SOME EFFECTS OF A WIDE SEPARATION OF SOURCE AND HYDROPHONE IN SHALLOW-WATER SEISMIC PROFILING

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The separation x of source and hydrophone in sparker or boomer surveying is usually sufficiently small to be ignored: i.e., in the interpretation outgoing and returning rays may be assumed to have travelled along the same path. This approximation is invariably satisfactory in deep water and is often so in shallow water. When it is not, interpretation may be carried out using equations given by Curry *et al.* (1965) which take x into account.

The latter equations are actually the "parametric equations" of the time-distance curve for reflections from the base of a second layer (see, e.g., Slotnick, 1959, p. 185). The parametric equations have interesting implications for profiling results obtained with a wide separation of source and hydrophone. In general, it may be stated that the reflection time-distance curve for any interface is asymptotic to the time-distance curve for refractions from the overlying interface; it follows that reflections from lower interfaces overtake reflections from higher interfaces as x is increased (see fig. 1).

In the case of shallow-water sparker or boomer surveying in an area of sediment cover, the reflection from bedrock (curve DD′, fig. 1) will arrive before the sea bed reflection (curve CC′, fig. 1) if x is sufficiently large. For example, if two metres of sediment (seismic velocity in this and later examples, 1.8 m/ms) underlie a water layer ten metres deep, the bedrock reflection will arrive before the sea bed reflection at all separations greater than approximately 60 metres. This effect provides a means of mapping a shallow bedrock surface simply by adjusting x until the bedrock reflection emerges above the sea bed reflection and is not obscured by the latter. In practice, of course, a survey with high resolution equipment offers a better solution to this particular problem.

Another effect of increasing x is to produce relative displacement of sea bed multiple reflections and sub-bottom reflections on the profiler

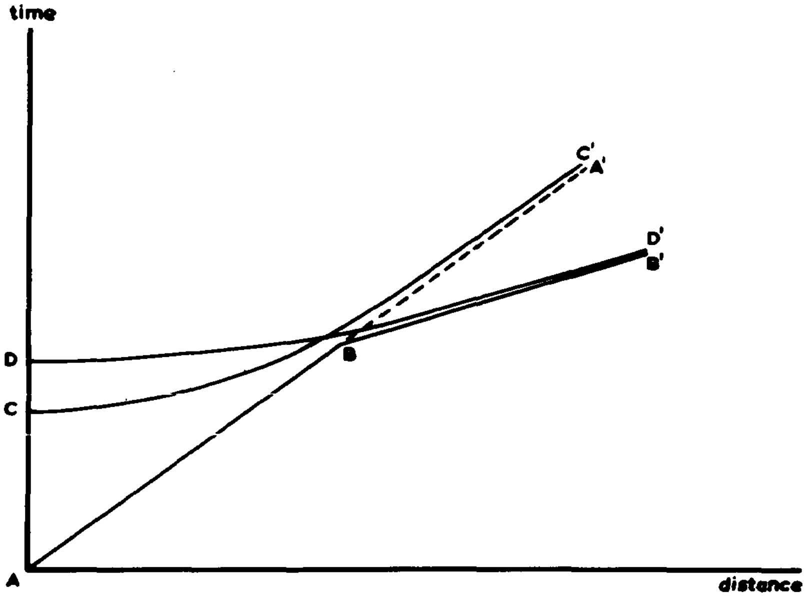

FIG. 1. — Time-distance curves.

AA' : direct ray;
CC' : sea bed reflection;
DD' : sub-bottom reflection;
BB' : ray refracted along sea bed.

record. For example, with a water layer of 14 metres and a sediment layer of 17 metres and with $x = 0$ the bedrock reflection and the first multiple of the sea bed reflection arrive simultaneously leading to an obscuring of real information. If x is increased to 60 metres, the arrival times of the above phases become separated by 12 milliseconds. Thus if interest is centred on a particular interface or depth interval for which the information on the profiler record is likely to be obscured by multiples, the information may be moved to a more favourable part of the record by altering x.

The most important result of using a large separation is the possibility of recording refracted arrivals from the sea bed as this provides a means of estimating the seismic velocity of the top layer.

Let h = water depth;
x = separation of acoustic source and hydrophone;
v_0 = velocity of sound in sea water;
v_1 = velocity of sound in top layer;
t_a = travel time of ray refracted from sea bed.

Then, for a horizontal sea bed, the equation for the refracted ray is given by:

$$t_a = x/v_1 + 2\,h(v_1^2 - v_0^2)^{1/2}/v_0 v_1 \qquad (1)$$

Rearranging terms,

$$v_1 = \{xt_a + 2\,h\,[(x^2 + 4h^2)/v_0^2 - t_a^2]^{1/2}\}/(t_a^2 - 4h^2/v_0^2) \qquad (2)$$

The best estimate of x for use in equation (2) is derived from the travel time of the direct ray. An alternative approach is to utilise the travel times of refracted *and* reflected rays from the sea bed since these allow an estimate of velocity to be derived without x having to be defined.

