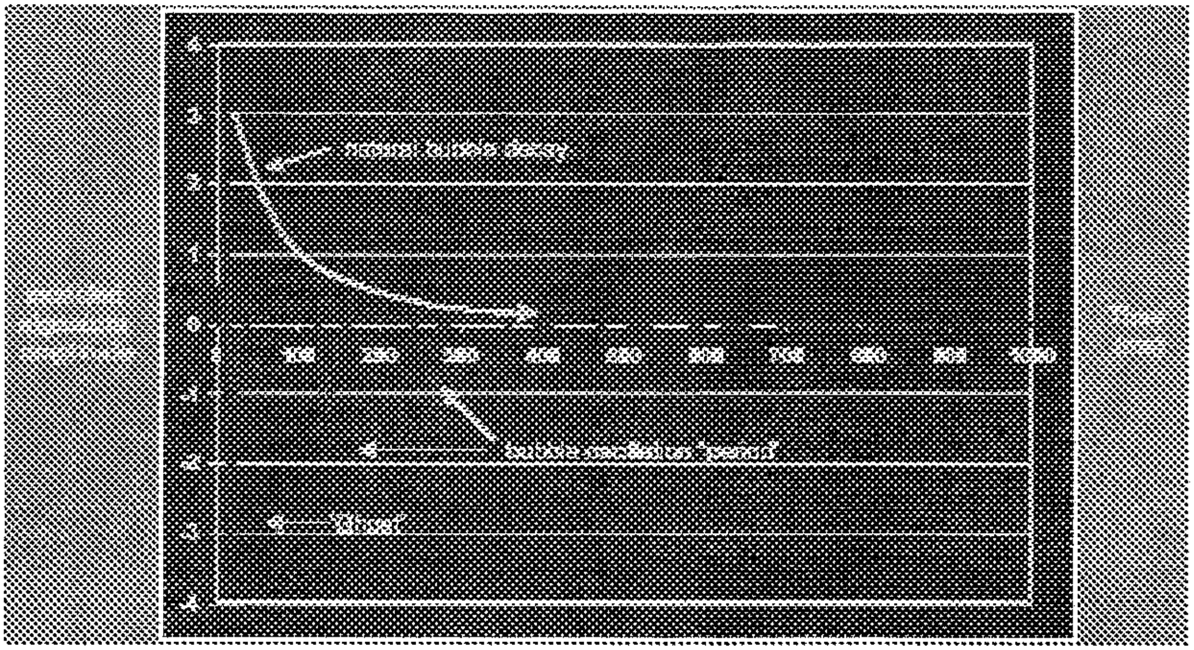

Figure 2 Output characteristics of a single large airgun

A typical waveform measured by a hydrophone beneath a large airgun source after firing is outlined in red in Figure 2.

The vertical scale of Figure 2 is in units of bar-metres[1] which is a pressure unit used in the survey industry. The horizontal scale is elapsed time in milliseconds where 1 millisecond is 1/1000 of the second. The total duration of this record is 1 second.

The initial positive peak pressure is 3.2 bar-m and this is the primary output from the source caused by the initial expansion of the high pressure air after release.

This parameter is a basis for categorising various sources and means that at a distance of 1 metre from the source, the peak pressure would be 3.2 bars. At 10m from the source the pressure would be 0.32 bars and at 100 metres from the source the peak pressure would be 0.032 bars etc.

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[1] **A pressure of 1 bar is approximately equivalent to the pressure of 1 atmosphere.**

The negative pressure peak is not produced by the air gun directly but by the upward going pressure wave after being reflected at the water-air interface. It will be delayed in time with respect to the direct downward travelling wave due to the extra distance travelled but it will have approximately the same amplitude and shape - in this case about - 3.4 bar-m and is often called the "ghost" pulse. Note the both the primary positive and negative impulses have duration of about 10 milliseconds or 10/1000 seconds. The amplitude of this negative impulse also reduces with distance.

The later lower amplitude pulses are due to the cyclical collapse and expansion of the air bubble at it loses energy.

