Imaging With Refraction Seismograms

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In reflection seismic prospecting the first arriving waves at long offsets (called refractions) are usually discarded by an operation called "muting". These waves are known to contain readily extractable information about shallow seismic velocity. The velocity determination technique involves a plane layer assumption and the fitting of first arrival times to a piecewise straight line travel time curve. The spatial resolving power is very poor, usually comparable to the shot-to-geophone offset. The purpose of the present paper is to describe a technique with resolving power comparable to a wavelength, hence the word "imaging" in the title. Whether this theoretical resolving power can be achieved in practice or whether the method will fail to work even for the best field data, is completely unknown at the present time.

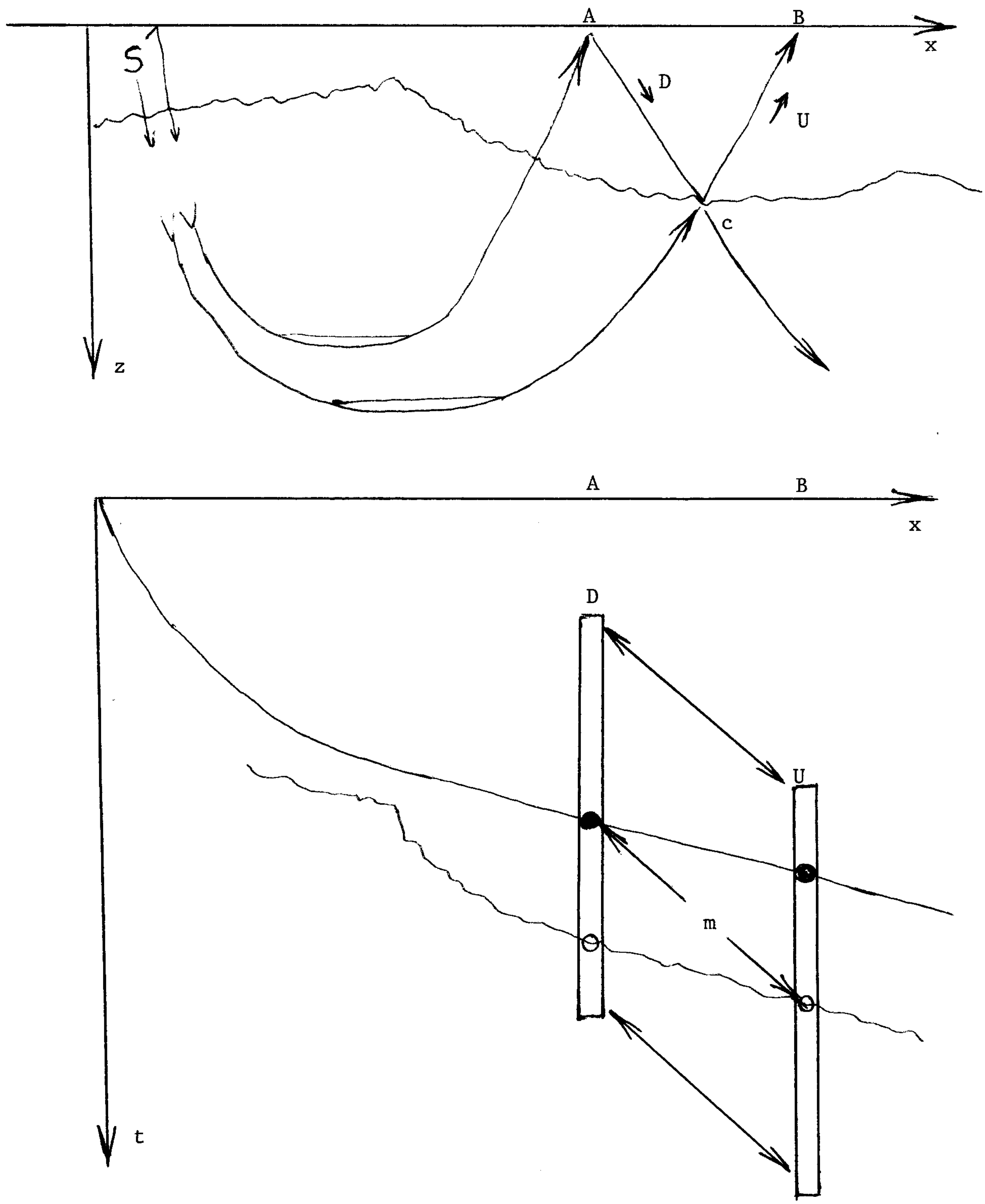

Figure 1. (top) Sample geometry for refraction imaging. (bottom) Data gates when upward and downward continuation are approximated by time shifts. 'm' indicates main term in cross-product.

Figure 1 illustrates the basic idea. Some typical rays emitted from the source S are shown on the top. On the bottom hypothetical data shows a first arrival and a first bounce from a reflector labeled 'c' . Given the surface data which defines both the upcoming wave U and the downgoing wave D at the surface we intend to downward continue D and U. Various techniques of downward continuation may be tried. Some techniques, akin to deconvolution, try to properly account for multiple reflection. Other techniques, akin to migration, try to properly account for diffraction. We could come up with a composite. Settling on a suitable downward continuation technique we then consider application of the idea that reflectors exist at points in the ground where there is time coincidence of up-and down-going waves. The question is how to choose a suitable definition of time coincidence. A simple, stable technique would be at each point in space to multiply U times D and sum over some time gate. Introducing a normalizing divisor we have as an estimate $\hat{c}$ of the reflection coefficient

$$\hat{c} = (U \cdot D) / (D \cdot D) \tag{1}$$

If the waves were vertically incident in an ideal plane layered media, then the value of c could be computed with the Burg estimator

$$\hat{\hat{c}} = 2(U \cdot D) / (U \cdot D + D \cdot D) \tag{2}$$

In a vertically incident ideal case $\hat{c}$ and $\hat{\hat{c}}$ turn out to be the same because the upward energy flux equals the downward flux. The Burg estimator $\hat{\hat{c}}$ has the advantage that it is less than unit magnitude for an arbitrary amount of noise in U or D . To understand why (1) gives an estimate of the reflection coefficient refer to figure 1 and assume that upward and downward continuation of surface data can be done with time shifts and space shifts. The main term in the dot product $U \cdot D$ is indicated by an 'm' . Omitting all other terms it is apparent that $(U \cdot D)/(D \cdot D)$ is an estimate of the reflection coefficient. When the source S contains an unknown waveform, or when an unknown waveform is generated by the near surface geologic structure at S , then the estimate $\hat{c}(z)$ picks up the autocorrelation of this unknown waveform. Further enhancement could be achieved by careful selection of gates, weighting functions, and also summation over various shot locations.