RESOLUTION IN CONTINUOUS SEISMIC PROFILING

by Olivier LEENHARDT
Oceanographic Museum, Monaco

The operation we shall refer to as continuous seismic profiling consists of emitting a short impulse underwater, receiving the echoes reflected by the bottom and the elastic discontinuity of the subsoil, and amplifying, filtering and recording these echoes on paper band in the same way as for echo-sounding, and then of repeating these operations several times per second, or per minute. The resulting time section resembles a geological section, for the elastic discontinuity of the subsoil corresponds roughly to the interfaces between the different sedimentary layers. It differs, however, from a geological section because the vertical scale is time graduated. Also, since the scale ratio is above one there is often much distortion. There are also a certain number of acoustical phenomena which give unwanted images.

I. — THE RESOLUTION DEFINED

One of the above phenomena is the " thickness " of the received signal, or its " duration ", according as to whether it is the width of the paper band in millimetres or the time in milli-seconds that the recording stylus takes to sweep this band that is being considered. I myself prefer to speak in terms of time. If we could use an infinitely short and sufficiently strong signal and receive and record this signal without distorting it, the resulting transcription of a sub-bottom reflection would be a very thin line. In other words, we would be able to distinguish between two reflectors on a recording even if they were as close to one another as could possibly be imagined, as for example in the case of a bevelled edge. For various reasons, some physical, others depending on the operation of the equipment, the received signal always lasts a certain " time ". I shall term " resolution " the measurement of this time in milliseconds.

Introduced in this way, the concept of " resolution " in continuous seismic sounding is related to the concept of resolution as used in physics. However, in our case, the smaller the number measuring the resolution the better is this resolution.

We must first of all define accurately the method adopted for the measurement of the resolution. It is evident that this measurement must be objective and independent of the place where it is carried out. Authors often pride themselves about the excellent resolution obtained with their equipment in a given case. However, if when measuring the resolution we are able to distinguish in the sub-bottom a layer with a low reflection coefficient rising above a bevelled layer that has a low reflection coefficient, then these are obviously very favourable conditions. The tail of the upper reflection will have less intensity than the beginning of the lower reflection, and it will be possible to follow the latter right up to the junction of the two reflectors. If the reflection coefficients are reversed, the resolution obtained will be very poor.

Let us now define more accurately the previous definition by considering a single reflector. Resolution is the length of a seismic signal and is due to instrumental effects. We thus obtain an objective value for resolution.

Measuring the resolution is thus measurement of the duration of a single reflection on, for example, a hard bottom.

II. — FACTORS IN THE RESOLUTION

Various factors influence the resolution, some pertaining to energetics, others to geometry or to electronics.

Energetic factors

A seismic signal can be defined in the form : time- -amplitude- -frequency. It is evident that the longer the signal, the poorer the resolution. (CREVOISIER).

It is known that a strong amplitude requires a certain time to return to zero. Therefore it is easy to see that the resolution of a very strong signal will be worse than that of a weaker signal. Finally, the higher the emission frequency, the better the resolution.

Let us consider some of the types of sources available for the electronics of a sediment probe. In a piezo-electric transducer the discharge of a capacitance via a thyratron makes it possible to emit a single peak only, provided the transducer's Q factor is sufficiently low (EDGERTON and HAYWARD, 1961).

Then take the case of a " pancake " coil coupled to a metal plate : the condenser discharges into the coil, inducing eddy currents in the plate, and the plate recoils abruptly from the coil, creating a short elastic impulse in the water. This principle is the one EDGERTON has used in the construction of his " Boomer " (figures 1 and 2).

The Boomer is for use on the Continental Shelf. Penetrations of up to 200 m can be achieved, with resolution of the order of 2 m (EDGERTON and LEENHARDT) (figure 3).