Initial Attributes of a Seismic Pulse referred to a standard distance, usually 1m

1) Positive Peak pressure
2) Negative peak pressure
3) Peak to peak pressure = 1) + 2)
4) Overall Pulse duration = duration of Positive pulse + duration of negative pulse

In the example shown in Figure 2

The Peak Positive pressure is 3.2 bar - m
The Peak Negative pressure is 3.4 bar - m
The Peak to Peak pressure is 6.6 bar - m

The primary pulse duration is 25 ms. (millisecond or about 1/40 second.

These are the units used in the seismic industry. However, in underwater sound a much small reference pressure is used and this is the µPascal (µPa).

A pressure of 1 bar = 10^{11} µPa

So a source emitting a peak pressure of 3.2 Bar - m is emitting

a peak pressure of 3.2×10^{11} µPa - m.

Also, because underwater sound can have a very wide range of values, say from

20 μPa up to 10^{12} μPa it has been found convenient to express an attribute of the sound impulse such as the peak values in a logarithmic form, i.e. in decibels (dB's).

Although this is not technically correct it is convenient for comparing different seismic source configurations.

Thus to convert to dB's we take the ratio of a specific measurement of the pressure waveform, say the positive peak value, and a reference pressure, say 1 μPa, and take the common logarithm (base 10) and multiply by 20.

Thus a seismic source which produces a signature with a positive peak pressure of 3.2×10^{11} μPa - m (3.2 bar-m) is said to have a Sound Pressure Level, $SPL_{(0\text{-peak})}$ of :

$20 \text{ Log}_{10} [(3.2 \times 10^{11})/1]$ dB's relative to 1 μPa and referred to distance of 1m.

This is usually written in a shorthand notation and when calculated will be

$$SPL_{(0\text{-peak})} = 230 \text{ dB // 1uPa @1m}$$

The // means relative to and the @1m means the measurements are referred to a distance of 1m from the source.

Thus: At 10m from the source the peak pressure in dB's will be 210 dB//1uPa

and At 100m the source the peak pressure in dB's will be 190 dB//1uPa.

Thus a reduction in a pressure measurement by a factor of 10 will be equivalent to a reduction of 20 dB's in peak pressure level, and a reduction by a factor of 100, the corresponding reduction will be 40 dB's and 60 dB's reduction for a factor of 1000.

Thus we have a 20 dB change for every multiple of 10.

This allows for a wide range of sound levels to be compared. Note that a decibel is always a ratio and not an absolute value. To say that a pressure pulse has a pressure of 230 dB without qualification is meaningless.

If we wish to include both the positive and negative peak pressures we will measure

$$SPL_{(\textbf{peak-peak})} = 236 \text{ dB} // 1\mu\text{Pa} @1\text{m}.$$

Note that although we are measuring the same pressure waveform, what we measure can vary and the resulting decibel figure will vary.

The question now is : What effect does the pulse width have on the characteristics and attributes of a seismic pressure wave?

Problem: Airguns come in a wide variety of chamber sizes which means that the amount of air stored before release can vary from 1 cubic inch to 2000 cubic in. If say a small volume gun and a large volume gun are charged to the same pressure what differences and similarities will they possess?

Attribute	Small Gun	Larger Gun
Operating pressure	2000 psi	2000 psi
Volume	1 cubic inch	200 cu inch
Pulse duration	1 ms	25 ms
Peak Positive amplitude	2 bar-m	3 bar-m
Stored Energy (relative)	1	200

Table 1 Comparison of attributes of a small and large air gun

We see that providing the charging pressure is the same, increasing the capacity of an air gun does not significantly increase the peak pressure of the seismic signature but does effect its duration.

This means that the <u>peak pressure</u> is not a good indicator of the amount of acoustic energy released and therefore not a reliable indicator of the amount of pneumatic energy stored in the air gun chamber and ultimately released into the water.

To go one step further, stored electrical energy if often used for even smaller electrodynamic and sparker sources used for profiling soft sediments. These sources produce pressure waveforms with about the same peak pressure as the air guns but with pulse durations of 100μs. These of course emit even less acoustic energy into the water than even the smallest of air guns.

The question is, What attribute can we measure in a pulse that better indicates the total acoustic energy released?

One option is to use a rms (root mean square) estimate measured only over the pulse duration. This will allow a better comparison between a pressure impulse and a continuous sound such as background ocean noise which is invariably given in rms terms but will not differentiate between pulses of different duration. The rms value can be easily calculated from the acoustic impulse and converted to decimal format.

