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Waveform Inversion of Seismic Data
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N00014-89-J-1018

Long Range Scientific Objectives

To understand the variations of the oceanic crust as expressed by variabilities in its seismic velocity structure. Such variations occur both with geological age (caused by hydrothermal alteration and pore sealing) and spatially, such as, distance along-ridge (variations caused by ridge segmentation, faulting, hydrothermal cells, etc).

Project Objectives

For this project I have developed and applied seismic waveform inversion methods that allow variations in seismic velocities from independent seismic data sets to be quantified. The flexibility of this approach allows independent data from two sites to be jointly analyzed for velocity variations, as well as P and S data to be analyzed in order to constrain Poisson's ratio.

Present Status and Progress During the Current Year

The primary results in the current year are the application of the waveform comparison methods to two groups of seismic data sets in the Atlantic, in one case to compare P-wave structure, and in the second case to constrain Poisson's ratio by comparing P and S data. The P-comparison analyzed data collected near the ridge crest [Detrick & Purdy, JGR 1980; Purdy & Detrick, JGR, 1986]. Figure 1 shows the pair of joint solutions, obtained by waveform inversion, that are as similar as possible while remaining consistent with the separate seismic waveform data sets [Shaw, JGR subm. 1992]. Both solutions fall within extremal bounds obtained from linear analysis of travel times (not shown in figure), indicating the importance of waveform information. Linearized uncertainty estimates, previously the only way to compare separate solutions (dashed lines in figure) are exceeded in places by the joint solution, indicating the inadequacies of this approximation.

The pair of joint waveform solutions delineates the differences in velocity structure with depth caused by the aging process occurring between formation and 7 m.y., as previously observed by Purdy & Detrick [JGR 1986]. The model comparison method confirms this difference in velocities, and indicates that differences occur throughout the crust, down to the Moho. Velocities increase with age, presumably due to cementation of pores from hydrothermal circulation. The fact that the velocity solutions are most different at the surface and approach each other at depth supports the hypothesis that the porosity of newly-formed crust is greatest at shallowest depths.

The criterion used for determining the degree of similarity of solutions appearing in Figure 1 was developed in part by this project (Jacobson & Shaw, 1991) as a general method to apply the statistical F-test to determine the cutoff point in inverse problems. Figure 2 illustrates the application of this method to fitting a spline that can have up to 75 free parameters; only the first 17 of these are significant at the 95% confidence level.

The variation of Poisson's ratio in oceanic crust was investigated using this methodology of seismic comparison, treating P and S waveforms and solutions as two systems to be compared within a joint inversion. This application of the method, yields realistic uncertainty bounds on P, S, and Poisson's ratio. Figures 3 and 4 illustrate results from this study (From Shaw, in prep., 1992). Figure 3 shows the waveform fit between the observed P and S waves and the WKBJ synthetics, both in first arrivals and later PmP and SmS arrivals. Data are from 140 m.y. crust (Purdy, GJRAS, 1983). In Figure 4, Poisson's ratio bounds hover around 0.28, in general agreement with lab data. Previously published results, from younger crust, have indicated greater extremes in Poisson's ratio than this study, possibly indicating variations with crustal age. Such a result could occur because closure of cracks and pores affect P and S speeds differently, making Poisson's ratio vary as the crust ages.

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Publications supported by this project in 1991

- Shaw, P. R., Isolation of source and receiver statics and scale factors in waveform inversion of marine refraction data, *Geophys. Res. Lett.*, 18: 1429-1432, 1991.
- Jacobson, R. S. and P. R. Shaw, Using the F-test for eigenvalue decomposition problems to find the statistically 'optimal' solution, *Geophys. Res. Lett.*, 18, 1075-1078, 1991.
- Shaw, P. R., Quantitative comparison of seismic data sets using waveform inversion, submitted to *J. Geophys. Res.*, 1992
- Shaw, P. R., Bounds on Poisson's ratio from joint waveform inversion of P and S seismic data, in prep. for *Geophys. Res. Lett.*, 1992