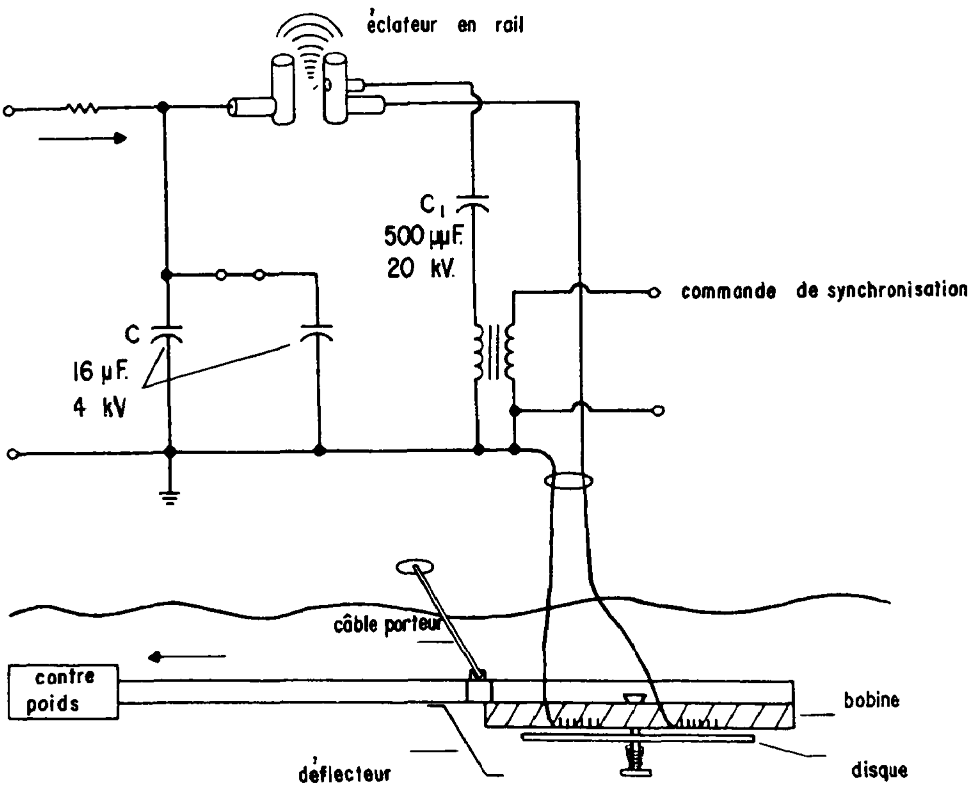

FIG. 1. — Block diagram of *Boomer*.
Commande de synchronisation = Synchronisation Control
Câble porteur = Suspension cable
Contrepoids = Counterweight
Bobine = Coil
Disque = Disc
Déflecteur = Deflector
Eclateur en rail = Trigger

Recently other possibilities, such as the Flexichoc source, have been developed. These, like the Boomer, utilize the implosion principle but are of a more advanced design.

Or else a capacitance discharge can be used to produce an electric spark which sends out a seismic signal through the water (figure 4). This instrument is called a " *Sparker* " or " *Etinceleur* " and the energy involved is :

$$E = \frac{1}{2} CV^2$$

Thus the emitted energy can be increased by varying either the circuit capacitance or the charging voltage of the condenser.

Sparkers exist in many sizes, from 50 to 500 000 Joules, and this equipment is widely used in seismic research work (figure 5) (CASSAND and LAVERGNE).

The abrupt discharge of a volume of compressed air will also produce a seismic wave (EWING and ZAUNERE). This discharge can be achieved

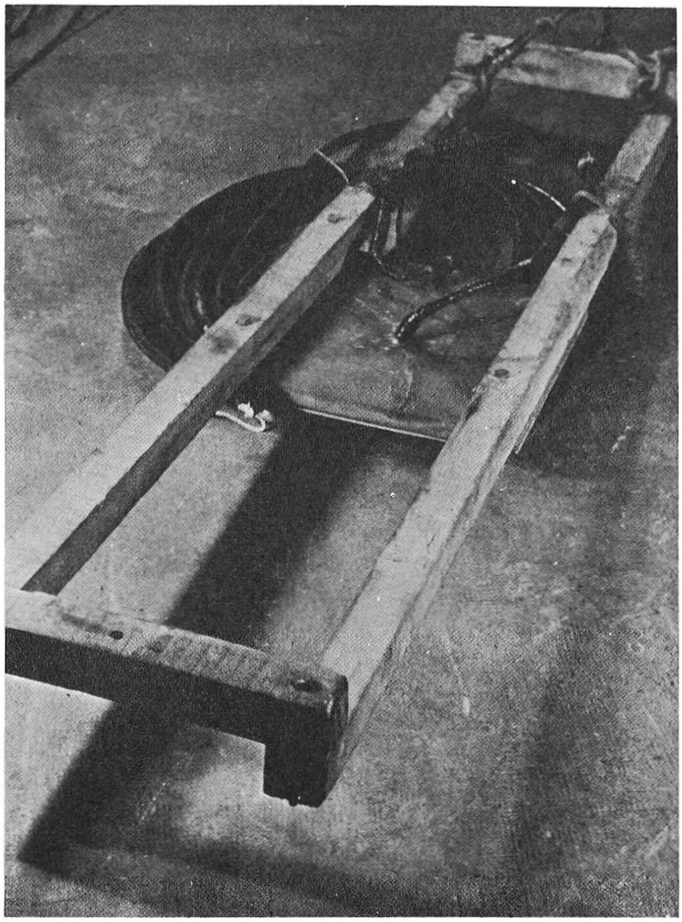

FIG. 2. — The *Boomer* 300 J on its fish.

with a special air-gun. The power of the air-gun varies with the volume of the compression chamber, the pressure of the compressed air, and the depth at which it is being used. It is used in general where deep penetration is required. By employing several air-guns simultaneously it is possible to obtain a wide range of frequencies and thus the resolution becomes somewhat better.