Table 2 gives the approximate adjustments to be made to the sound pressure level's in decibel format for two type of seismic sources.

Waveform Attribute	Typical airgun pulse 25 ms duration	Boomer type pulse 100 μs duration
SPL $_{(p\text{-}p)}$	0 dB	0 dB
SPL $_{(0\text{-}p)}$	-6 dB	-3 dB
SPL $_{(rms)}$	-11 dB	-9 dB
SEL	***-27 dB***	***-49 dB***

Table 2 Comparison of decibel attributes for a typical airgun pulse and a boomer type pulse

It is seen that there is little difference between all the SPL's for the airgun signature and the boomer signature - which could be shorter in duration by a factor of 1000.

To overcome this limitation of the rms measurement another concept has been introduced with modifies the rms values by the pulse duration. This is given the name SEL or Sound Exposure Level and the resulting measurements will truly include the effects of pulse duration. This adjustment is made by estimating

$$10 \log_{10} Tp/1 \ \text{dB}$$

where Tp is the Primary (+ve and -ve) pulse duration and the "1" means that the measurement is averaged over 1 second as opposed to the pulse duration as in the case of the rms measurement.

Thus for the 25 ms duration pulse the adjustment would be $10 \log_{10} 0.025 = -16$ dB

For a 100 μs boomer pulse the adjustment is -40dB with respect to the rms value.

The final entry in Table 2, SEL, now includes the effects of pulse duration so that seismic sources are represented in decibel format more in line with their energy content.

Thus a seismic pulse as in Figure 2 would have an SEL of 236-27 dB // 1μPa @1m or 209 dB// 1μPa @1m and the much narrower and less energetic boomer pulse would have a typical SEL of (220-49) or 171 dB // 1μPa @1m. This is equivalent to a factor of about 6300 in acoustic energy between the two sources whereas their peak pressures differ only by a factor of 3.

Summary of Discussion on Decibel use

1) A decibel is always a ratio of a measurement and a reference with the same units.
2) Different attributes of a pressure waveform can be given in the decibel format
3) Only decibels of the same attribute can be used for comparisons between measurements
4) A increment of say 20 in decibel format means a factor of 10 in amplitude and a factor of 100 in power or energy.
5) Adding decibels is like multiplying normal pressure measurements.

Introducing Spectra

As we have seen described above, it is common in the seismic industry to quote the output of a particular seismic source in terms of a pressure versus time display called the time domain signature. We have seen that different seismic sources can produce pressure signatures that can vary greatly in pulse duration and therefore energy content but with their peak amplitudes being of the same order of magnitude.

An alternative way to present the total energy concept is to mathematically transform the pressure signal by frequency analysis and to present a different form of display in the form of a power spectrum.

Here the power in the signal is expressed as the amplitudes of the various frequency components that come together make up the complex signal.

The frequency characteristics of an airgun signature relate to how a signal sounds. Air gun signatures are called broad band because they contain a whole range of frequencies. Short impulses have predominantly high frequency components and longer duration pulses have a predominantly lower frequency content.

Figure 3 shown the pressure signature shown in figure 2 "transformed" as an amplitude spectral density where the levels of the various frequency components are displayed against frequency.