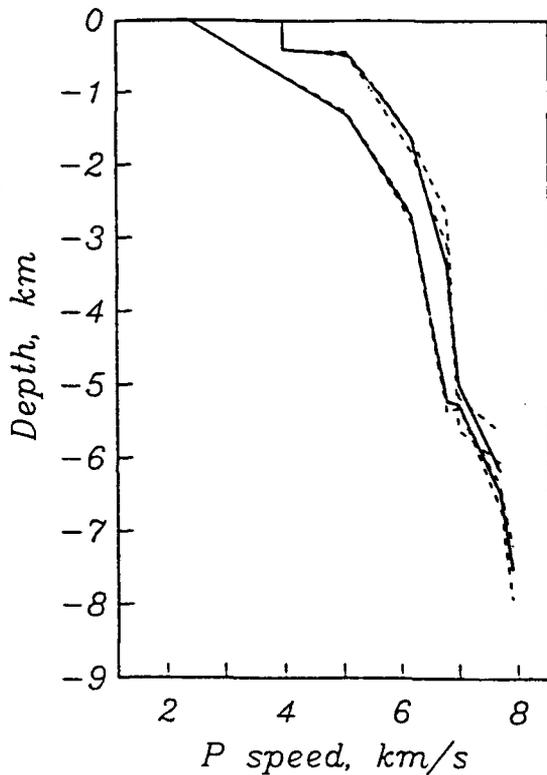


Figure 1. Pair of P-wave velocity solutions corresponding to seismic data from 0- and 7-m.y. crustal ages. Data are obtained from a single joint waveform inversion that forces the two solutions to be as similar as possible while still satisfying the data (as determined by the F-test). Solutions exceed linearized uncertainty estimates (dashed lines), indicating where this approximation breaks down. The general convergence of solutions with increasing depth points to infilling of pores, which are more abundant at shallower depths, as the aging mechanism. (From Shaw, [JGR, subm., 1992])

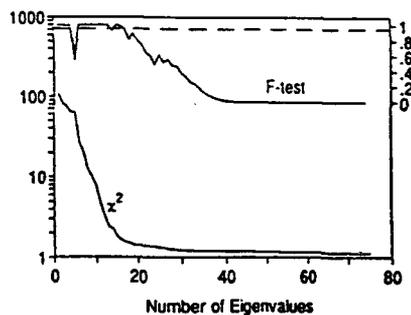


Figure 2. F-test significance and χ^2 residual error resulting from fitting Geosat repeat track data with variable-stiffness spline, demonstrating the utility of the objective F-test in determining the degree of detail to retain in an inverse problem. Although 75 free parameters are available in the spline, only 17 of these are significant at a 95% confidence level. (From Jacobson & Shaw [GRL, 1991]).

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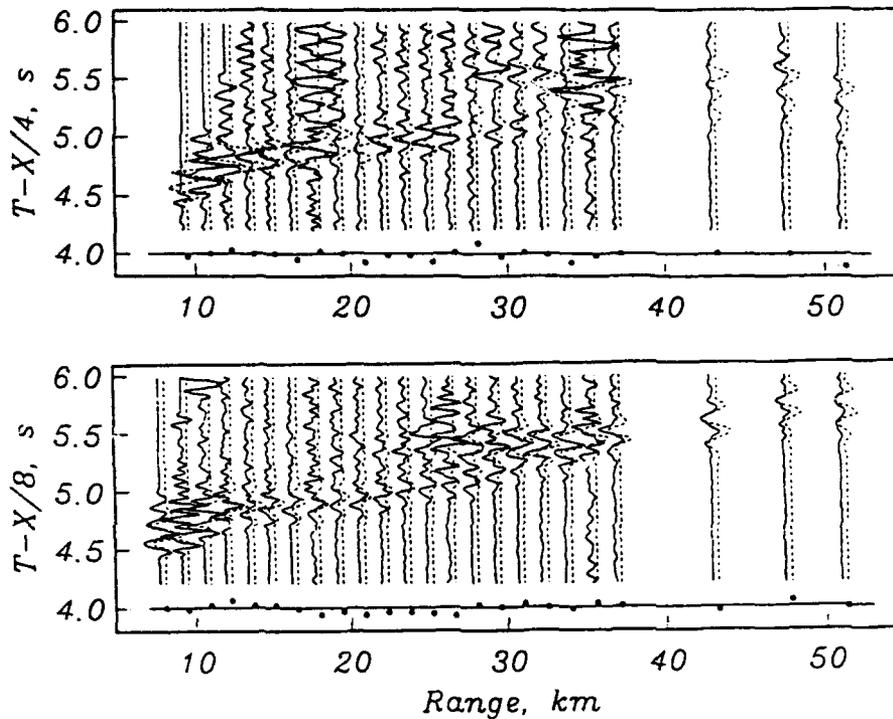