Other methods exist, the commonest being no doubt the use of explosives with forces ranging from that exerted by a simple fuse to that of the discharge of several tons, as the circumstances dictate (cf. CASSAND *et al.*).

These processes, with the exception of the first, all give rise to secondary phenomena whose effect is to prolong the emitted signal.

A cavitation wave builds up immediately following the Boomer's peak wave. This corresponds to the return of the displaced water against the plate. With the Sparker, the air-gun, or with explosives, the physico-chemical phenomena that result from the emission of the impact wave lead to the creation of a gas or air bubble. If the source is at too great a depth this

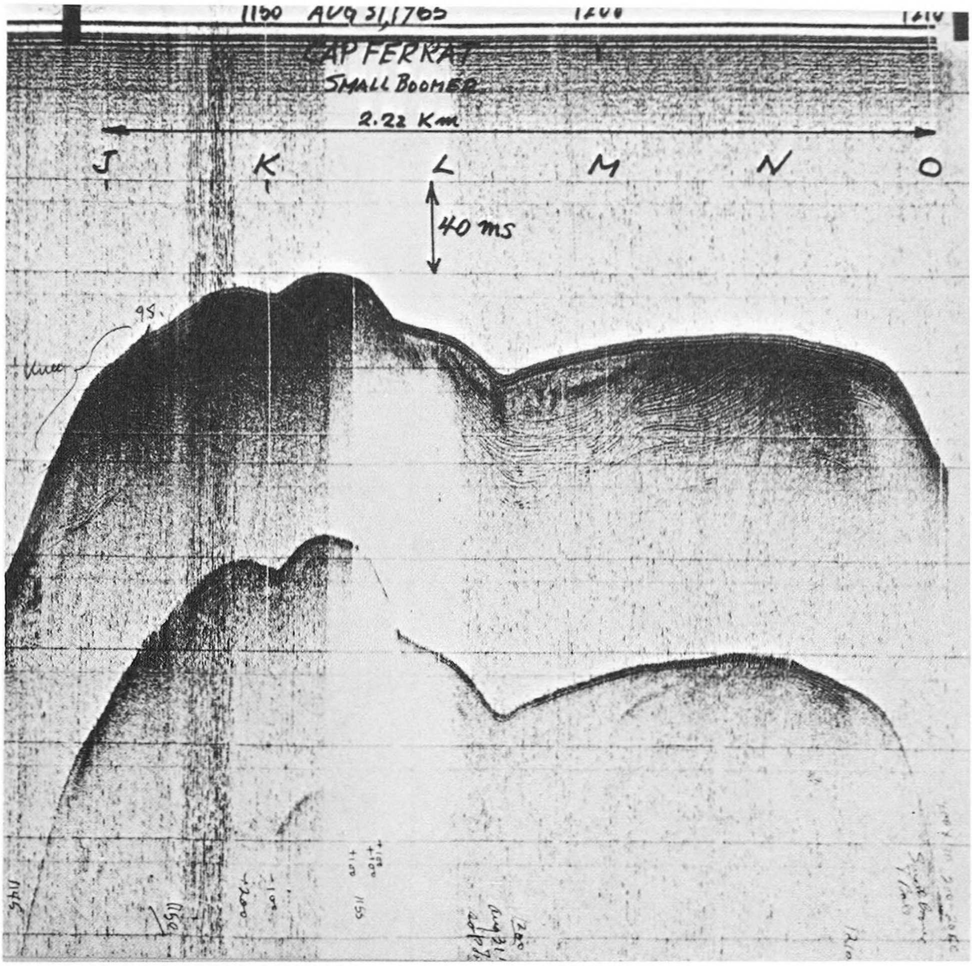

FIG. 3. — Record from a precision *Boomer*.
A record taken during trials with this system; the signal is a little thick on account of the instruments being at too great a depth (40 ms between scale lines).

bubble will oscillate in volume, creating a fresh wave every time it is at its minimum diameter. Simultaneously, under the effect of hydrostatic pressure this bubble rises to the surface where it bursts.

Although we can regard all seismic sources as creating impact waves — and the longer these are, the more powerful — yet we should realise that the bubble effect is not always the same for all the instruments; in particular, the bubble from the Sparker is actually constituted of decomposed water. Most of this water subsequently recombines, and the bubble becomes smaller. In the case of both the air-gun and the explosives, the bubble is much larger and its contribution to prolonging the seismic signal emitted is appreciable. The influence of the buble is dependent upon the depth at which the source is operated.