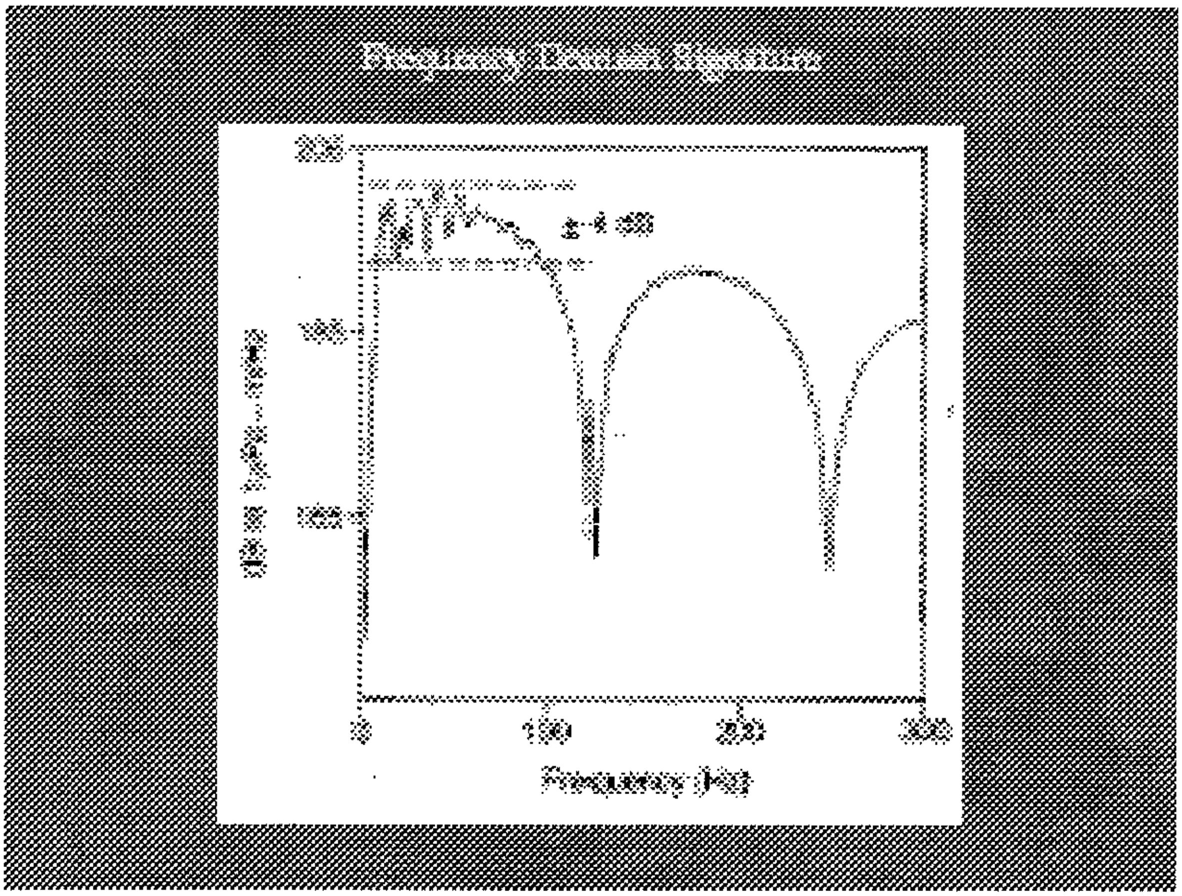

Figure 3 The amplitude spectral density of the air gun signature shown in Figure 2

The vertical axis is invariably scaled in dB's relative to 1 μPa-m/√Hz and shows the amount of acoustic energy in a 1Hz band over a range of frequencies.

The general shape of the spectrum is typical of an airgun source fired just below the water surface. The effect of the surface reflector is to generate the notches at certain frequencies due to cancellation of certain frequency components between the up going and down going portion of the impulse.

The majority of energy is contained in the main (highest amplitude) lobe that for air gun sources is usually the lowest frequency lobe.

The advantage in using the spectral density display is that it is similar to the way in which other noise sources both man-made (anthropogenic) and natural are displayed and much in use by environmental scientist who study wildlife behaviour in the sea.

