REMARKS ON MULTIPLE REFLECTIONS*

B. GUTENBERG† AND C. Y. FU†

One cannot help being impressed by the wonderful arrays of seismograms depicted in Mr. Ellsworth's paper and in the prepared discussions. The regularity of the time intervals of successive impulses and the alternating sequence of the change of phase are readily adapted to a mechanism of multiple reflections. If the latter is accepted, the following questions seem to merit some consideration: (a) the energy concentration, (b) the positions of the reflecting surfaces, (c) the sharpness of the source-impulse, and (d) the velocity contrast of the adjacent media.

Even if the absorption of the ground could be entirely neglected, the intensity of energy of a seismic disturbance undergoing multiple reflections would be diminished for at least two reasons. First, the energy may be spread out owing to the divergence of the pencils of rays as shown in Figure 1a. This is true when the reflector is a plane. When it is a syncline or a depression as shown in Figure 1b, the spreading may be compensated by the curvature of the reflecting surface. There may even be a focusing effect if the curvature is very favorable, e.g., one optimum focusing is obtained if the surface is a sphere around the source.

Secondly, the amplitude of the disturbance is decreased after each reflection as shown in Figure 2a, because a part of the energy must be transmitted. Since there is no perfect reflector of seismic waves in nature, a multiple reflecting layer can never be a conservative system. The loss depends on the transmission coefficient of the interface and cannot be compensated by any converging effect of the reflecting surface. But there might be an accumulation effect in the manner as shown in Figure 2b, if the source is not a sharp pulse, but of finite extent.

In the configuration described in Mr. Ellsworth's paper, there are two regions in which multiple reflections might travel: the disturbance may be multiply reflected by the earth's surface and the upper surface of the basalt or, it may be multiply reflected by the upper and lower surfaces of the basalt bed itself, this latter being rather thin. One can, of course, decide which of these alternatives is responsible for the

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† California Institute of Technology, Pasadena, California.

Balch Graduate School of the Geological Sciences, California Institute of Technology, Pasadena, California, Contribution No. 403.

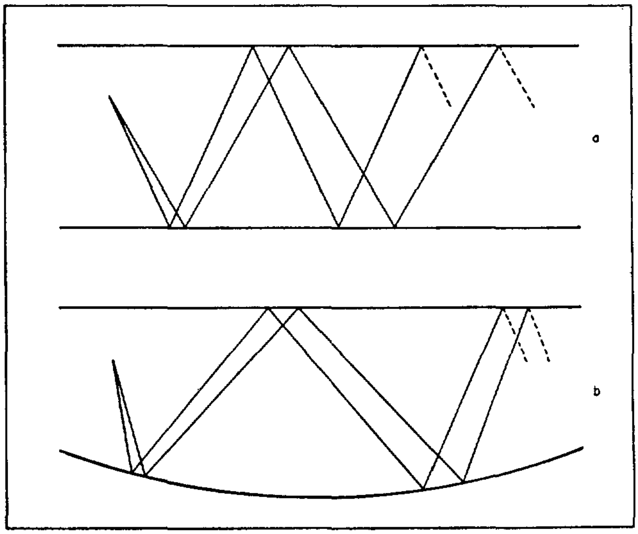

FIG. 1. (a) Energy dispersion by divergence of rays from plane reflector. (b) Concentration of energy by concave reflecting surface.