The type of instrument to be used in order to solve a problem for which a given resolution is necessary depends not only on the power of the instrument but also on the intrinsic qualities of the phenomena involved.

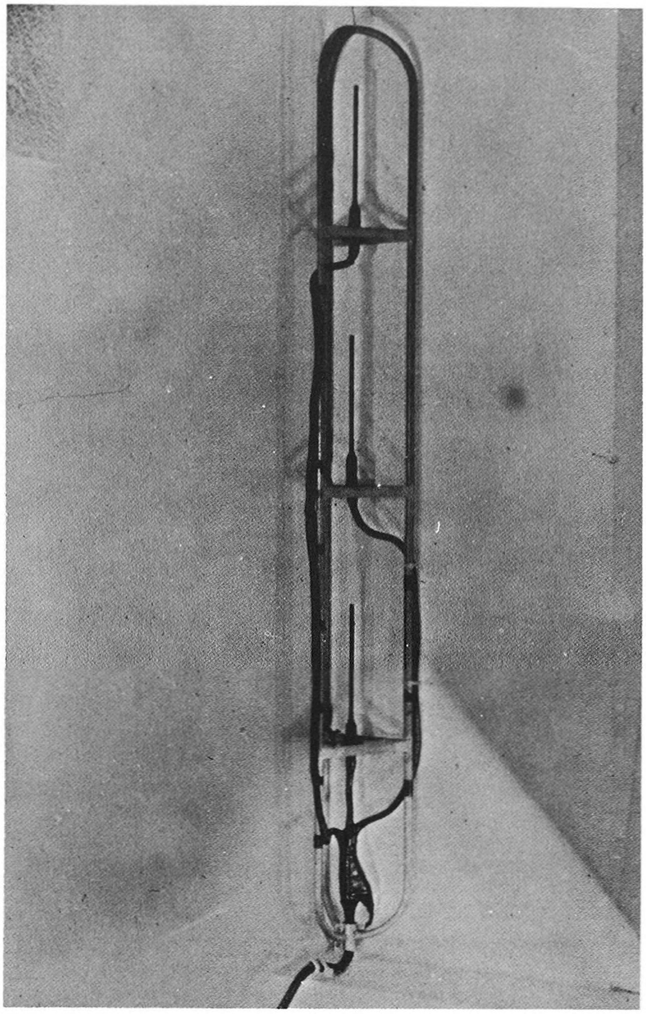

Fig. 4. — The *Sparker* 9 000 J manufactured by E.G. & G.
This instrument works at 1 000 to 5 000 J per electrode. It is plugged into an electronic circuit of the type shown in figure 1.

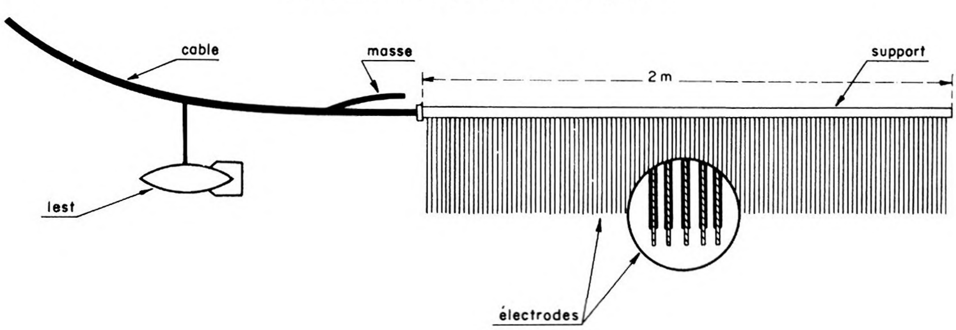

Fig. 5. — Sketch of an "*Etinceleur*".
This instrument works at 1 to 5 J per electrode on an electronic circuit such as is shown in figure 1. The gain in resolution is due to the fact that the bubble is reduced in size, having been split into a large number of small bubbles.
Lest = Sinker

(GRAU). By a rational choice of equipment we govern the energetic factors of the resolution.

Geometric factors

For the sake of simplicity let us suppose that we are dealing with an emitted signal that has a single sinusoidal period. At a first approximation, all the sources we are considering are omnidirectional. They would be directional only if the diameter of the active surface of the source was large in relation to the length of the emitted wave. This, however, can only be the case in high frequency sounding. The wave is therefore here emitted upwards as well as downwards. At the water surface the wave is reflected practically without loss, but with a change of sign. The wave reflected from the surface is then propagated towards the bottom, combining with the initial wave to form the emitted seismic signal. This has two consequences :

1. The deeper the instrument, the more the reflection from the surface lengthens the signal;

2. If the source is placed at a depth equal to a quarter of the length of the emitted wave, the signal will be stronger and its frequency altered (cf. LEENHARDT, 1969).