For a horizontal sea bed, the equation of the sea bed reflection travel time t_b is given by:

$$t_b = (x^2 + 4\,h^2)^{1/2}/v_0 \qquad (3)$$

From which:

$$x = (v_0^2\,t_b^2 - 4\,h^2)^{1/2} \qquad (4)$$

Adjusting equation (2) on the basis of equations (3) and (4) yields:

$$v_1 = \{t_a\,(v_0^2\,t_b^2 - 4\,h^2)^{1/2} \pm 2\,h\,(t_b^2 - t_a^2)^{1/2}\}/(t_a^2 - 4\,h^2/v_0^2) \qquad (5)$$

Several records obtained by the author in the Bristol Channel using a wide separation have yielded intermittent refracted arrivals, commonly from the higher parts of gentle bedrock culminations. Refracted arrivals are most easily recognised in cases where they arrive before the direct ray; of course, unlike reflections they do not have associated multiples and this aids in their identification. An example is shown in fig. 2 which is a sketch from a sparker record obtained in an area of Carboniferous Limestone outcrop off the coast of Gower, Glamorgan. From this record the following values were derived: $t_a = 27$ ms; $t_b = 35$ ms; $h = 10.7$ m. Using equation (5) these values yield a velocity $v_1 = 3.37$ m/ms (= 11 050 f/s). If equation (2) is used in conjunction with an x-value of 48.2 metres based on the measured direct-ray travel time of 32 ms, an identical value of v_1 is obtained.

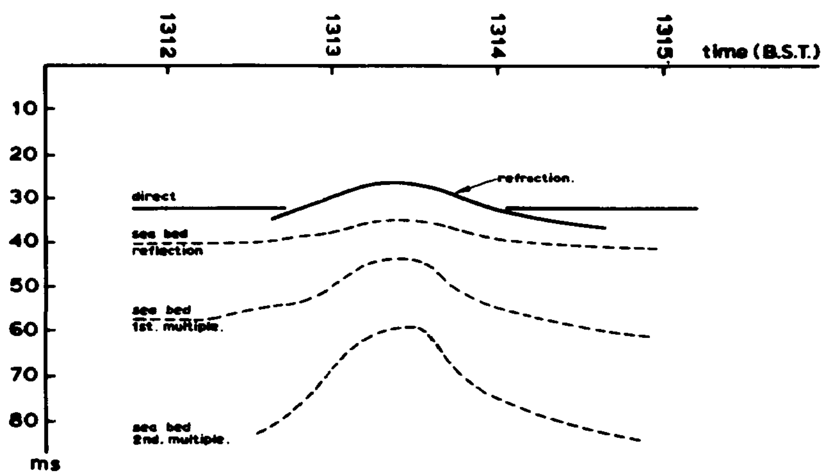

FIG. 2. — Sketch of sparker time-section showing refracted arrival, obtained off the Gower Coast, Glamorgan.

In practice, equations (2) and (5) yield two solutions for the sea bed velocity. In cases where the refraction is the first arrival (i.e., x is greater than the critical distance), the larger velocity value represents the real solution. This can be verified empirically by testing the two values of v_1 in equation (1) [if necessary, with x substituted according to equation (4)] and selecting the value which correctly reproduces the original refraction time t_a. When x is less than the critical distance ambiguity cannot be removed by this means, for both solutions will correctly yield the original refraction time when used in equation (1). In such cases, a repeat experiment with a different spacing will remove the ambiguity.

Error in v_1 using equations (2) or (5) is a complex function of error in t_b and/or t_a but it can be stated that to obtain a good estimate of v_1, times should be read to the nearest millisecond.

The above method of deriving velocity information from refracted arrivals in shallow water is easier in practice than the method (described, for example, by SARGENT 1970) of moving source and hydrophone apart at a constant rate and using the relationship $\Delta t_d/\Delta t_a = v_1/v_0$, where t_d is the travel time of the direct ray. Indeed, refractions may be recorded during normal surveying with a wide separation.

However, a disadvantage of routinely working with a large separation in shallow investigations is that estimates of depth to sub-bottom interfaces are subject to larger error than with a small separation. This is because at large separations changes in depth to a reflector produce proportionately smaller changes in the travel time of the reflected ray. Fig. 3 illustrates this effect for the particular case of a sediment layer of seismic velocity 1.8 m/ms underlying a water layer ten metres deep. It can be seen that, for small thicknesses, the rate of change of reflection time with layer thickness is more than three times as great for the case where $x = 0$ as for the case where $x = 60$ metres. In actual surveying, this disadvantage must be weighed against some of the advantages of a wide separation discussed above.

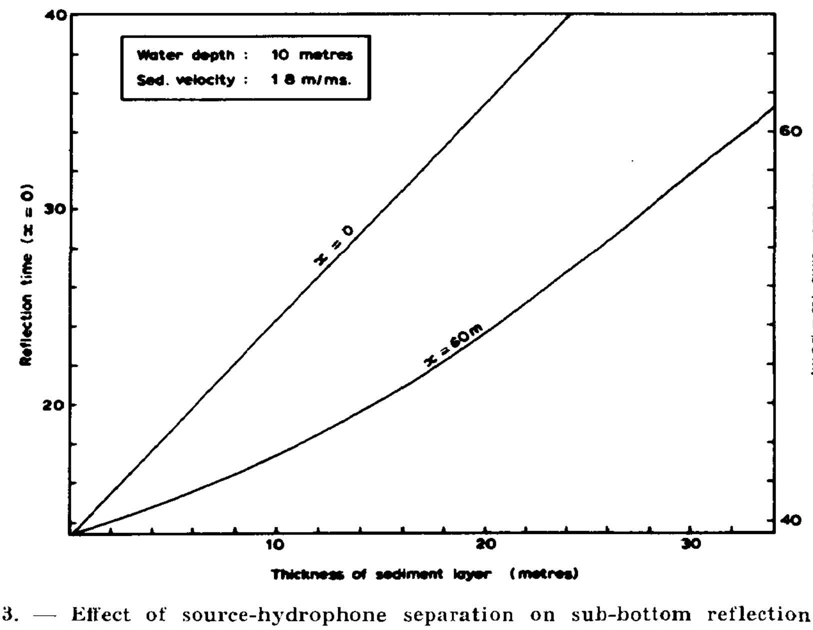

FIG. 3. — Effect of source-hydrophone separation on sub-bottom reflection times.

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