III. Resolution of Stratigraphic Traps

The reflection seismic method is well suited for defining structural prospects since it is relatively easy to detect horizontal and vertical velocity discontinuities. However, stratigraphic traps are often indicated by velocity gradations rather than discontinuities. Reflection seismology must be pushed to the extremes of its capabilities in order to get a suitable resolution of these gradations. None-the-less we find that computer model building techniques in reflection seismology are extremely crude compared to those in other branches of geophysics. Because of this we believe there is at present a considerable opportunity for theoretical investigation. At the present time reflection seismic velocity analysis is based on "picks" of events in the space of time, NMO, and dip (Sherwood and Poe, "Continuous Velocity Estimation and Seismic Wavelet Processing", GEOPHYSICS, Oct. 1972). Some idea of the kind of information carried in waveforms but probably not carried nor readily extracted from picks is indicated in Figure 4.

It is our believe that the maximum amount of information will be extracted from the data only when modern "inversion" methods are applied to the whole wave field. (The word "inversion" comes about because the standard text book problem, or forward problem, is the calculation of waves given the complete specification of the material and geometry whereas in the inverse problem one starts with the waves and deduces the material and geometry. Also in inverse geophysical problems one usually ends up inverting a lot of matrices.) The matrix involved in the reflection seismic problem would be called the partial derivative matrix of the theoretical seismograms with respect to the model parameters (e.g.

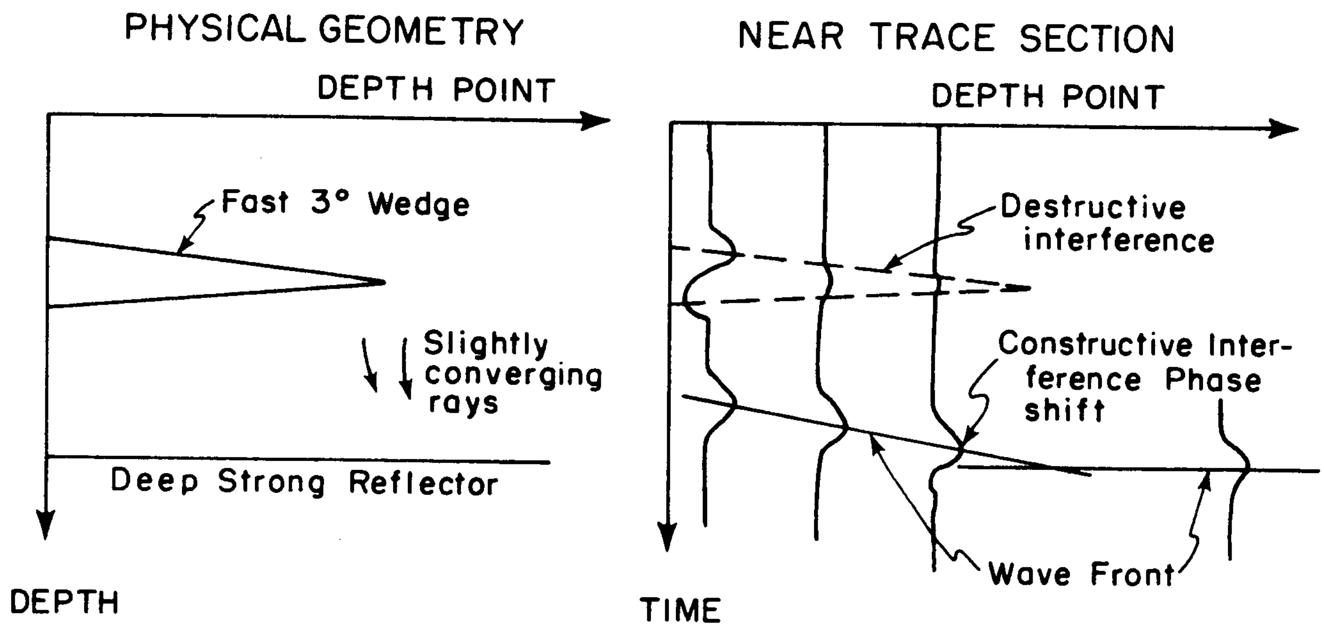

Figure 4. Illustration of a simple stratigraphic trap geometry where the existence of a pinchout is exhibited seismically by amplitude and waveform anomalies some distance below the pinchout. It would be worthwhile to compute synthetic data of this nature and see how well the tip of the pinchout can be located. If it is theoretically locatable then it would be worthwhile to attempt to identify this situation with field data examples, and attempt to find a theoretical method which would make systematic and optimal use of these wave phenomena in the construction of a velocity model. The limitations on this method will be different from the 5/8 wavelength resolution limit commonly assumed. However, we don't know if they will be better or worse.

velocity as a function of position). Since a mile of seismic survey collects about 2 million words of seismic data and if we take the information density as perhaps as much as 100 times less than that of the data, then it is clear that the partial derivative matrix is immense (about 10^{10} words). Furthermore we must recompute and solve the matrix many times as we iterate to a solution. In addition local minima in the error surface can present problems.

Clearly, a straight-forward approach applying the method of say Backus and Gilbert ("Numerical applications of a formalism for geophysical inverse problems", GEOPHYS. J. ROY. ASTR. SOC., 1967, v. 13, p. 247-276) directly to the seismic waveforms is impractical. However, even in their application (they determine velocity as a function of depth only) they do not work directly with all the waveforms but instead extract only a modest number of free oscillation frequencies as "data" for the inversion. In other words what we are saying is that our partial derivative matrices are actually not very sparse but if we are clever we may be able to find a suitable set of approximations and transformations to transform them to sparse enough matrices that we can afford to deal with them. We are proposing theoretical research which would attempt to determine a practical solution of the problem of deducing an accurate stratigraphic-trap-like velocity structure from the observed waveforms. Because of our previous experience in computing numerical solutions to the wave equation we can at least compute portions of the partial derivative matrix.

Inversion methods are more highly developed in potential and diffusion theory than in seismology. Because they generally have a simpler physical situation and far less data, people working in these fields have extensively used the partial derivative matrix method of inversion. They routinely determine 2 and 3 dimensionally inhomogeneous models for things like resistivity. It is entirely probable that seismologists could benefit from a thorough grasp of the material contained in Theodore R. Madden's work "Transmission Systems and Network Analogies to Geophysical Forward and Inverse Problems" (Office of Naval Research Report N-0001-14-67-A-0204-0045/371-401/05-01-71). Fortunately Prof. Madden has agreed to visit Stanford for 4 months and would participate in the proposed research.