The depth at which to operate will therefore be carefully chosen, both to increase the power of a low frequency and to avoid a lengthening of the signal as this is detrimental to the resolution (fig. 6). In such a case

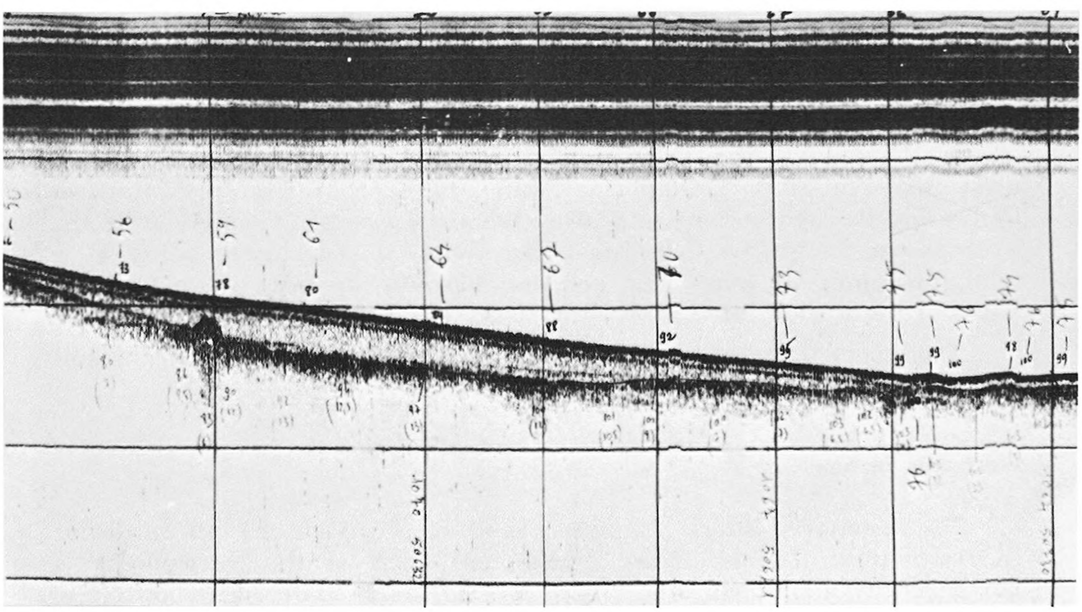

FIG. 6. — Profile from a sediment probe. Effect of source depth on resolution. The fish is being trailed at too great a depth. It is seen that the signal is split by reflection from the surface, and this is prejudicial to the resolution (vertical scale : 40 ms between the horizontal scale lines; horizontal scale : 900 m between vertical marks).

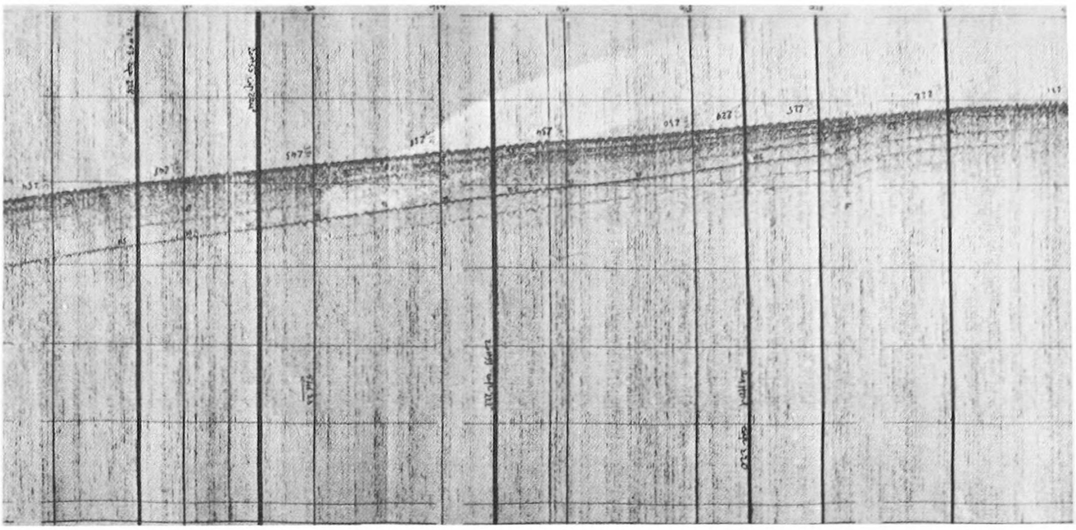

FIG. 7. — Profile from a sediment probe.
The instrument is here working well. The resolution is a little weak, since power has been heightened in order to obtain better penetration (the scales are those shown for figure 6 : the frequency 4.5 kHz).

it would be necessary to place the source at sea surface level, and this cannot be done with all types of instrument, and moreover it sets delicate operational problem since the sea surface is rarely a perfect mirror.