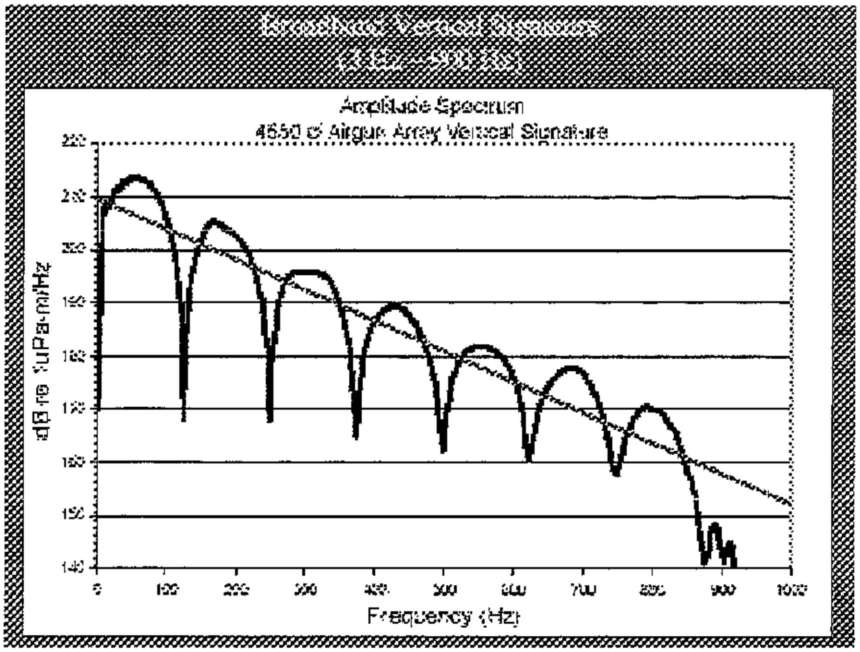

Figure 4 Spectrum for an array of air guns typically used in deep seismic exploration

Figure 4 shows the broad band spectrum for an air gun array typically used in deep seismic exploration. In this display the horizontal or frequency axis is scaled linearly but often this is scaled logarithmically. About 99% of the acoustic energy is contained in the two lower frequency lobes.

Again, it is important to bear in mind that the decibels indicated in a spectrum cannot be directly compared with decibels calculated from attributes taken from the pressure signature. They are not the same features that are being described.

Figures 5 and 6 show the spectrum levels of anthropogenic and natural sound in the ocean. Note that in these two displays the frequency scale is in log format.

In both graphs the sources are divided into roughly into two main groups, the continuous ambient, or background noise sources generally less than 100 on the decibel scale and the anthropogenic and animal derived sounds higher than 100 on the decibel scale.