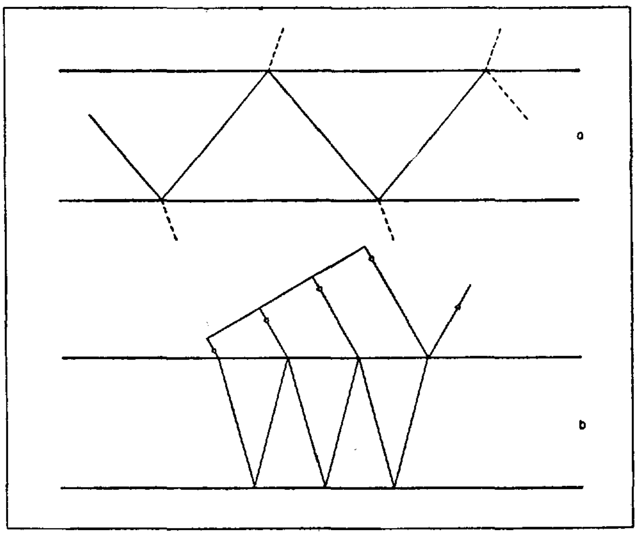

FIG. 2. (a) Energy loss by imperfect reflection. (b) Accumulation effect for source of finite extent.

multiple reflections observed by the time intervals of the successive impulses.

One might doubt whether sufficient reflection at ground surface would occur, because the transition from the weathering layer to the subweathering medium is usually a gradual one and this transition zone is not a good reflector. However, under suitable circumstances, this reflection *is* observed. The *pP* phase in seismology is frequently well recorded. In seismic prospecting, surface reflection has been reported by Leet[1]. The reason for this is that for the long-wave component of the source, the weathering layer is too thin to give appreciable effect and the reflection really occurs at the free surface. On the other hand, the thin basalt bed can hardly affect the long waves. But for a source of the form of a sharp pulse, it is not impossible that multiple reflections may also occur in the thin bed.

The phase relations of the successively reflected pulses depend on the contrast of properties of the contiguous media. The theory has been worked out by Sezawa[2–3] who treats the multiple reflections in a surface layer, but certainly the general nature would be similar for an inner bedding. To illustrate the relations, we reproduce below two of his graphs in which H is the thickness of the layer, c, a parameter signifying the width of the pulse, μ' and μ are the rigidities of the layer

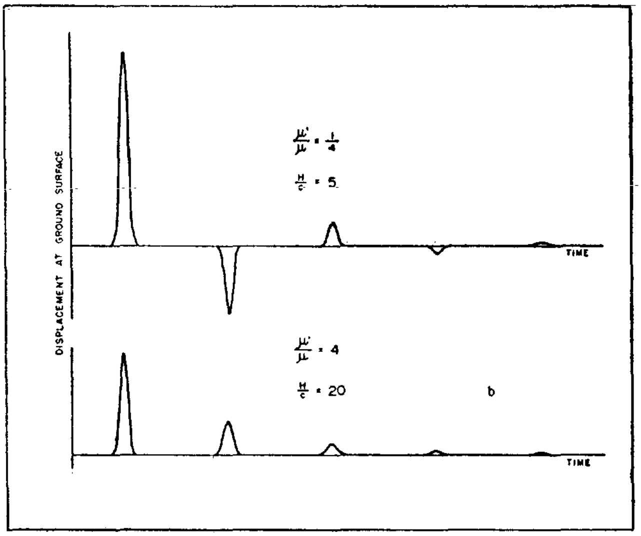

FIG. 3. (After Sezawa) Phase relations in multiple reflections.

[1] L. Don Leet, Bull. Seism. Soc. Am., 27, 97–98, 1937.
[2] K. Sezawa, Bull. Earthquake Res. Inst. Tokyo, 8, 1–11, (1930).
[3] *Ibid.*, 13, 251–262, (1935).

and the lower medium respectively, and the Poisson ratio of both being assumed equal to 1/4. It is seen from these graphs that the phase may or may not change depending on the relative rigidities.

Finally, it may be of interest to point out that in multiple reflections, the over-all reflection and transmission coefficients depend on both the ratio of the thickness of the reflecting layer to the wavelength and the frequency of the wave component even when the latter is plane, homogeneous, and of infinite extent. This can obviously be inferred from the theory of parallel plates in physical optics. Hence, the coefficients as ordinarily calculated for an interface of two semi-infinite media are quite inadequate in the present case. The indiscriminate application of them might lead to misleading results.