These considerations apply to the sources but they also hold good for the receivers if we apply the reciprocity principle.

However, although it is difficult and rarely possible to use directional instruments, hydrophones of a width greater than the seismic wave-length are on the other hand widely used.

At the receiver we endeavour to be free of all unwanted noise. The noise made by ships is important, but can be considerably diminished by trailing the hydrophone well away from the vessel. By lengthening the hydrophone we give it cylindrical directivity, its sensitivity being at a minimum along its axis. This question has already been treated in the pages of the Review (cf. LEENHARDT, 1969).

The geometric factors influencing the resolution essentially result from the operation of the instrument.

Electronic factors

The receivers, filters, amplifiers and recorder chosen all influence the resolution. The electronic background noise of the instruments is not generally a problem since there is also much more important noise caused by the water. These noises depend essentially on the quality obtained in the first stage of amplification.

On the other hand the Q factor of the hydrophone, the amplifiers, and the filters is important. It should be low so that for a short input

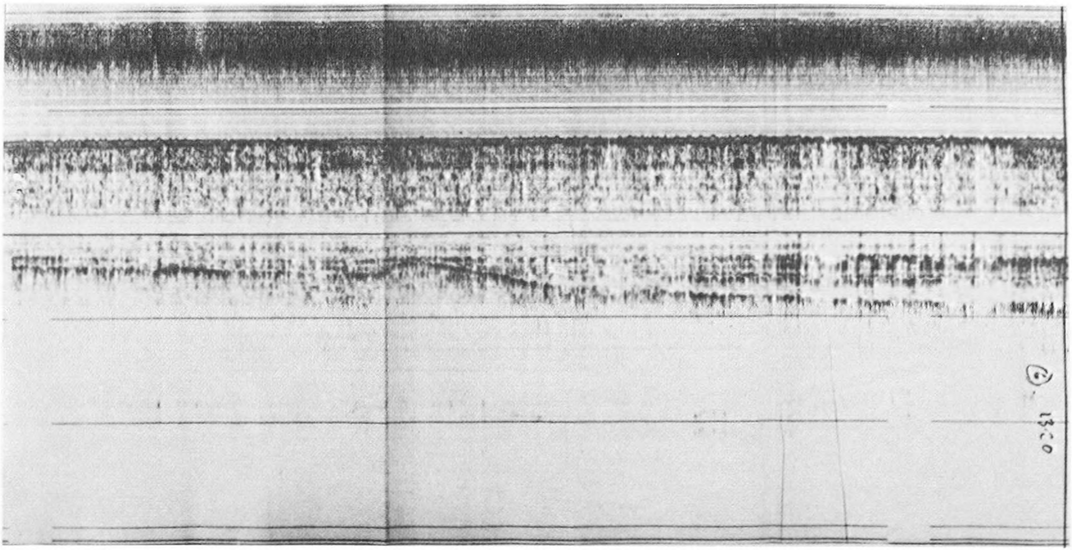

FIG. 8. — Profile from a sediment probe.
This is for a 6 kHz frequency, but the Q factor is higher and hence the signal is a little less clear. A penetration can be seen under the second multiple (10 ms between scale lines).