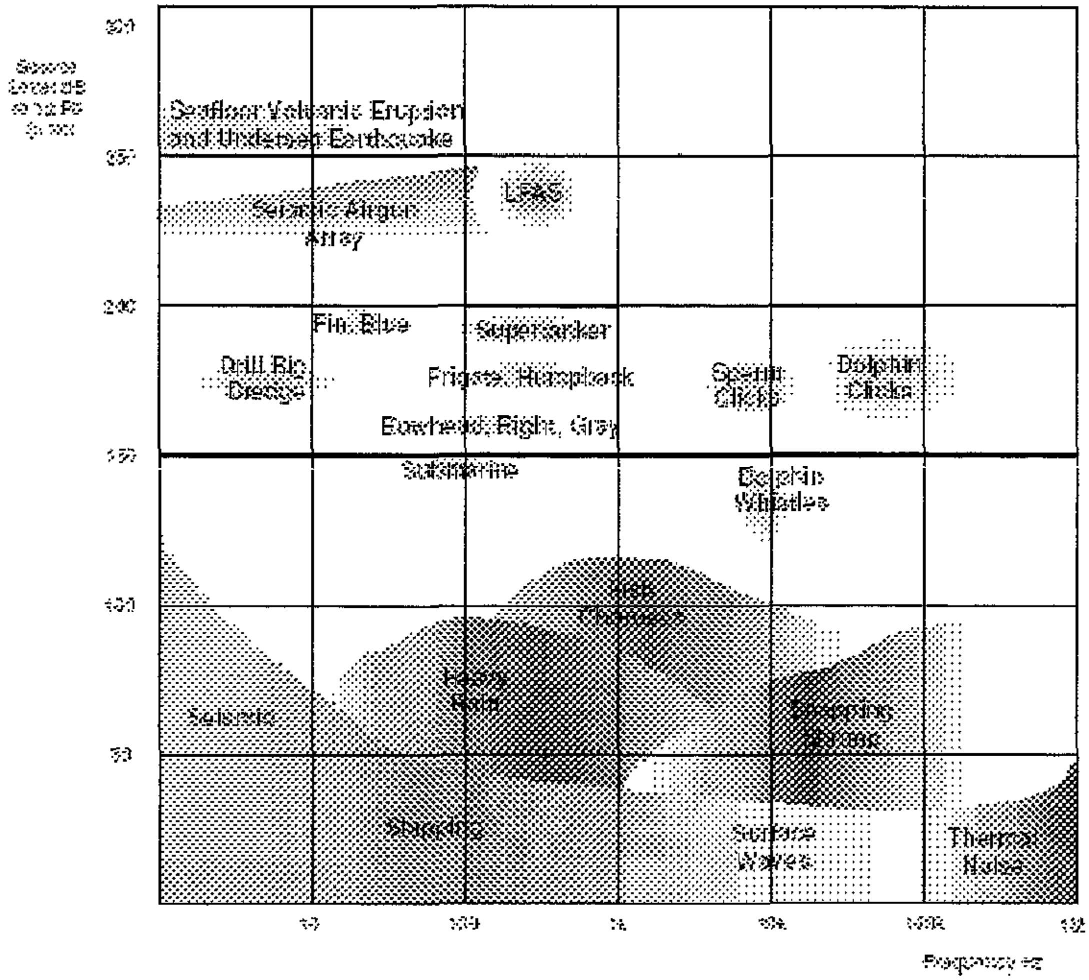

Fig 3.2. Noise Sources in the ocean (indicative purposes only)

Figure 5 Noise sources in the ocean, I - GSI cartoon

The latter group are in fact point sources and in comparing these sources with the lower, ambient noise group, transmission loss due to of the natural effect of a reduction in pressure due to distance travelled has to be taken into account.

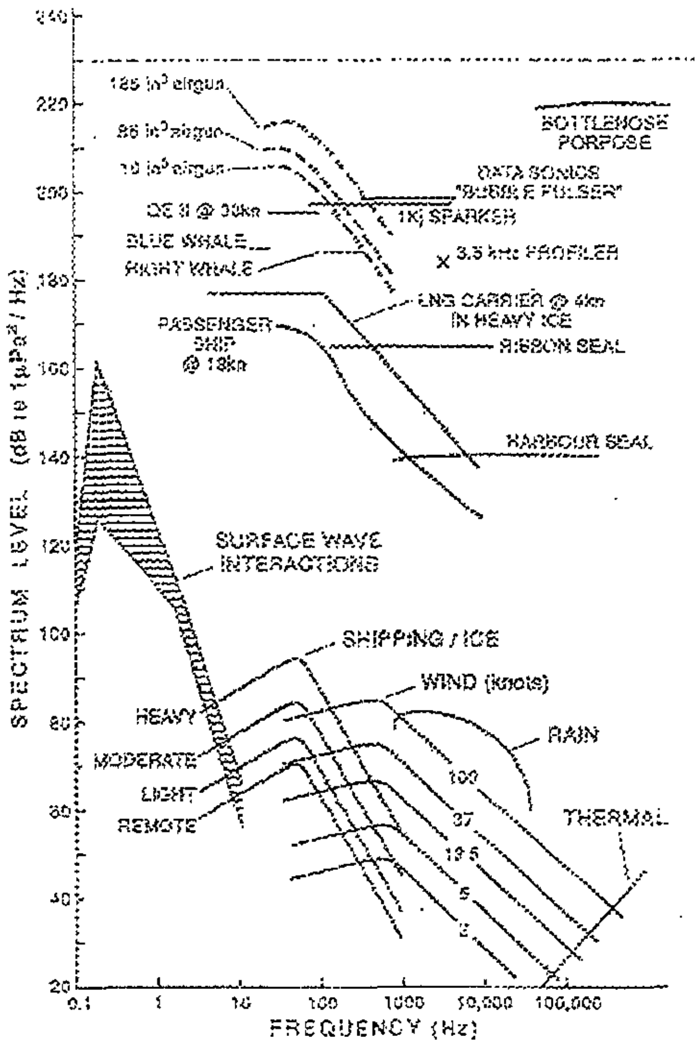

Figure 6 Noise sources in the ocean. II

Conclusions

In this brief note I have tried to explain the techniques and some of the terminology that surrounds the subject of seismic sources used for geophysical investigation beneath the sea. The effects of using multiple sources in an array to direct sound downward, and the effects of long range propagation, particularly in the horizontal direction have not been included at this stage for brevity. However, these would have to be included to describe fully the complete seismic scenario.

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