Figure 3. Waveform fit to seismic shear waves (top) and compressional waves (bottom) using WKBJ joint inversion for S and P solutions. Solid lines: data; dashed lines: WKBJ synthetics. Dots at bottom of seismograms: residual statics, after topographic correction, necessary in aligning synthetics with data. (From Shaw [in prep, 1992])

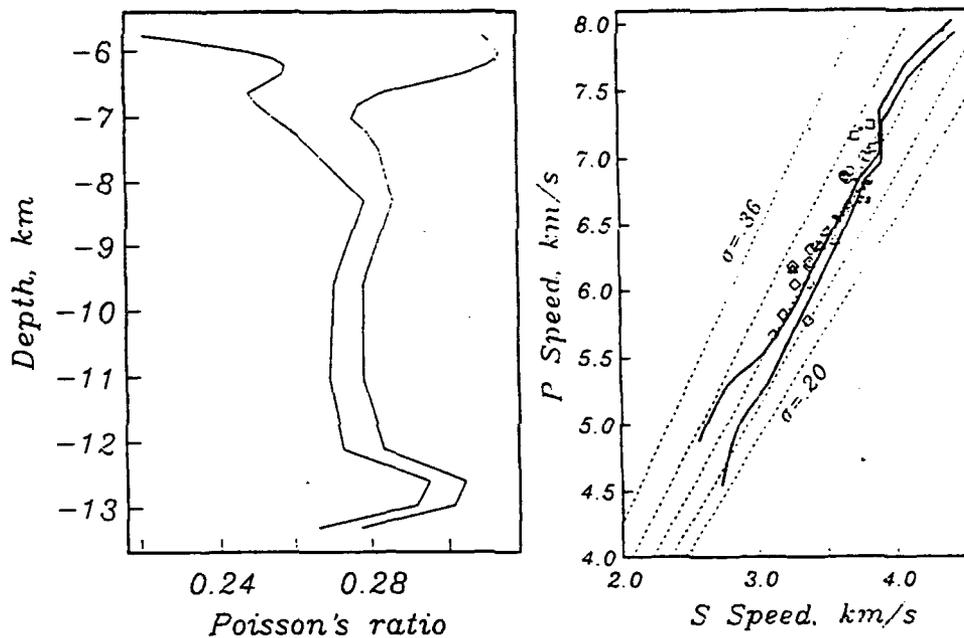


Figure 4. Results of joint P and S waveform inversion. Left: Maximum and minimum bounds on Poisson's ratio versus depth obtained from the joint inversion. Resolution is best at intermediate depths that are sampled by turning rays. Right: P- versus S-speed bounds plotted against lab measurements (Salisbury, 1974; Christensen, 1978; from Spudich & Orcutt, JGR, 1980). Dashed lines are loci of constant Poisson's ratio. Results do not require the Poisson's ratio deviating greatly from the lab measurements. (From Shaw [in prep, 1992])