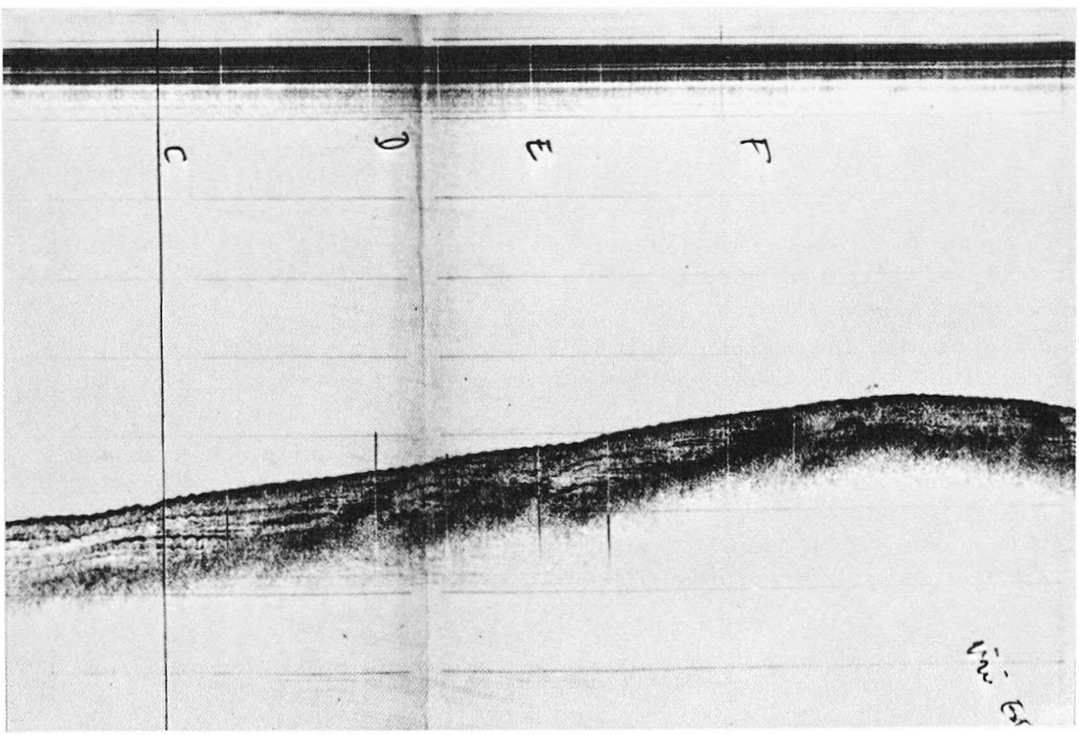

FIG. 9. — Profile from the "Mud Penetrator" sediment probe. At a 12 kHz frequency a resolution of better than 150 ms is achieved (10 ms between scale lines).

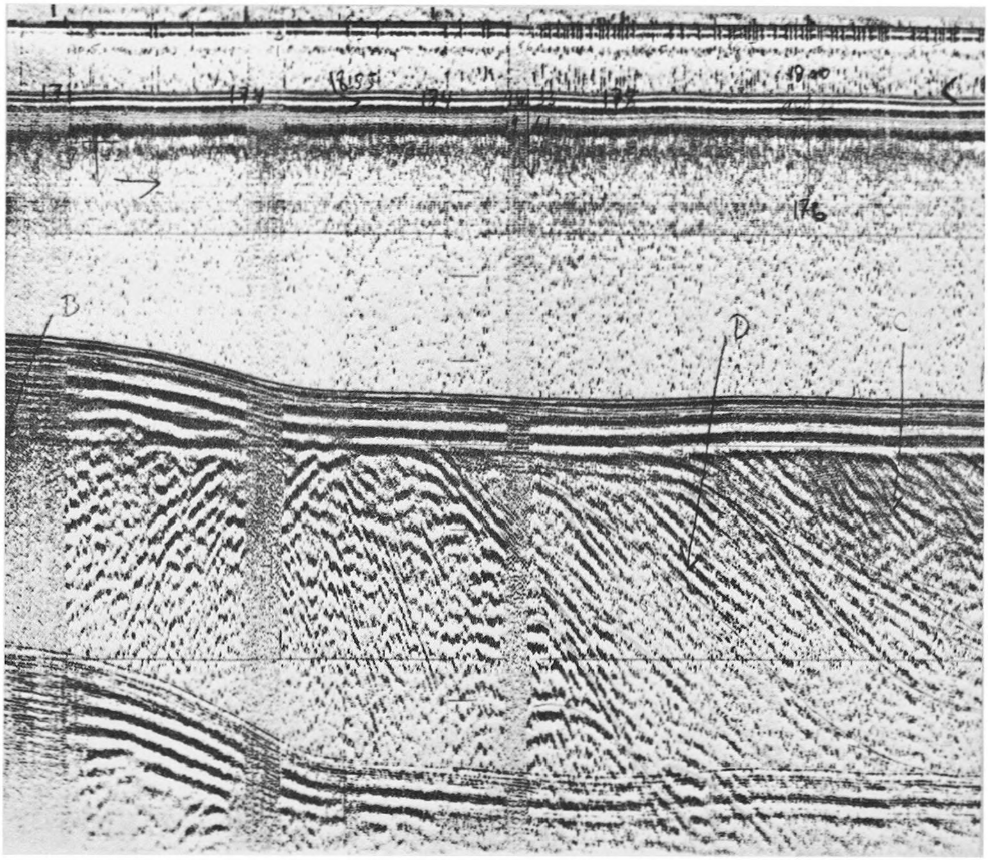

FIG. 10. — Effect of filtering on a 3 000 J Sparker record.
The 200-800 Hz filters on the left are too high to obtain a good record. The operator then tried 80-800 Hz which gave him a better result (100 ms between scale lines).

signal there is a correspondingly short output signal. This is not the case in cheap hydrophones. Nor is it the case if the pass-bands of the filters are too narrow.

Finally, the recorder must have a sufficiently high pass speed and good graphical sensitivity. We ourselves prefer to employ recorders using Alfax damp electro-chemical paper.

The choice of instrument, and above all the way in which it is used, has a determining influence on the quality of the resolution. To obtain good resolution depends as much on a clear conception of the problem as it does on the painstaking care with which the operations at sea are carried out.

III. — ADVANTAGES OF RESOLUTION

The first advantage of the concept of resolution is that it permits comparison between the qualities of the different varieties of equipment.

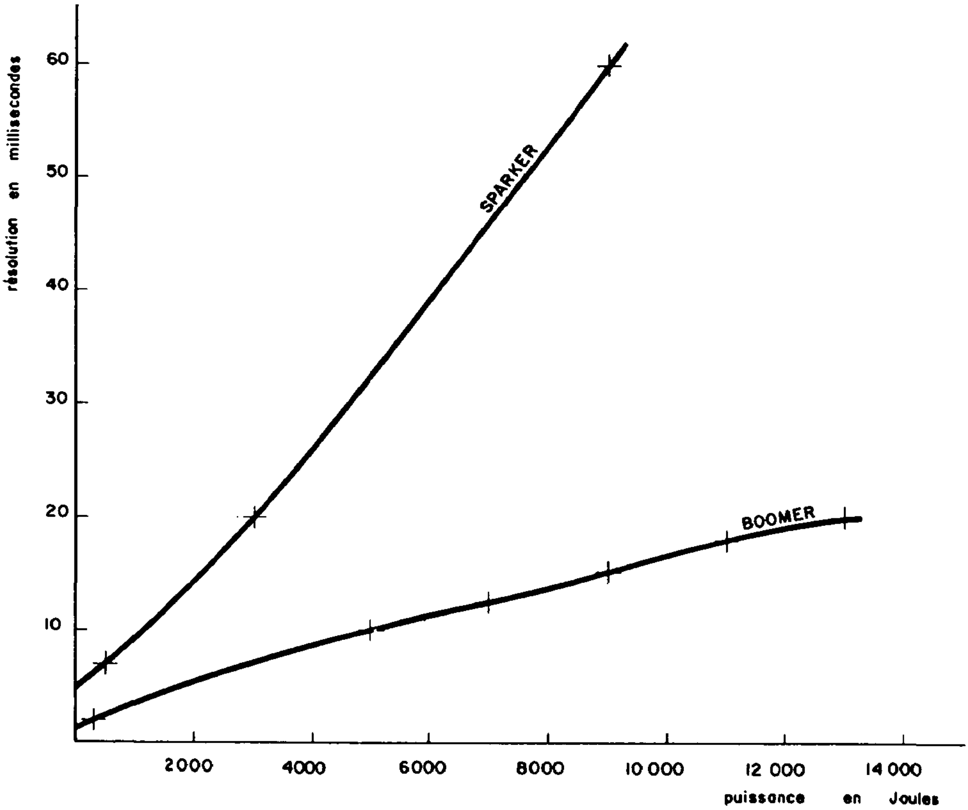

FIG. 11. A curve showing resolution as a function of electric power for the *Boomer* and the *Sparker*.

For the *Boomer* we use :

For 300 J : a resolution *Boomer*,

For 1 000 J : the *Boomer* shown in figure 2,

For higher powers : a two-plate *Boomer* (but this was abandoned after trial on account of the difficulty of operating it at sea).

For the *Sparker* : the "*Etinceleur*" signal at 500 J (taken from a publication). Above this value the signal is measured on a 3-electrode *Sparker*.

When the whole object of a seismic sounding is to penetrate as deeply as possible into the marine sub-soil, resolution is not the preoccupation. On the other hand resolution has obvious advantages when it is a question of distinguishing the different layers of the sub-soil, and this is the case in most instances in pure geological research (cf. SERRUYA and LEENHARDT). It is also the case for all applications of continuous seismic sounding to engineering work. Finally, resolution is the major objective in sedimentary studies when the surveyor hopes to be able to correlate a particular level identified in a core with a seismic reflector, and as a result to draw geographical conclusions that are not necessarily limited to the spot where the core was lifted.

The achievement of good resolution, however, also has another advantage.

We have so far been studying the seismic signal of which we are the masters — that is to say that it is we who have fixed its amplitude, frequency and duration. This signal is filtered by the sub-soil, each reflector giving it a particular "character", thus permitting its identification (LEENHARDT, 1970).

Only with signals of good resolution is it possible to analyse the character of the reflection. This enables us to recognize and to trace the same reflector throughout the whole study area, or even to identify the same reflector in two different study areas not geographically contiguous.

Some examples are shown in figures 7 to 11.

CONCLUSION

The resolution — the duration of a seismic signal after reflection against a single reflecting surface — depends on the characteristics of the source used, the conditions in which the emitter and hydrophone are operated, and finally on the quality of the receiver and of the recording chain. Resolution has a double interest : it offers the technician a means of measuring the quality of an instrument objectively, and for the geophysicist it permits accurate and detailed analysis of his recordings.

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